PEACE RIVER INTEGRATED MODELING PROJECT (PRIM)

PHASE V:

PREDICTIVE MODEL SIMULATIONS

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cfs	cubic feet per second
ET	evapotranspiration
FLUCCS	Florida Land Use, Cover, and Forms Classification System
Ft.	Fort
GW	groundwater
HGL	HydroGeoLogic, Inc.
IAS	Intermediate Aquifer System
in/yr	inches per year
Mgd	Million gallons per day
MODHMS	MODFLOW Hydrologic Modeling System
NEXRAD	NEXt Generation Weather RADar
NHD	National Hydrography Dataset
NPDES	National Pollutant Discharge Elimination System
NWS	National Weather Service
PBS&J	Post, Buckley, Schuh and Jernigan, Inc.
PRCIS	Peace River Cumulative Impact Study
PRIM	Peace River Integrated Model
PRMRWSA	Peace River Manasota Regional Water Supply Authority
SA	Surficial Aquifer
SD	Southern District
SW	surface water
SWFWMD	Southwest Florida Water Management District
SWUCA	Southern Water Use Caution Area
UFA	Upper Floridan Aquifer
USGS	United States Geological Survey
WWTP	Waste water treatment plant

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1.0 INTRODUCTION

1.1 THE PEACE RIVER INTEGRATED MODELING PROJECT

The Peace River watershed located in Polk, Hardee, and De Soto Counties comprises the largest watershed in the Southwest Florida Water Management District (SWFWMD) with a total area 2,350 square miles. The Peace River is an important ecological, water supply, and recreation resource. There has been extensive agricultural and industrial development in the watershed for many years with a heavy reliance on groundwater resources. Peace River flows have been in a long-term decline beginning in the early 1960s. The impact has been most pronounced in the Upper Peace River where sections of the river have lost all flow in recent dry seasons. The factors affecting flows in the Peace River include natural phenomena as well as human impacts. Long-term natural variation in rainfall is understood to have a major influence on river flows in the Peace River and similar river systems in Florida. In addition, there are numerous human influences that impact the Peace River. These include lowering of the Floridan aquifer potentiometric surface due to groundwater pumping for industrial, agricultural, public supply, mining and recreational water use; structural alterations and regulation of surface water; land use changes; and wastewater discharges to the Peace River and its tributaries. Although numerous studies have been conducted to investigate and understand the phenomena that have impacted flows in the Peace River, the relative importance and quantifiable impact of these phenomena are not thoroughly understood.

The SWFWMD initiated the Peace River Integrated Modeling Project (PRIM) to gain a better understanding of the hydrologic processes and interactions that affect the Peace River basin and flows in the river itself. The principal goal of this project has been to develop a numerical groundwater-surface water model of the Peace River watershed to assist in identifying the effects of previous development in the watershed and ways of meeting SWFWMD-identified recovery goals in the Peace River basin. The development of the PRIM is documented in HydroGeoLogic, Inc. (HGL, 2009, 2011, 2012). The end result of this work was an integrated groundwater-surface water model, developed using the MODFLOW Hydrologic Modeling System (MODHMS®) simulation software (HGL, 2007). The PRIM is comprised of a MODFLOW-like groundwater component that includes the Surficial Aquifer (SA), the Intermediate Aquifer System (IAS) and the Upper Floridan Aquifer (UFA). The groundwater (subsurface) component is linked to a surface water component that simulates watershed processes, including rainfall and evapotranspiration (ET), streamflow, overland flow, lakes, and hydraulic structures. The hydrologic processes among all components are coupled through water flux terms, such as infiltration, recharge, soil and groundwater ET, lake and stream leakage, groundwater discharge to streams, redistribution of water from groundwater withdrawals, irrigation infiltration, and return flows. The model extent comprises the Peace River basin above the Peace River-Manasota Regional Water Supply Authority (PRMRWSA) intake point near Arcadia. Regional groundwater impacts are accounted for in the PRIM by linking the model to the regional Southern District (SD) groundwater model (Beach, 2006) via prescribed but time-varying heads in the IAS and UFA model layers at the PRIM lateral boundaries. The PRIM is driven by daily rainfall stress periods, monthly ET, and withdrawal and discharge (i.e., groundwater pumping and National Pollutant Discharge Elimination System [NPDES] discharges) stress periods. The model was calibrated to a nine-year period from 1994 through 2002. The model calibration is documented in HGL (2011).

1.2 PURPOSE AND SCOPE

The work described in this report comprises Phase V of the PRIM project and involves the application of the PRIM to perform a series of simulation scenarios to assess the impact of rainfall variation, groundwater withdrawal variation, and land use changes on flows and other hydrologic characteristics. The impact of each factor was evaluated in terms of the following metrics:

- Changes in stream flows,
- Changes in lake levels,
- Changes in groundwater heads in the SA and UFA, and
- Changes in water budgets.

Stream flow and lake level impacts were evaluated in terms of the changes in the 10^{th}, 50^{th}, and 90^{th} percentile values, as well as the changes in the mean (average) values of these hydrologic characteristics. Changes in groundwater heads were evaluated in terms of difference maps of the heads in the SA and UFA, respectively. Changes in water budgets were evaluated in terms of the basinwide water budget, as well as sub-basin water budgets. The model-generated flows were also compared to the long-term observed changes in flow to better understand the degree of influence each factor has on historical flow declines.

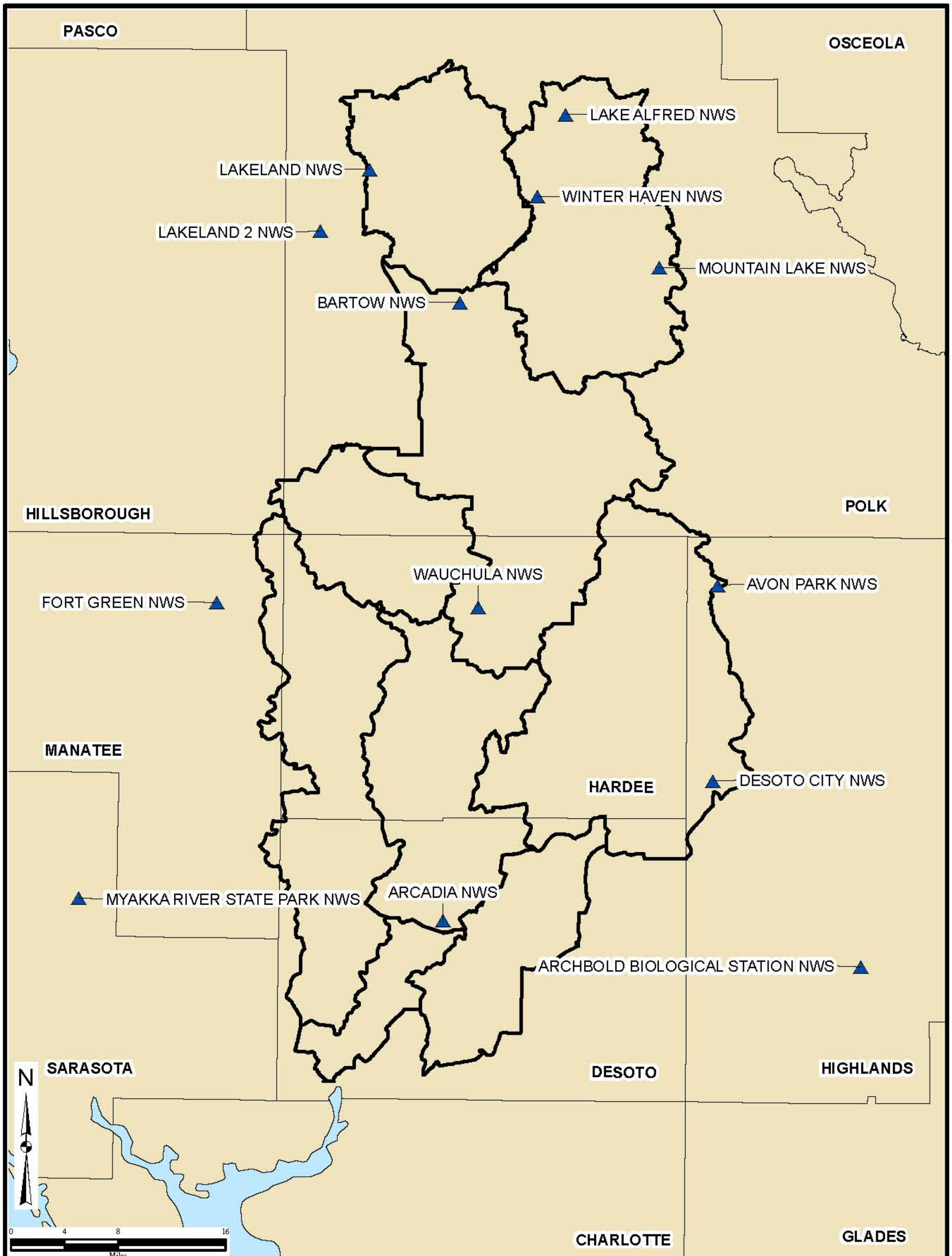
2.0 BASE CASE SCENARIO

The Base Case scenario for evaluating the impacts listed above was a modification of the basinwide PRIM as developed in Phase IV of the project (HGL, 2011, 2012). These modifications involved extending the simulation period from 1994 through 2006, for a 13-year period compared to the 1994-2002 (nine years) period for the Phase IV PRIM. A second change was to replace the rainfall input data set for the model from the NEXt Generation Weather RADar [NEXRAD] weather radar-derived rainfall (used in the initial phases of the PRIM project) with rainfall data obtained from National Weather Service (NWS) rain gages. The motivation for this change was to ensure that consistent rainfall data was used throughout the scenario simulation series, which included comparison of different historical rainfall periods. The NWS rain gage network provides a continuous rainfall record data set. The model rainfall data set was constructed using daily rainfall data from the following NWS gage stations: Bartow, Lakeland/Lakeland 2, Winter Haven, Lake Alfred, Mountain Lake, Avon Park, Wauchula, DeSoto City, Archbold Biological Station, Myakka River State Park, Fort (Ft.) Green, and Arcadia. The locations of these rain gages are shown in Figure 2.1. Rainfall values at the centroid locations of the model grid cells were calculated as weighted averages of surrounding gage locations using inverse distance weighting.

Groundwater and surface water withdrawals, NPDES discharges, and Reference ET were incorporated into the model for the extended 2003-2006 model simulation period, using the same procedures as documented in the PRIM Phase IV report (HGL, 2011). The same methodology was also used to assign lateral model boundary head values for the IAS (model layers 2 and 3) and UFA (model layers 4 and 5). Specifically, the regional SD model (Beach, 2006) was run using the entire 1994-2006 regional groundwater withdrawal data set. SD model head values were combined with observed data from monitor wells located around the perimeter of the PRIM domain, using the spatial interpolation methodology described in the PRIM Phase IV report (HGL, 2011), to provide prescribed, monthly varying boundary heads for the Base Case model.

It is noted that use of the NWS rainfall data set resulted in higher rainfall amounts in most years of the simulation period as compared to the NEXRAD data set that was used to calibrate the model in Phase IV of the project. Because of this and the different simulation time periods (13 years versus 9 years), the scenario simulations are compared only to the Base Case scenario, and not to the Phase IV model.

Annual values of the primary model stresses (i.e., rainfall, reference ET, pumping, and NPDES discharges) over the Base Case modeling period of 1994-2006 are summarized in Figures 2.2 through 2.5. Each figure presents the basinwide average annual value of that stressor. The values are expressed in inches per year. In the case of pumping withdrawals and NPDES discharges, the secondary y-axis in the plots is used to display the values in Million gallons per day (Mgd), using the conversion that for the entire basin area in the model (1,876 mi^2), one inch of water corresponds to 3.3×10^{10} gallons. By summarizing the data this way, trends in the data over time can be easily distinguished.



HGL

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Rainfall Gage

Basin and Sub-Basin Boundaries

Figure 2.1
Locations of NWS Rainfall Gages

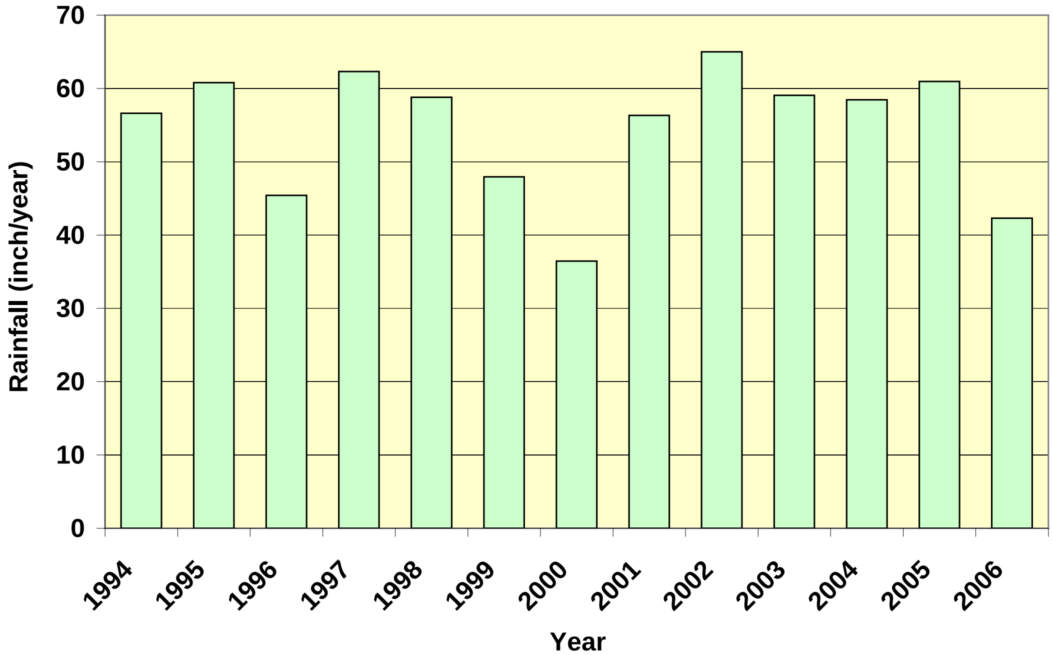

Figure 2.2 Average Annual Rainfall in Peace River Basin for the Base Case Scenario

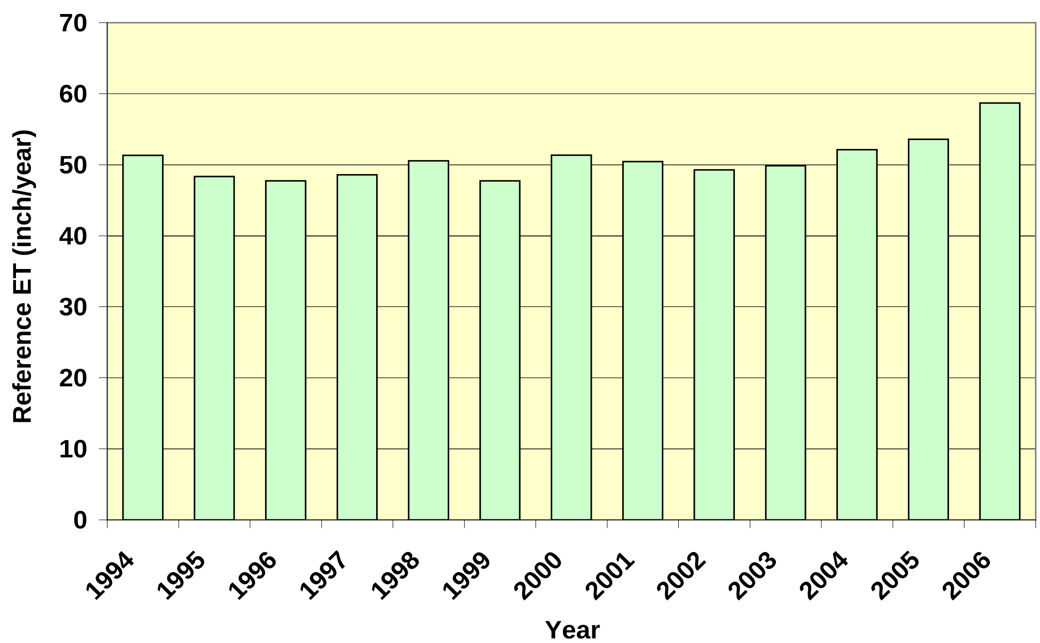

Figure 2.3 Annual Reference ET

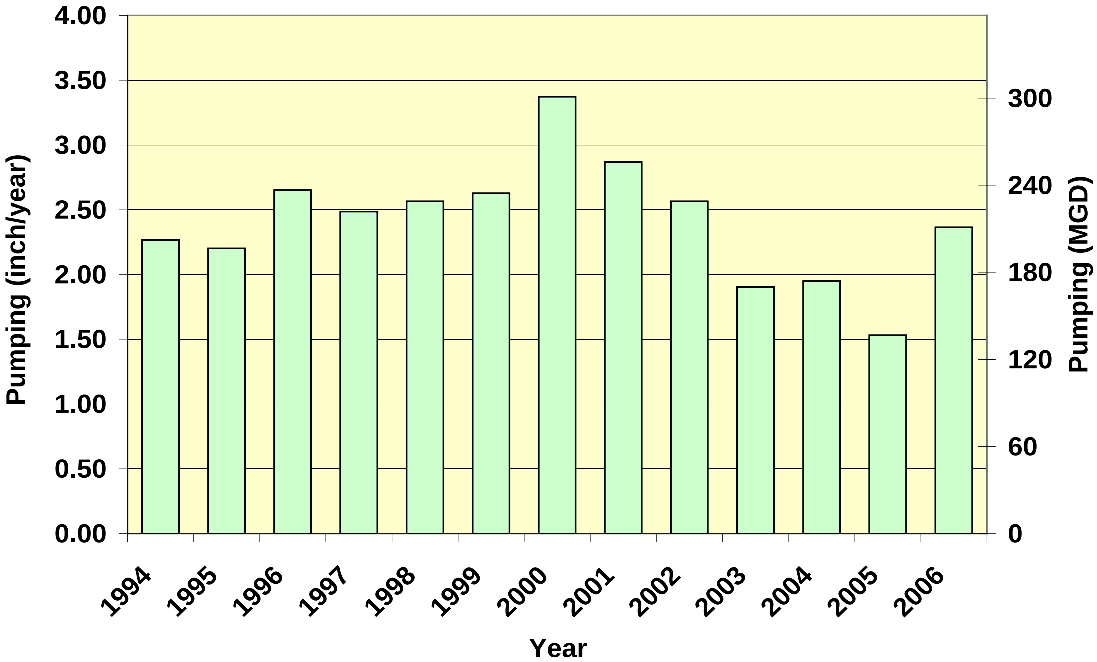

Figure 2.4 Annual Groundwater Withdrawals

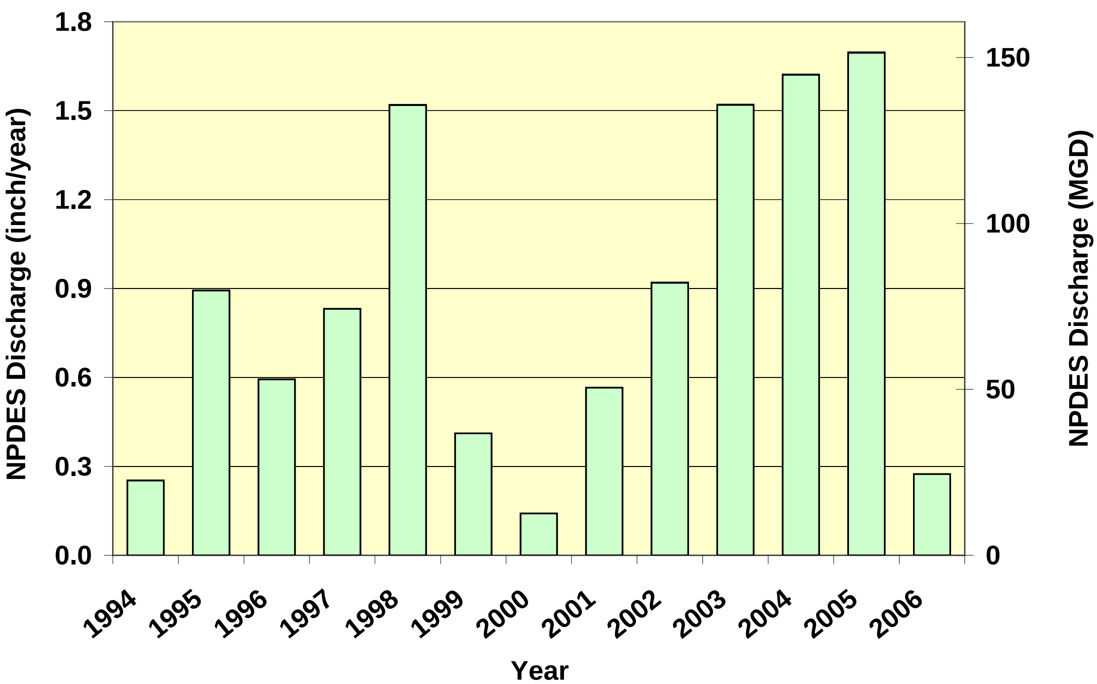

Figure 2.5 Annual NPDES Discharges

Figure 2.2 shows that of the four years (2003-2006) that were added to the PRIM modeling period, the first three years had above-average rainfall, while 2006 was a dry year. The average annual rainfall over the 13-year period from 1994-2006 was 55 inches per year, with a high of 65 inches in 2002, and a low of 36.5 inches in 2000. Reference ET data shown in Figure 2.3 were obtained from the United States Geological Survey (USGS) Hydrologic Data Web Portal (http://hdwp.er.usgs.gov/et.asp) which provides statewide estimates of daily potential and reference ET[1] estimated from solar radiation data (Jacobs et al., 2008). Figure 2.3 shows that reference ET is fairly constant on an annual basis, with values around 50-inches per year (in/yr).

Groundwater withdrawals in the Peace River basin (Figure 2.4) varied from 130 Mgd in 2005 to 300 Mgd in 2000, and averaged around 220 Mgd. On a basinwide basis, this is equivalent to about 2.5 inches of water. NPDES discharges, shown in Figure 2.5, varied from less than 15 Mgd in 2000 to 150 Mgd in 2005, or on a basinwide area basis, from 0.2 to 1.7 inches/year. NPDES discharges are associated with phosphate mining operations as well as domestic and industrial waste water treatment facilities. Except for the City of Arcadia's William Tyson waste water treatment plant, all NPDES discharges included in the model are located in the Upper Peace River basin above Zolfo Springs. As can be seen in Figures 2.4 and 2.5, groundwater withdrawals and NPDES discharges are both correlated with rainfall. Groundwater withdrawals have a negative correlation with rainfall, as withdrawals increase during dry periods to satisfy irrigation demands. Groundwater pumping was highest in the very dry year of 2000. NPDES discharges have a strong positive correlation with rainfall, as a considerable portion of NPDES discharges is stormwater runoff. Phosphate mining operations capture stormwater for use in the mine circulation process, and therefore limit NPDES discharges during dry periods, but release water during wet periods when mine water storage is already at capacity. The pattern of high NPDES discharges during wet years (e.g., 1998) and low discharges during dry years (e.g., 2000) is clearly evident when comparing Figure 2.2 and Figure 2.5. In 2002, although rainfall was high, the total amount of NPDES discharge was not more than average. This can be attributed to the fact that watershed storage in the basin was still recovering from the drought in 2000. In other words, rainfall during the year 2002 was used to replenish surface water storage rather than generate high NPDES discharges. Conversely, after several fairly wet years, much more water was released as NPDES discharge in 2005.

[1] Reference ET (ET_0) is the evapotranspiration from a well-watered, standardized grass surface. Adjustment factors, called crop coefficients (k_c) are used to convert ET_0 to the ET for each specific vegetation type in the model.

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3.0 RAINFALL SCENARIO

This scenario evaluated the impact of a "Dry" rainfall period versus a "Wet" period. For the Dry period, rainfall data from 1969-1981 were used; the Wet period used rainfall data from 1951-1963. All other model inputs and stresses were kept the same as in the Base Case. The two periods were selected based on NWS Bartow gage historic rainfall. The Bartow gage cumulative rainfall for each 13-year period was 645 inches (49.6 in/yr) for the 1969-1981 Dry period, and 764 (58.8 in/yr) for the 1951-1963 Wet period. For comparison, Bartow cumulative rainfall for the 1994-2006 period was 714 inches (54.9 in/yr). Figure 3.1 shows a year-by-year comparison of basinwide annual rainfall for the 13-year Dry and Wet periods. Because this scenario used actual historic rainfall data, there are some years for which the Dry scenario has higher rainfall than the Wet scenario: for example Year 5 and Year 11. Annual rainfalls were relatively constant during the Dry period, whereas both the Base Case and the Wet period showed greater variation in annual rainfall quantities. Overall, however, the Dry scenario has considerably less rainfall than the Wet scenario. Averaged over the entire Peace River basin, the average annual rainfall for the Dry scenario was 49.0 in/yr, compared to 55.6 in/yr for the Wet scenario. All other model inputs for these scenarios were the same as we used in the Base Case scenario.

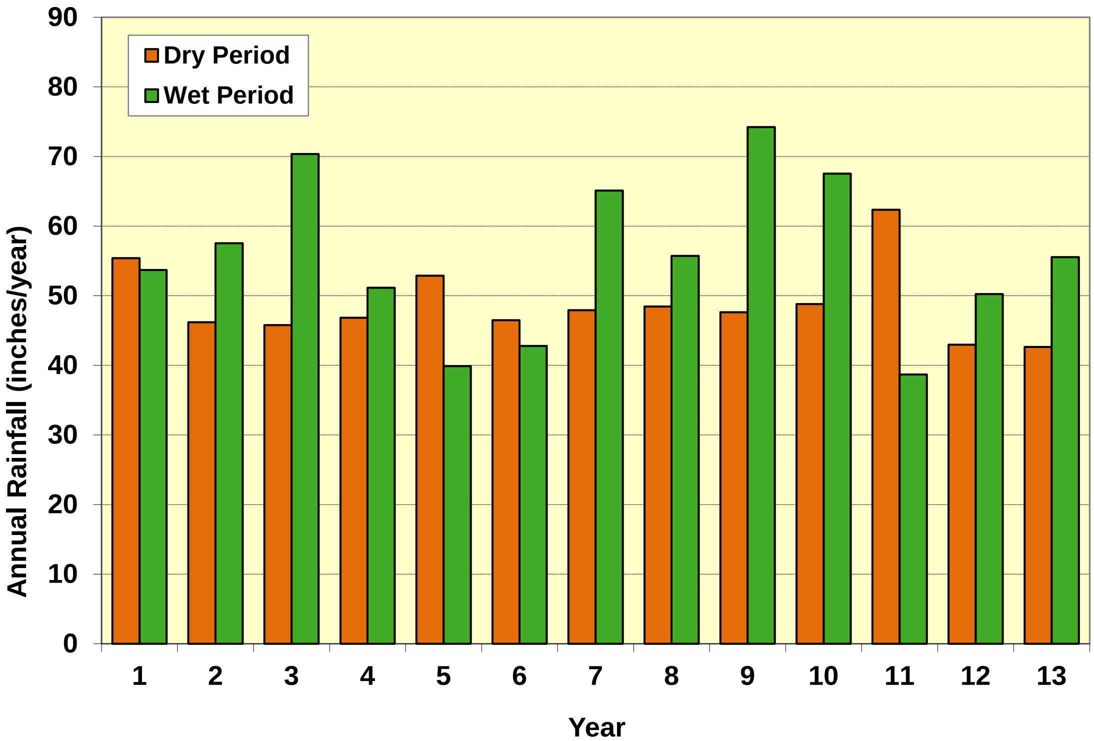


Figure 3.1 Annual Rainfall Amounts for the Wet and Dry Periods

3.1 IMPACT OF RAINFALL ON STREAMFLOWS

The effects of the Wet versus the Dry scenario on simulated streamflows are summarized in Table 3.1. This table presents the 10th, 50th, and 90th percentile stream flows, as well as average flows, at the main Peace River stream gages at Bartow, Ft. Meade, Zolfo Springs, and Arcadia. The locations of these gages, along with the stream gage locations for the primary sub-basins, are shown in Figure 3.2. The streamflow percentiles are listed for the Dry and the Wet scenarios, along with the percentage change. The table shows that the 6.6 inches of extra rainfall in the Peace River Basin in the Wet scenario causes a significant increase in streamflow at all the gages. The impacts of higher rainfall on flows are more pronounced in the upper part of the basin (Bartow and Ft. Meade gages) as compared to the middle and lower parts of the basin (Zolfo and Arcadia gages). Rainfall also has a larger impact on low flows (10^{th} percentile) and high flows (90^{th} percentile) as compared to median (50^{th} percentile)flows. At the Bartow and Ft. Meade gages, the changes from Dry to Wet rainfall conditions roughly doubles the flows at all percentiles (at Ft. Meade, the 10^{th} percentile flows differ by nearly a factor of three). At the Zolfo and Arcadia gages, the relative change diminishes when flows are higher, although it is still greater than 50% in all cases.

Table 3.1
Streamflow Percentiles for the Dry and Wet Scenarios

Gage Name	Streamflow Percentile	Streamflow (cfs)		
		Dry	Wet	% Change
Peace River at Bartow	10th	10	20	+102%
	50th	81	141	+74%
	90th	371	778	+110%
	Mean	147	288	+96%
Peace River at Ft. Meade	10th	20	55	+179%
	50th	137	230	+65%
	90th	497	928	+87%
	Mean	217	377	+74%
Peace River at Zolfo Springs	10th	84	166	+98%
	50th	318	480	+51%
	90th	1065	1719	+61%
	Mean	498	771	+55%
Peace River at Arcadia	10th	123	230	+87%
	50th	493	740	+50%
	90th	1849	3054	+65%
	Mean	845	1356	+61%

cfs – cubic feet per second

The greater impact on the Bartow and Ft. Meade gages may have been caused in part by rainfall variations across the basin. As referenced above, the difference in Wet versus Dry rainfall was more than 9 in/yr at the Bartow NWS rain gage (49.6 versus 58.8 in/yr) compared to 6.6 in/yr across the entire basin (49.0 versus 55.6 in/yr). However, other basin characteristics contribute to the larger impacts in the upper part of the basin. These include greater watershed storage in lakes in the Saddle Creek and Peace Creek sub-basins, and greater groundwater recharge in the upper part of the basins. These characteristics tend to reduce runoff and streamflow, especially at lower rainfalls. When rainfall increases beyond the point where both watershed storage and groundwater recharge demands are satisfied, the result is a proportionally greater increase in runoff than is seen in the lower parts of the basin.

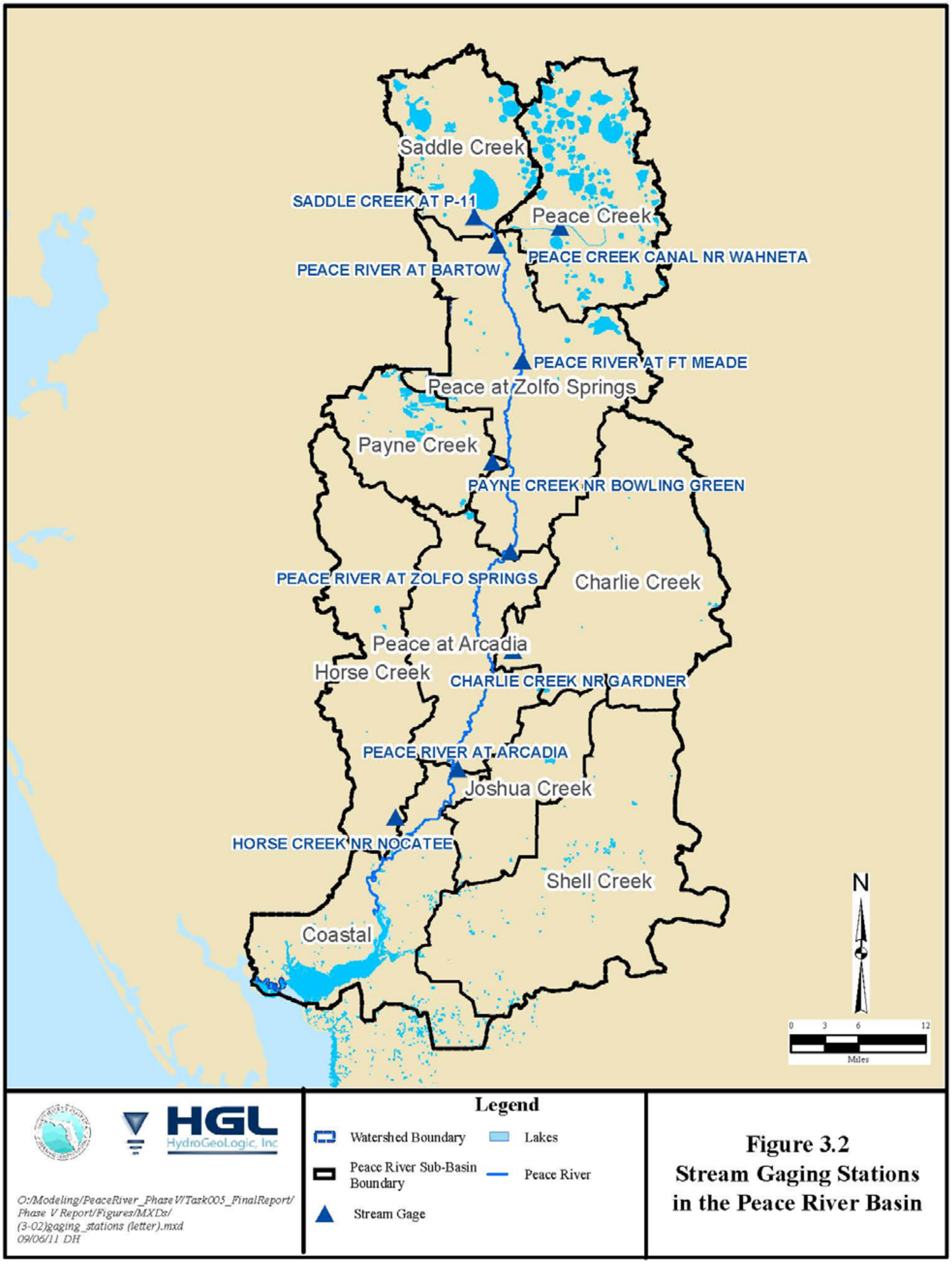


Figure 3.2
Stream Gaging Stations in the Peace River Basin

3.2 IMPACT OF RAINFALL ON LAKE LEVELS

Table 3.2 summarizes the effect of Wet versus Dry rainfall conditions on lake level statistics for selected lakes in the Saddle Creek and Peace Creek sub-basins. Locations of the lakes in this table are shown in Figure 3.3. These are the same lakes that were used to evaluate the lake level calibration of the PRIM in Phase IV of this project (HGL, 2011). The rainfall effects are expressed in terms of the difference in lake levels (in feet) at selected percentiles as well as on the average lake levels between the Wet and the Dry rainfall scenarios. The statistics were calculated over the 13-year simulation period. When the lake level change was less than 0.1 foot, it is indicated in the table with a dash (-) symbol.

Table 3.2
Effect of Rainfall on Lake Levels

Lake	Lake Level Increase Wet - Dry (feet)[1]			
	10th percentile	50th percentile	90th percentile	Mean
Lake Hancock	+0.3	-	-	+0.1
Lake Parker	+0.3	+0.1	+0.6	+0.2
Lake Gibson	+0.1	-	+0.1	+0.1
Lake Arietta	+0.1	+0.7	+4.3	+1.5
Lake Ariana	+0.3	+0.3	+0.1	+0.2
Lake Lena	+1.9	+1.5	-	+1.2
Spirit Lake	+3.6	+2.0	+0.1	+1.8
Eagle Lake	+4.3	+4.7	+0.2	+3.5
Lake Alfred	+0.7	+0.5	+0.6	+0.9
Lake Conine	-0.1	+0.1	+0.3	+0.1
Lake Haines	-0.1	+0.1	+0.3	+0.1
Lake Smart	-0.1	+0.1	+0.3	+0.1
Lake Fannie	-1.6	+0.5	+0.7	+0.3
Lake Hamilton	-0.5	+0.2	+0.5	+0.1
Lake Howard	-	+0.2	+0.4	+0.2
Lake Shipp	-	+0.2	+0.4	+0.2
Lake Annie	+3.3	+4.7	+6.3	+5.1
Lake Myrtle	-0.4	+0.3	+0.4	+0.2
Lake Garfield	+0.4	+0.2	+0.2	-
Surveyors Lake	+0.1	+0.1	+0.2	+0.2

[1] + indicates lake level is higher in the Wet scenario; - indicates lake level is lower

As expected, simulated lake levels were higher in the Wet rainfall scenario compared to the Dry scenario. For most of the lakes included in this comparison, the effect was fairly slight, with only a small number of lakes showing a difference of more than a foot. The lakes with the greatest response were Eagle Lake in Saddle Creek and Lake Annie in Peace Creek. A few lakes − Lake Conine, Lake Haines, Lake Smart, Lake Fannie, Lake Hamilton, and Lake Myrtle − showed a negative impact at the 10th percentile, meaning that the lake level was lower in the Wet scenario than in the Dry scenario. This seemingly anomalous result can be

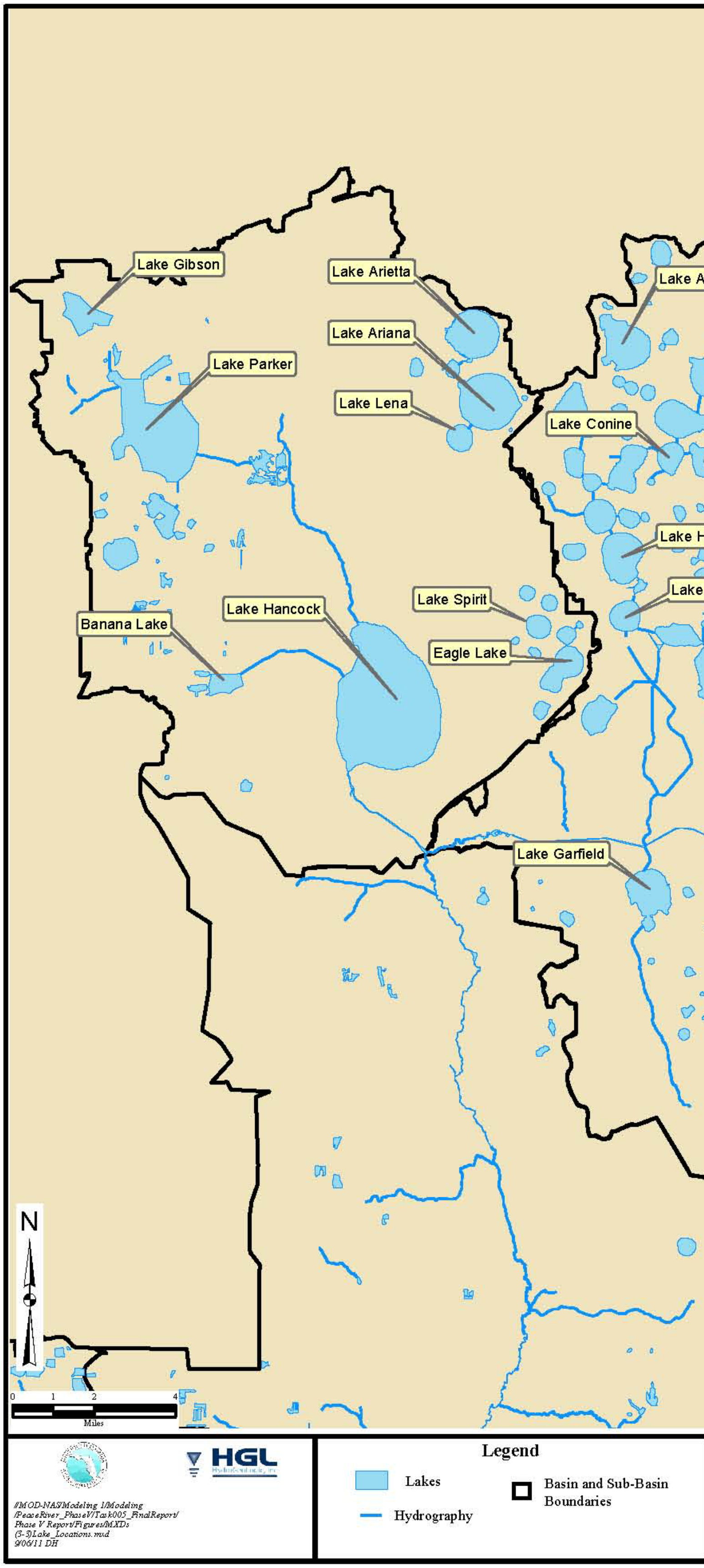


Figure 3.3
Locations of Lakes Used in Scenario Evaluations

explained by the fact that in a number of years, the rainfall in the Wet scenario was actually lower than the Dry scenario. For lakes that are sensitive to dry conditions, as represented by the 10^{th} percentile value, this can show up as a negative result in the table.

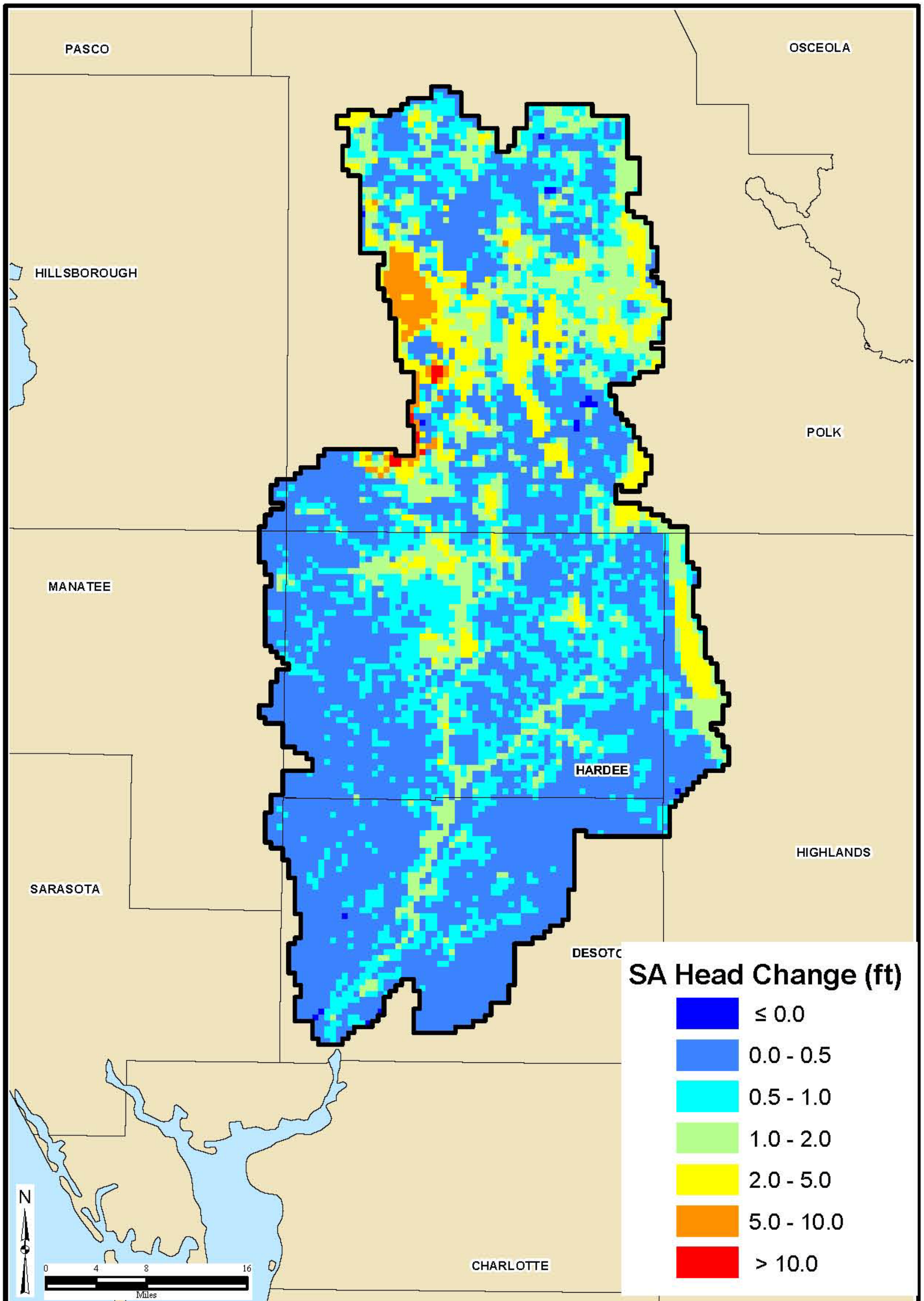
The rainfall response for a number of the lakes is further illustrated for a number of the lakes in lake level hydrograph plots for the Wet and the Dry case. These comparisons are shown in Appendix A. The lakes shown in the figure include some of the major lakes in Saddle Creek and Peace Creek, as well as Eagle Lake and Lake Annie, which are smaller lakes, but showed the greatest sensitivity to rainfall. These lake level plots illustrate that lakes which have a similar statistical response in terms of the percentile values shown in Table 3.2, can still have a significantly different temporal response. For Lake Hancock in Saddle Creek, the lake level is controlled by the P-11 outflow structure, and the lake levels for the Wet and the Dry scenario are the same for much of the simulation period, with deviations occurring only during high rainfall periods (mostly for the Wet scenario) or very dry periods (mostly for the Dry scenario). The difference in average lake level for Lake Hancock is only 0.1 foot. Conversely, Lake Parker, another Saddle Creek lake, also shows a relative small difference in average lake level (0.3 foot), but much more pronounced differences in the temporal lake level responses shown in Appendix A. In the case of Lake Annie and Eagle Lake, the lake level hydrographs start at the same elevation at the beginning of the simulation (because all rainfall scenarios started from the same initial condition, representing long-term average rainfall), but significantly diverge during the simulation period.

3.3 IMPACT OF RAINFALL ON GROUNDWATER HEADS

The impact of Wet versus Dry rainfall on average groundwater heads in the SA and UFA was evaluated in terms of head differences between the two scenarios (i.e., [$head_{Wet}$ – $head_{Dry}$]) averaged over the 13-year simulation period.

Figure 3.4 shows the impacts on average potentiometric heads in the SA. The head increase associated with higher rainfall was less than 2 feet in most of the basin, with greater impacts in localized areas. Ridge areas (e.g., Lake Wales Ridge, Lakeland Ridge, and Lake Hendry Ridge) tended to show greater increases in SA heads, with the greatest increases, up to 5 feet, occurring along the northwestern boundary of the model underneath the Lakeland Ridge.

Impacts on UFA heads are shown in Figure 3.5. Head increases in the UFA were less than 0.5 foot across most of the basin. The largest head increases occurred in the southern portion of the Peace Creek sub-basin, with increases in the average UFA head of up to 1.4 feet. In general, the pattern of rainfall impacts on UFA heads was consistent with the distribution of the effective vertical leakance between the SA and UFA. As shown in Figure 4.5 of the PRIM Phase IV model report (HGL, 2011), greater impacts occurred in the northern portion of the basin, which has higher leakance values, (i.e., the UFA is less confined). There is less impact in the lower portion of the basin where the UFA is much more tightly confined and leakances are much lower. Figure 3.5 shows that there was essentially no change in the UFA head below the Hardee – De Soto County line. In simulating the rainfall scenario, IAS and UFA boundary heads, i.e, the heads around the model perimeter were not changed from the Base Case scenario. These heads were interpolated from the regional SD model, which uses a fixed SA head as the upper boundary condition and therefore cannot easily accommodate changing



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(3-4)Rainfall Scenario SA Sim Heads Change (Wet vs Dry).mxd
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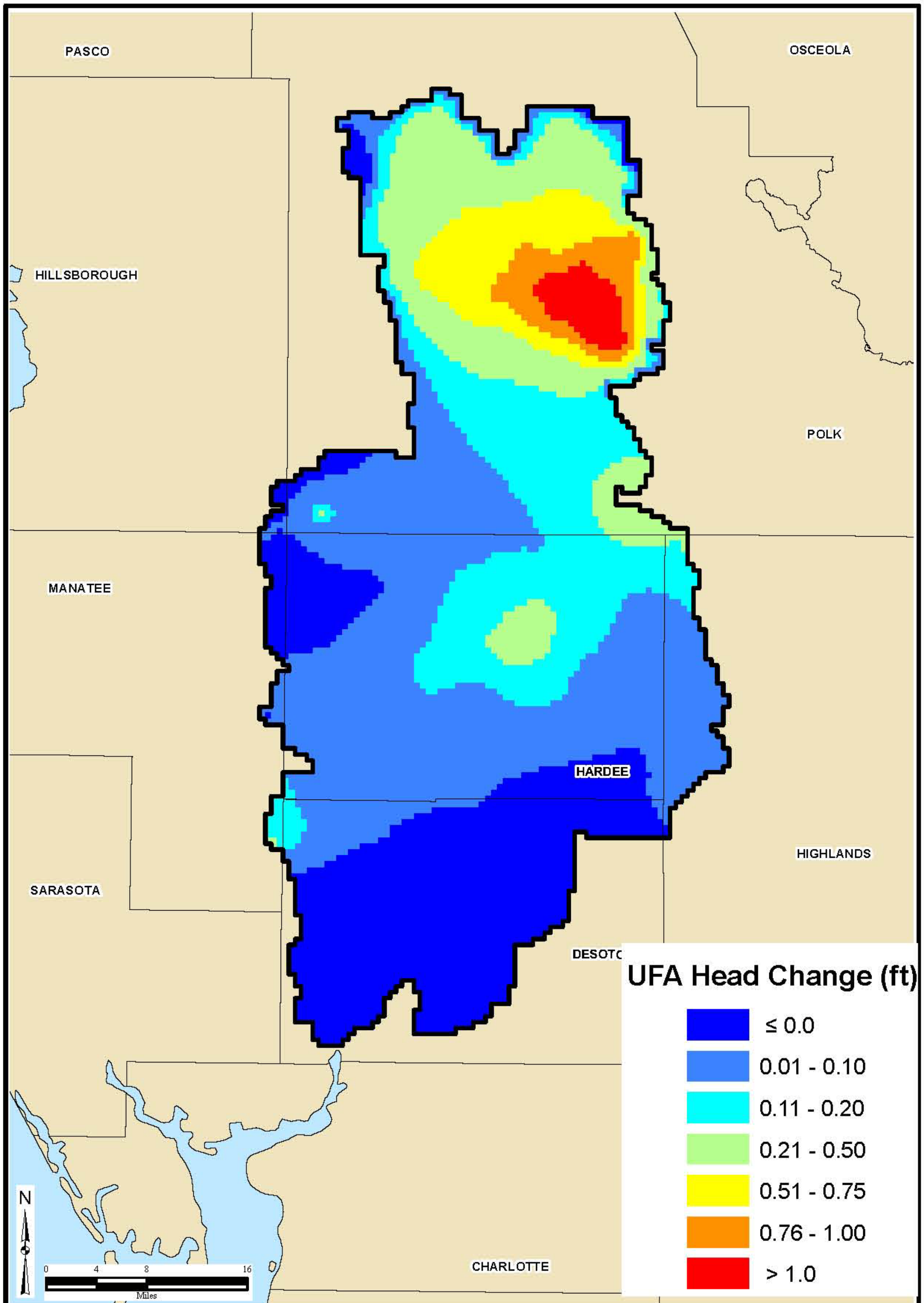
Model Boundary

Figure 3.4
Average Groundwater Head Change in Layer 1 (SA) of Rainfall Scenario (Wet vs. Dry Scenario)



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Model Boundary

Figure 3.5
Average Groundwater Head Change in Layer 5 (UFA) of Rainfall Scenario (Wet vs. Dry Scenario)

rainfall conditions. As a result, the rainfall scenario probably underestimates the impact of the Wet versus Dry scenario on UFA heads, especially near the model boundaries. These boundary effects can be seen most notably in Figure 3.5 in the upper part of the basin; the largest head changes occur in the interior of the model while the boundary conditions constrain head changes near the model perimeter.

3.4 IMPACT OF RAINFALL ON WATER BUDGETS

Table 3.3 summarizes the effect of the Wet versus Dry scenario on the simulated basinwide water budget. Appendix B provides the water budgets for individual sub-basins. The sub-basin locations are shown in Figure 3.2. The water budget terms are expressed in inches and represent the annual volumes of water per unit area of the basin or sub-basin[1], averaged over the 13-year simulation period. The water budget terms are defined as follows:

- **Rainfall** is the amount of precipitation;
- **Groundwater (GW) Pumping Addition** is the amount of water that is added to the land surface from groundwater withdrawals. The model treats groundwater withdrawals as a transfer of water from the subsurface aquifer system to the surface water system, either in the form of areally distributed groundwater pumping additions or as point NPDES discharges;
- **Surface Water (SW) Inflow** is water that enters the (sub-)basin as streamflow or surface runoff;
- **Lateral GW inflow** is groundwater that enters underneath the (sub-)basin as a result of lateral head gradients;
- **TOTAL IN** is the sum of the above water inflow terms;
- **TOTAL OUT + Δ Storage** is the sum of all outflow terms, plus the change in storage. The difference between this term and TOTAL IN is the water budget error;
- **ET Loss** is the water lost as a result of evapotranspiration;
- **GW Pumping** is water withdrawn from the subsurface underneath the (sub-) basin. This term is approximately, but not exactly, equal to the GW Pumping Addition, because a portion of the GW Pumping (NPDES discharges) is accounted for in the SW Inflow term;
- **SW Outflow** is the water that leaves the (sub-) basin as streamflow or as surface runoff;
- **Lateral GW Outflow** is the groundwater water that leaves the (sub-)basin as a result of lateral head gradients;

[1] The sub-basin water budgets are based on the active model cells. In the Payne Creek and Peace at Zolfo sub-basins, a number of land surface model cells were set as inactive to represent operational phosphate mining areas. The inactive cells account for 23% of the sub-basin area in Payne Creek and 17% in the Peace at Zolfo sub-basin. Rainfall and ET in the water budgets for these sub-basins are, therefore, low by the same percentages. This is also refected in the basin wide water budget in Table 3.3.

- **Storage Change** is the change in the amount of water stored in the (sub-)basin, including groundwater in aquifer layers underneath the basin;
- **UFA Recharge** is the net vertical flux of water into the UFA underneath the (sub-) basin.

Table 3.3
Basinwide Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	% Change
Rainfall	53.1	46.6	+ 14 %
GW Pumping Addition	2.1	2.1	0
NPDES Discharge	0.8	0.8	0
SW Inflow	0.0	0.0	0
Lateral GW Inflow	2.9	3.0	- 3 %
TOTAL IN	59.0	52.5	+ 12 %
TOTAL OUT + Δ Storage*	59.3	52.7	+ 13%
ET Loss	38.9	38.2	+ 2 %
GW Pumping	2.4	2.4	0
SW Outflow	13.6	8.4	+ 62 %
Lateral GW Outflow	4.5	4.3	+ 5 %
Storage Change	-0.2	-0.6	- 67%
UFA Recharge	2.2	2.0	+ 5 %

*Error is less than 1%

The overall model water budget [TOTAL IN - (TOTAL OUT + Δ Storage)] has an error of 0.5% which is a good result. Note that the UFA Recharge represents an internal flux in the model and is not included in the overall water budget calculation.

Table 3.3 indicates that the primary effect of the increase in rainfall between the Dry and the Wet scenario is increased stream flow. The average rainfall increase of 6.5 in/yr results in a basinwide stream flow increase of 5.2 in/yr. Increasing rainfall also increases ET and recharge to the UFA, although the latter effect is fairly small. The effects of increasing rainfall on streamflows are consistent across individual sub-basins (Appendix B), but the effects on streamflow are most pronounced in Saddle Creek and Peace Creek. In these two sub-basins, average annual streamflow was approximately twice as high in the Wet scenario as compared to the Dry scenario. In the other sub-basins the streamflow increase was between 55% and 65%. The effects of rainfall on ET and UFA recharge were also higher in the upper part of the basin (including Saddle Creek, Peace Creek, and Peace at Zolfo) as compared to the lower portion of the basin.

3.5 COMPARISON OF SIMULATED AND OBSERVED STREAMFLOWS

The final aspect of the evaluation of rainfall impacts is a comparison of the simulated stream flows for the Wet and the Dry scenarios against observed streamflows for the respective time periods, i.e., 1951-1963 in the Wet case and 1969-1981 in the Dry case. These comparisons are presented graphically in Figures 3.6, 3.7 and 3.8. These figures show the 10^{th}, 50^{th} and

90th percentiles of simulated and observed flows at the main Peace River stream gages. No data for Ft. Meade are presented, because this gage did not exist until mid-1974. There are no data for this gage for the Wet period and only partial data for the Dry period.

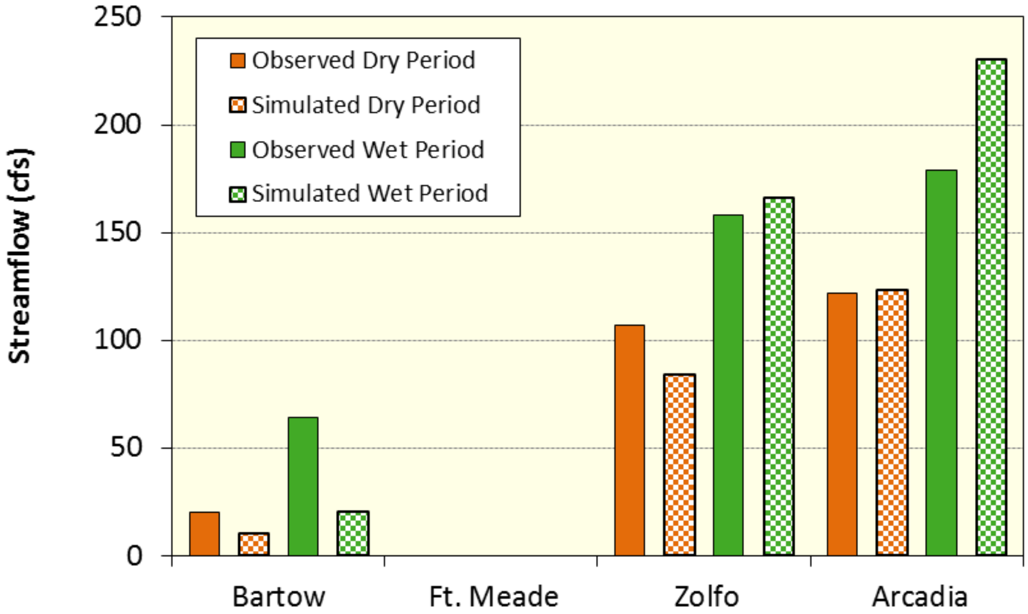


Figure 3.6 Observed and Simulated – 10th Percentile Streamflows

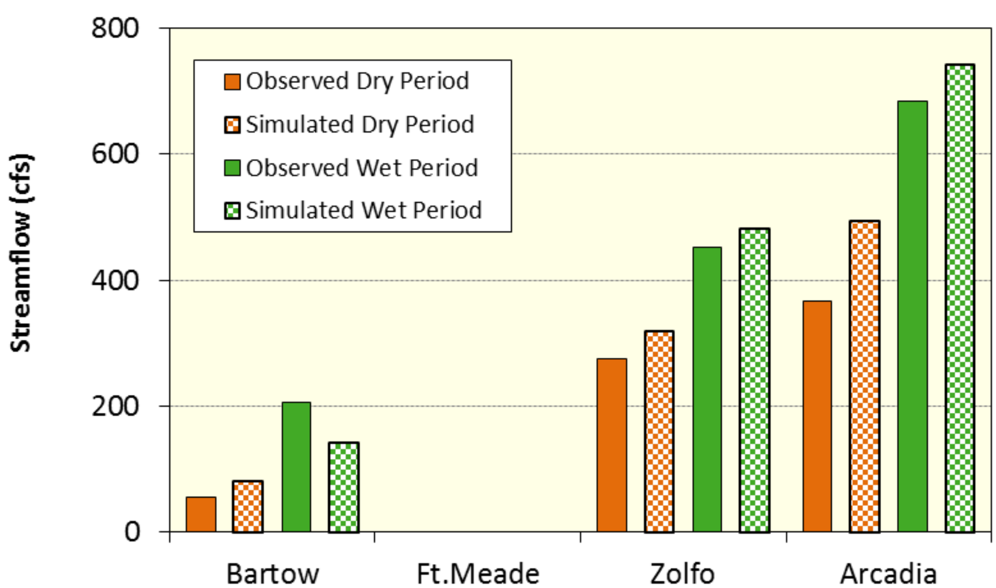


Figure 3.7 Observed and Simulated – 50th Percentile Streamflows

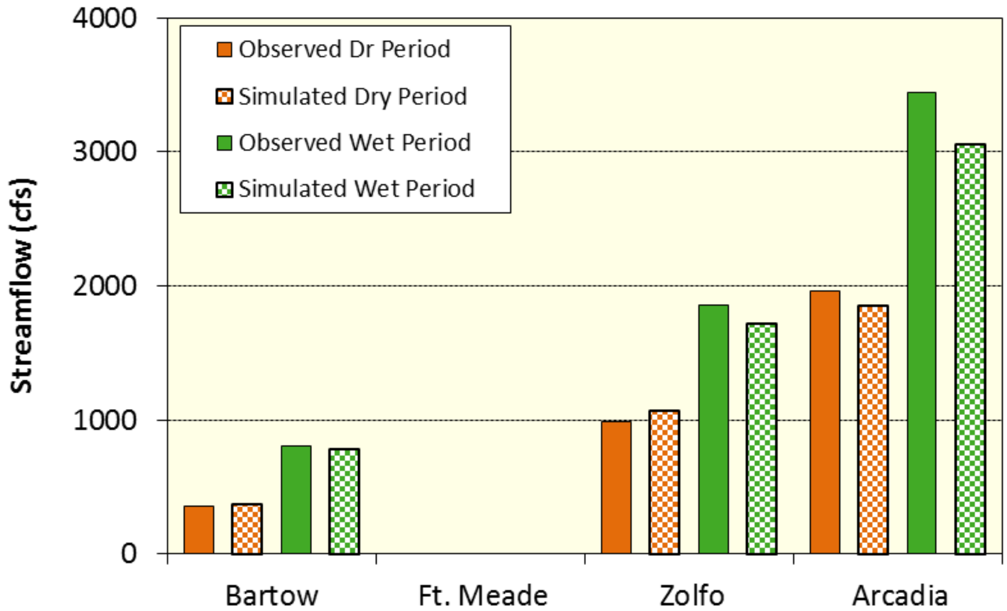


Figure 3.8 Observed and Simulated – 90th Percentile Streamflows

The comparison between simulated flows and the actual historical flows shows a number of pronounced differences at the Bartow gage under low-flow conditions (10th percentile flows; Figure 3.7). One notable feature is that the simulated flows for both Wet and Dry conditions are much lower than the historical flows for the same periods. While the simulated 10th percentile flow for the Wet rainfall scenario was about two times higher than the simulated flow for the Dry case (17.7 cfs versus 9.2 cfs, see Table 3.1), the actual flows at Bartow in the 1951-1963 period were above 60 cfs. Likewise, the actual 10th percentile flows during the Dry period of 1969-1981 were significantly higher than the simulation results. In fact, the actual flows during the 1969-1981 dry period were similar to simulated Wet flows, even though the actual rainfall in this period as measured at the Bartow NWS gage was nearly 9 in/year less than the rainfall in the Wet simulation. In addition to differences in withdrawals and land use, a factor that may explain these results, is the augmentation of streamflows from anthropogenic discharges, i.e, mining and waste water treatment plants (WWTPs) that occurred prior to the establishment of water conservation and water quality regulations in the 1980s (e.g., Garlanger, 2002; PBS&J, 2007). For example, The City of Lakeland's Glendale WWTP discharged effluent to Banana Lake until 1987 (EPA, 2004). It then switched to an artificial wetland treatment system in a former phosphate mining site near Mulberry. Overflow from the wetland system is discharged to the Alafia River. Average flows to the wetland system in 1993 were reported as 8 mgd (12.4 cfs). This discharge from the Glendale plant would have contributed to the observed Peace river flows at Bartow prior to 1987, but the model simulations of the Wet and Dry Periods only accounted for discharges that existed in the 1994-2006 Base period. Unfortunately, there is no quantitative data on the magnitude of the historical flow augmentations to confirm whether they can completely explain the apparent streamflow deficit in the simulated results[1].

At the Zolfo gage, there is a similar streamflow deficit in the simulation results for the Dry case but not for the Wet scenario. The streamflow deficit for the Dry case at Zolfo may reflect the influence from the upper part of the basin, above Bartow, combined with reduction of mining-related flow augmentations in the basin between Bartow and Zolfo. The deficit that was shown at Bartow for the Wet case is no longer present in the Zolfo results. The 10th percentile simulated flows agree well with historical flows at Arcadia, and in fact the simulated 10th and 50th percentile flows at this gage for the Wet case were higher than the historical flow for that period.

At the 50th and 90th streamflow percentiles, simulated flows at all three gage locations are in good agreement with historical flows, with Wet versus Dry conditions accounting for a much bigger streamflow difference than simulated versus observed results.

These results lead to a conclusion that changes in the basin above Bartow that have occurred since 1950s for the Wet case, and since the 1970s for the Dry case, have a more dominant effect on streamflow at Bartow under low-flow conditions than rainfall by itself. In this context, it is worth noting that the observed 10th percentile streamflows in the Base Case period, i.e, 1994-2006, were considerably lower than observed 10th percentile flows in either the Dry or the Wet periods, even though average rainfall in the Base Case period was close to that of the Wet period, at 55 versus 55.6 inches/year. At the Bartow gage, the 10th percentile flow during the 1994-2006 Base Case period was 6.2 cfs, versus 20 cfs in the Dry period (1968-1981) and 64 cfs in the Wet period (1951-1963). Part of the explanation for the low 10th percentile flows in the Base Case period is that this period included the exceptionally dry year 2000. Between the different historical periods that were considered in the rainfall scenarios, the lowest observed flows at Bartow occurred in the Base Case period rather than the Dry period, during the years 2000 and 2006, respectively. Conditions during very dry years will have a strong influence of 10th percentile flows, but the difference may also reflect other changes in the basin that have occurred over time, and which primarily affected low flows. It is likely that reductions in historical flow augmentations is an important factor.

Conversely, at high-flow conditions at Bartow, and at all flow conditions at the Zolfo and Arcadia gages, these changes do not appear to have a significant effect on streamflows. Rather, rainfall is the dominant influence on streamflow, and the model simulations provide a reasonable to good match to actual historical flows under both Wet and Dry conditions even though land use/vegetation and groundwater pumping in the model were different from historical conditions during both the Wet and the Dry periods.

Comparing the observed Wet and Dry period streamflows with each other confirms the above findings of impacts in the upper part of the Peace River basin. Figures 3.6 to 3.8 show a proportionally much bigger difference between historical Wet and Dry period flows as

[1] Garlanger (2002) estimated that in 1980, return flows from mining, industrial users and waste water treatment plants totaled 185 cfs. Nearly all of the discharges associated with these uses occur in the basin above Zolfo (HGL, 2009). Since observed historical median (50th percentile) flows at Zolfo ranged from less than 300 to about 450 cfs (see Figure 3.7), Garlanger's estimated contribution from return flows seems quite high.

compared to the Zolfo and Arcadia gages. These differences are summarized in Table 3.4 which shows a summary of the observed flows at the three gages. Note that the streamflows in this Table are presented in inches/year, rather than in cfs as was done in the preceding tables. Comparing the streamflows in units of inch/year normalizes the data for the difference in drainage area of each gage. The tables shows that the historical flow changes between the Wet and the Dry periods were much larger at the Bartow gage than at the Zolfo and Arcadia gages. The magnitude of the changes in the observed historical flows at Bartow is even larger than in the simulated Wet and Dry scenarios (see Table 3.1). This further indicates that factors other than rainfall differences between the Wet and Dry periods have influenced streamflow changes at Bartow, while at the Zolfo and Arcadia gages the streamflow changes are consistent with rainfall differences.

Table 3.4
Observed Streamflow Percentiles for the Dry and Wet Periods

Gage Name	Streamflow Percentile	Streamflow (in/yr)		
		Wet Period (1951-63)	Dry Period (1969-81)	% Change
Peace River at Bartow (drainage area = 390 mi^2)	10th	2.2	0.7	+ 220%
	50th	7.2	1.9	+ 275%
	90th	27.9	12.3	+ 127%
	Mean	12.0	4.7	+ 155%
Peace River at Zolfo Springs (drainage area = 826 mi^2)	10th	2.6	1.8	+ 48%
	50th	7.4	4.5	+ 64%
	90th	30.6	16.2	+ 89%
	Mean	13.6	7.6	+ 79%
Peace River at Arcadia (drainage area = 1,367 mi^2)	10th	1.8	1.2	+ 47%
	50th	6.8	3.6	+ 87%
	90th	34.2	19.5	+ 76%
	Mean	13.8	8.0	+ 73%

4.0 GROUNDWATER WITHDRAWAL SCENARIO

The Groundwater Withdrawal scenario addressed the impact of changes in groundwater pumping. Specifically, the effects of reducing pumping in the Base Case scenario to 75% and 50% were evaluated. For these two cases, the pumping rates for all extraction wells in the model were reduced by 25% and 50%, respectively. Because in the PRIM all water withdrawn from either groundwater or surface water in the basin is returned as either a point (NPDES) discharge or distributed across the land surface, reductions in groundwater withdrawals caused a proportional reduction in these return flows.

In order to account for regional effects of reduced groundwater pumping, the heads in the IAS and UFA along the lateral boundaries of the model were assigned as prescribed, but time-varying, head boundary conditions were also updated to reflect reduced pumping outside the PRIM domain. The procedure followed the same methodology as used in Phase IV of this project: the regional SD groundwater model was re-run with pumping for all wells reduced to 75% and 50% of actual 1994-2006 pumping, and the predicted heads in the IAS and UFA were then interpolated onto the locations of the PRIM lateral boundaries. The impacts of changes in pumping were evaluated in terms of streamflows, lake levels, SA and UFA groundwater heads, and water budgets. In addition, a comparison was made between simulated and historical UFA potentiometric elevations and spring flows at Kissengen Spring. To enable this comparison, a vertical flow conduit (flow link) was inserted in the model for the withdrawal reduction scenarios as well as the Base Case scenario, at the location of Kissengen Spring to create a direct hydraulic connection between the UFA and the surface flow layer of the model, with the spring outlet elevation set to 83.5 feet NVGD (Basso, 2003).

4.1 IMPACT OF GROUNDWATER WITHDRAWALS ON STREAMFLOWS

Table 4.1 summarizes the effects of reductions in groundwater withdrawals on streamflows, expressed as changes in streamflow from the Base Case scenario at the 10th, 50th, and 90th percentiles, as well as the difference in mean flows.

Table 4.1
Impact of Groundwater Withdrawals on Streamflows

Gage Name	Withdrawal (% of Base Case)	Streamflow Changes at Selected Percentiles[1)]			
		10th	50th	90th	Mean
Peace River at Bartow	75%	+4%	+3%	+3%	+3%
	50%	+14%	+7%	+6%	+6%
Peace River at Ft. Meade	75%	+13%	+3%	+3%	+3%
	50%	+28%	+7%	+5%	+6%
Peace River at Zolfo Springs	75%	+2%	+1%	+1%	+1%
	50%	+4%	+5%	+1%	+2%
Peace River at Arcadia	75%	-2%	0%	0%	0%
	50%	-2%	+1%	+0%	+1%

[1)] + indicates higher streamflow compared to Base Case, - indicates lower streamflow

The table shows that reducing withdrawals has a significant impact on low and median flows at Bartow and Ft. Meade, but much less impact on flows at Zolfo and Arcadia. The lesser impact at Zolfo and Arcadia can be attributed to the much tighter confinement on the UFA in this part of the Peace River basin. In fact, the model indicates a slight reduction in the 10th percentile flows at Arcadia when pumping is decreased. This effect can be attributed to the reduction in groundwater extraction return flows when withdrawals are reduced. In the PRIM, groundwater extraction is modeled as a transfer of water from the subsurface to the surface, while a portion of the return flows are lost to ET or re-infiltrate the subsurface, they also contribute to surface runoff and streamflow. This is most clearly seen in the Payne Creek and Joshua Creek sub-basins, where groundwater extraction associated with phosphate mining (Payne Creek) and agriculture (Payne Creek and Joshua Creek) increase base-flow compared to other sub-basins of the Peace River (HGL, 2009). Reducing groundwater pumping reduces this contribution to streamflows.

4.2 IMPACT OF REDUCED GROUNDWATER WITHDRAWALS ON LAKE LEVELS

Table 4.2 summarizes the effects of reduced groundwater withdrawals on simulated water levels for selected lakes in the Saddle Creek and Peace Creek basins. The impacts are expressed in terms of the changes in lake level, at selected percentiles, between the two reduced-withdrawal scenarios and the Base Case scenario. Positive values mean an increase in the lake level when pumping was reduced. Instances where the magnitude of the change was less than 0.1 feet are indicated using a dash (-) symbol. Groundwater extraction affects lake levels indirectly, through the hydraulic connection between lakes and groundwater. Lowering groundwater levels will tend to cause lake level drawdowns, and higher groundwater levels will tend to cause higher lake levels.

Table 4.2 shows that as expected, reductions in groundwater extraction generally lead to higher lake levels. On the whole, however, the model indicates that changes in groundwater pumping have little effect on lake levels. The sensitivity of lake levels to groundwater heads (and therefore to groundwater withdrawals) is greatest at the 10th percentile level (i.e., under low lake levels conditions). These correspond to dry periods when lakes receive little surface water inflow to maintain lake levels. At the 50th percentile of lake levels and above, Table 4.2 indicates little or no sensitivity to groundwater withdrawals, with only Lake Arietta and Lake Annie showing an impact greater than 0.1 feet.

For Lake Ariana, Lake Lena, Lake Fannie, and Surveyors Lake, the 10th percentile lake level elevation was actually lower for the reduced withdrawal scenarios compared to the Base Case. The cause for this behavior is that reductions in groundwater withdrawals were accompanied by corresponding reductions in the amounts of extracted water that was re-applied to the land surface. These reductions reduced infiltration and recharge to the SA, which in turn tends to lower groundwater levels in the SA and lake levels (which are very sensitive to the SA groundwater level).

Reductions in groundwater withdrawals therefore have two opposing effects: On the one hand, higher potentiometric heads in the UFA result in higher groundwater levels in the SA and lake levels, at least in the upper part of the basin where there is good hydraulic communication between the SA and UFA. On the other hand, reducing the amount of water transferred from the UFA to the land surface tends to cause a drop in SA groundwater levels and lake levels. The relative importance of these factors on lake levels varies with location, as a function of the amount of extracted water that is re-applied in the immediate area of each lake, and variations in leakance between the SA and UFA.

Lake level hydrographs for a number of the lakes are shown in Appendix C. On the whole, they show very similar results for the two withdrawal scenarios and the Base Case scenario. To the extent that reduced groundwater withdrawals increase lake levels, the impacts occur during dry periods. Lake levels varied more under these conditions in the Base Case scenario than in the withdrawal scenarios.

Table 4.2
Effect of Groundwater Withdrawal Reductions on Lake Levels

	Lake Level Differences (feet)[1]							
	75% GW Extraction				50% GW Extraction			
Lake	10th	50th	90th	Mean	10th	50th	90th	Mean
Lake Hancock	-	-	-	-	-	-	+0.1	-
Lake Parker	-	-	-	-	-0.1	-	-	-
Lake Gibson	-	-	-	-	-	-	-	-
Lake Arietta	+0.1	+0.1	+0.2	+0.1	+0.1	+0.2	+0.4	+0.2
Lake Ariana	-0.1	-	-	-	-0.1	-	-0.1	-0.1
Lake Lena	-0.2	-	-	-	-0.2	-	-	-
Spirit Lake	-	-	-	-	-	-	-	-
Eagle Lake	+0.2	+0.1	-	+0.1	+0.4	+0.1	-	+0.2
Lake Alfred	-	-	-	-	-	-	-	-
Lake Conine	-	-	-	-	+0.1	-	-	-
Lake Haines	-	-	-	-	+0.1	-	-	-
Lake Smart	-	-	-	-	+0.1	-	-	-
Lake Fannie	-0.2	-	-	-	-0.3	-0.1	-	-0.1
Lake Hamilton	-	-	-	-	-0.1	-	-	-
Lake Howard	+0.1	-	-	-	+0.1	-	-	-
Lake Shipp	+0.1	-	-	-	+0.1	-	-	-
Lake Annie	+0.1	+0.3	-	+0.1	+0.2	+0.5	-	+0.2
Lake Myrtle	+0.1	-	-	-	+0.2	-	+0.1	+0.1
Lake Garfield	+0.1	-	-	-	+0.1	-	-	-
Surveyors Lake	-0.1	-	-	-	-0.2	-	-	-0.1

[1] + indicates higher lake level compared to Base Case, - indicates lower lake level

4.3 IMPACT OF REDUCED WITHDRAWALS ON GROUNDWATER HEADS

Figures 4.1 and 4.2 show the effect of the 75% withdrawal scenario on potentiometric heads, averaged over the 13-year simulation period, in the SA and UFA, respectively. Figures 4.3 and 4.4 show the same for the 50% withdrawal scenario. In each case, the figures depict the head difference with the Base Case scenario, i.e, the changes is shown as ($h_{Reduced\_Withdrawal}$ – h_{Base_Case}). As expected, reductions in groundwater withdrawals have a significant impact on potentiometric levels, especially in the UFA from which most of the pumping occurs.

The withdrawal scenarios incorporated changes in pumping not only within the Peace River basin boundaries, but also regional pumping changes (through the linkage with the SD groundwater model). The pattern of the potentiometric surface recovery in the UFA under pumping reductions is consistent with the pattern of regional groundwater drawdowns in the Southern Water Use Caution Area (SWUCA), which encompasses the Peace River basin and exhibits the greatest amount of UFA drawdown in southern Hillsboro and Manatee Counties, to the west of the Peace River basin (SWFWMD, 2006). The patterns of groundwater head changes caused by reduced withdrawals are essentially the same for both scenarios, which differ only in the magnitude of the head changes. The greatest head increases in the UFA (Figures 4.2 to 4.4) occurred along the western boundary of the model in Hardee County and were up to 10 feet in the 75% withdrawal scenario and 20 feet in the 50% withdrawal scenario. In the upper portion of the Peace River basin, above Bartow, the UFA head increases varied between approximately 5 feet to less than 1 foot in the 75% withdrawal scenario, and between 10 feet to less than 2 feet in the 50% withdrawal scenario.

The potentiometric head responses to changes in pumping in the SA (Figures 4.1 and 4.3) reflect the head changes in the UFA and variations in the vertical leakance between the SA and UFA. The impacts on the SA potentiometric heads were the greatest in the northwestern side of the Peace River basin, combining the effects of greater UFA head changes along the western basin boundary and higher leakance in the northern portion of the basin. In the 75% withdrawal scenario, the head response in the SA varies from about 2 feet to negligible; in the 50% withdrawal scenario, there was a somewhat greater SA head response in the upper Peace River basin, but head changes remained below 2 feet in the majority of the model domain. The figures also show that the areas of significant changes in SA heads are relatively localized; over most of the basin area, the impact on the SA is less than 0.25 feet in the 75% withdrawal scenario, and less than 0.5 feet in the 50% withdrawal scenario.

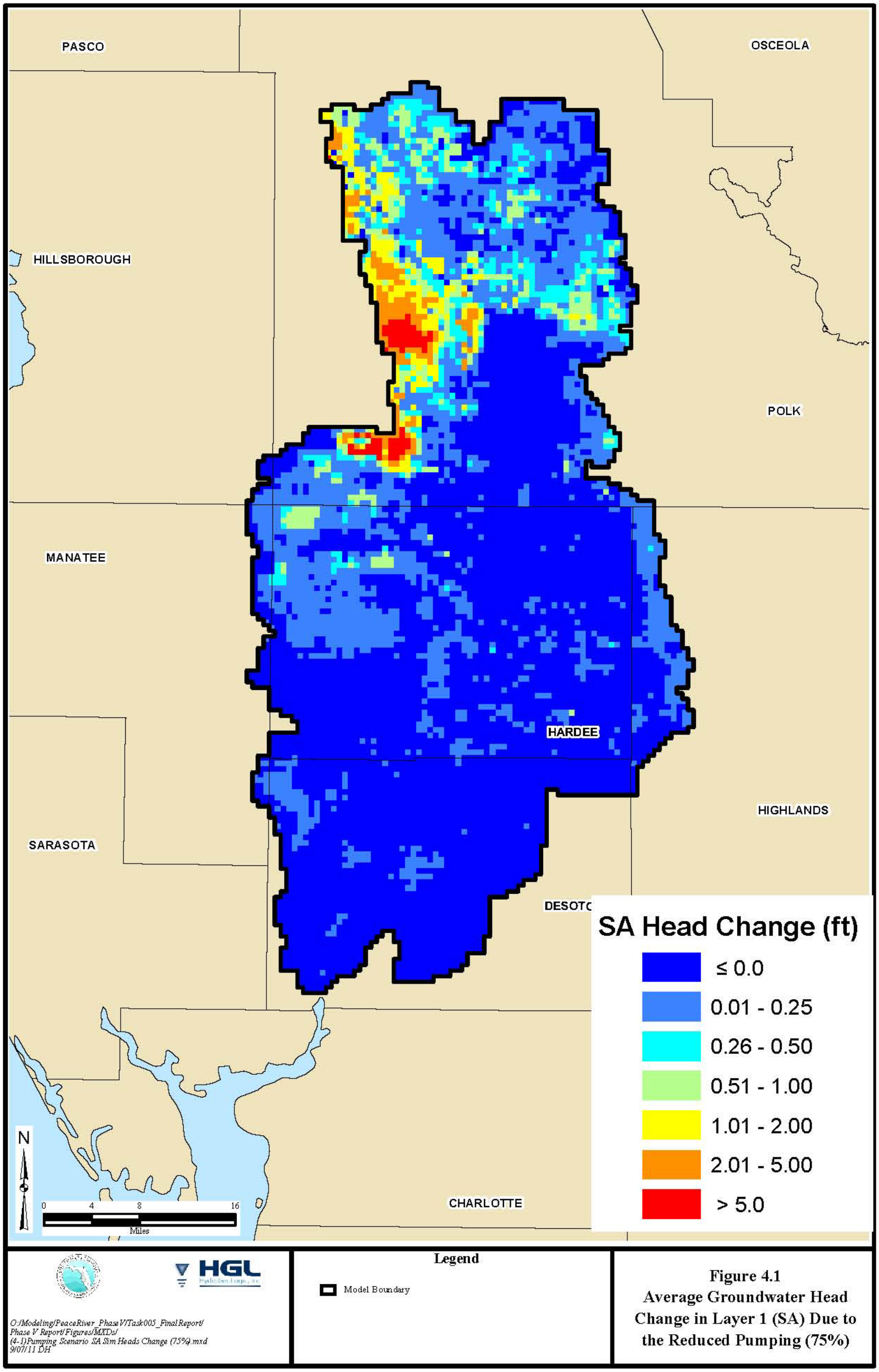
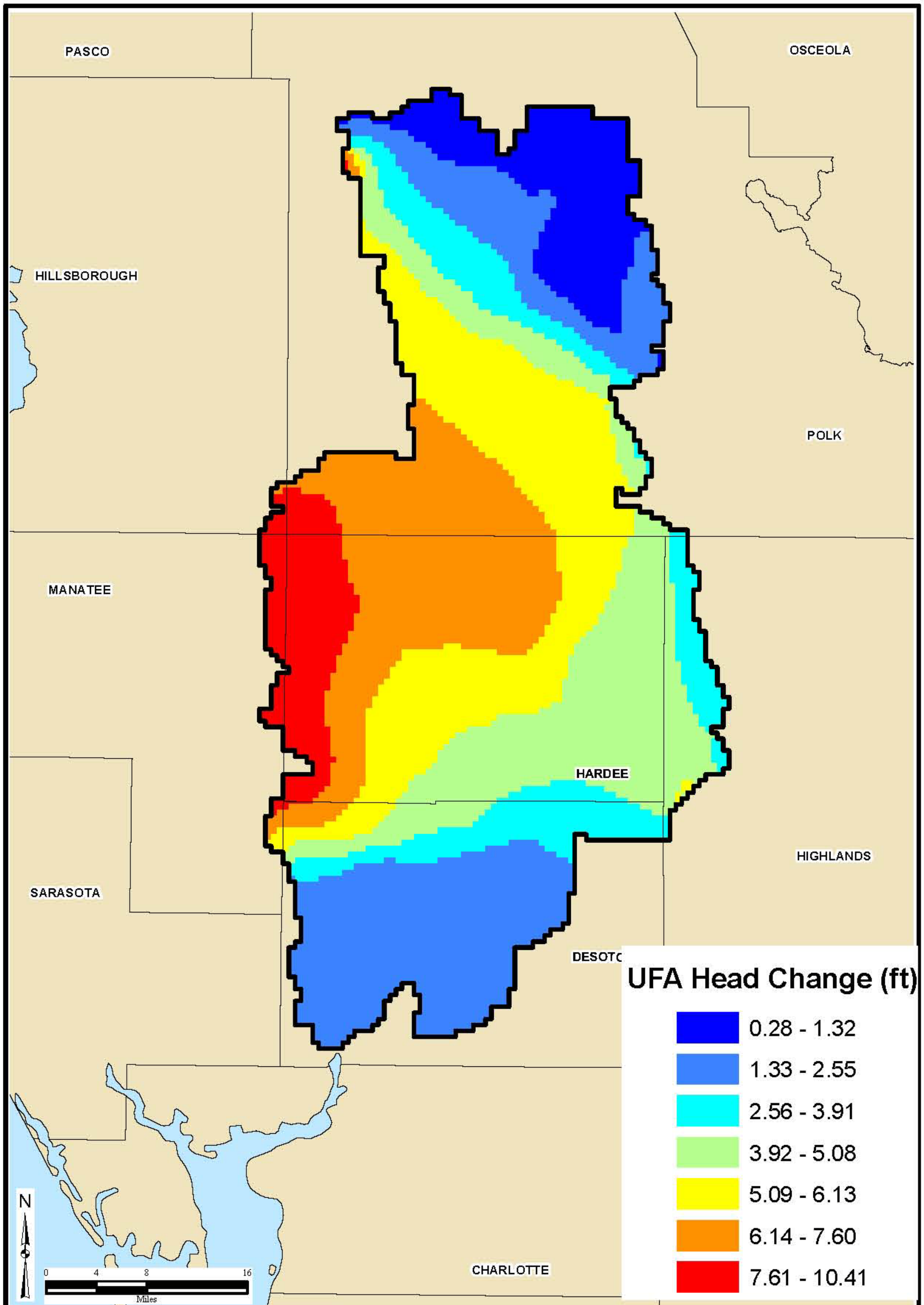


Figure 4.1
Average Groundwater Head Change in Layer 1 (SA) Due to the Reduced Pumping (75%)



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Phase V Report/Figures/MXDs/
(4-2)Pumping Scenario UFA Sim Heads Change (75%).mxd
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Legend

Model Boundary

Figure 4.2
Average Groundwater Head Change in Layer 5 (UFA) Due to Reduced Pumping (75%)

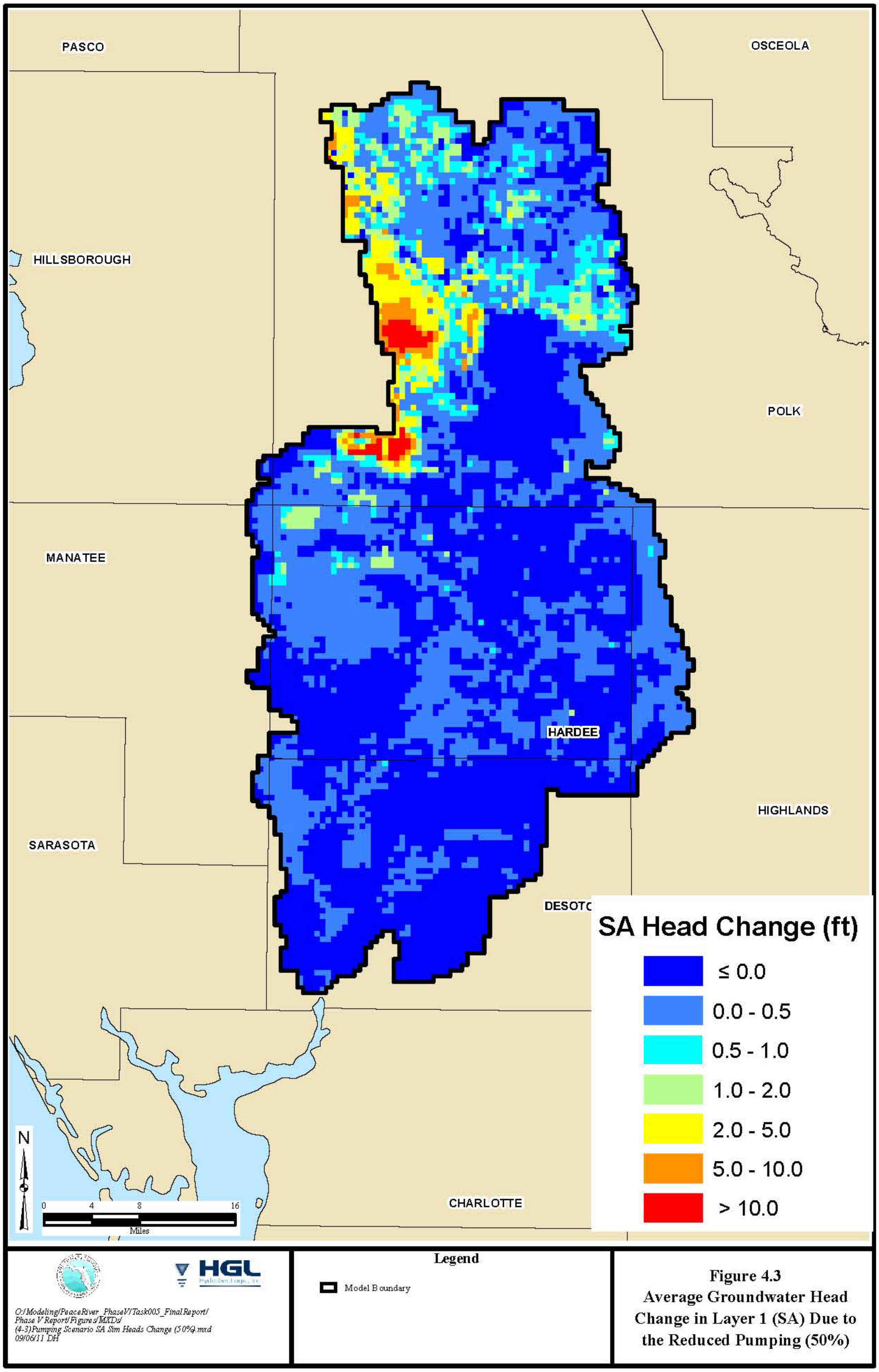


Figure 4.3
Average Groundwater Head Change in Layer 1 (SA) Due to the Reduced Pumping (50%)

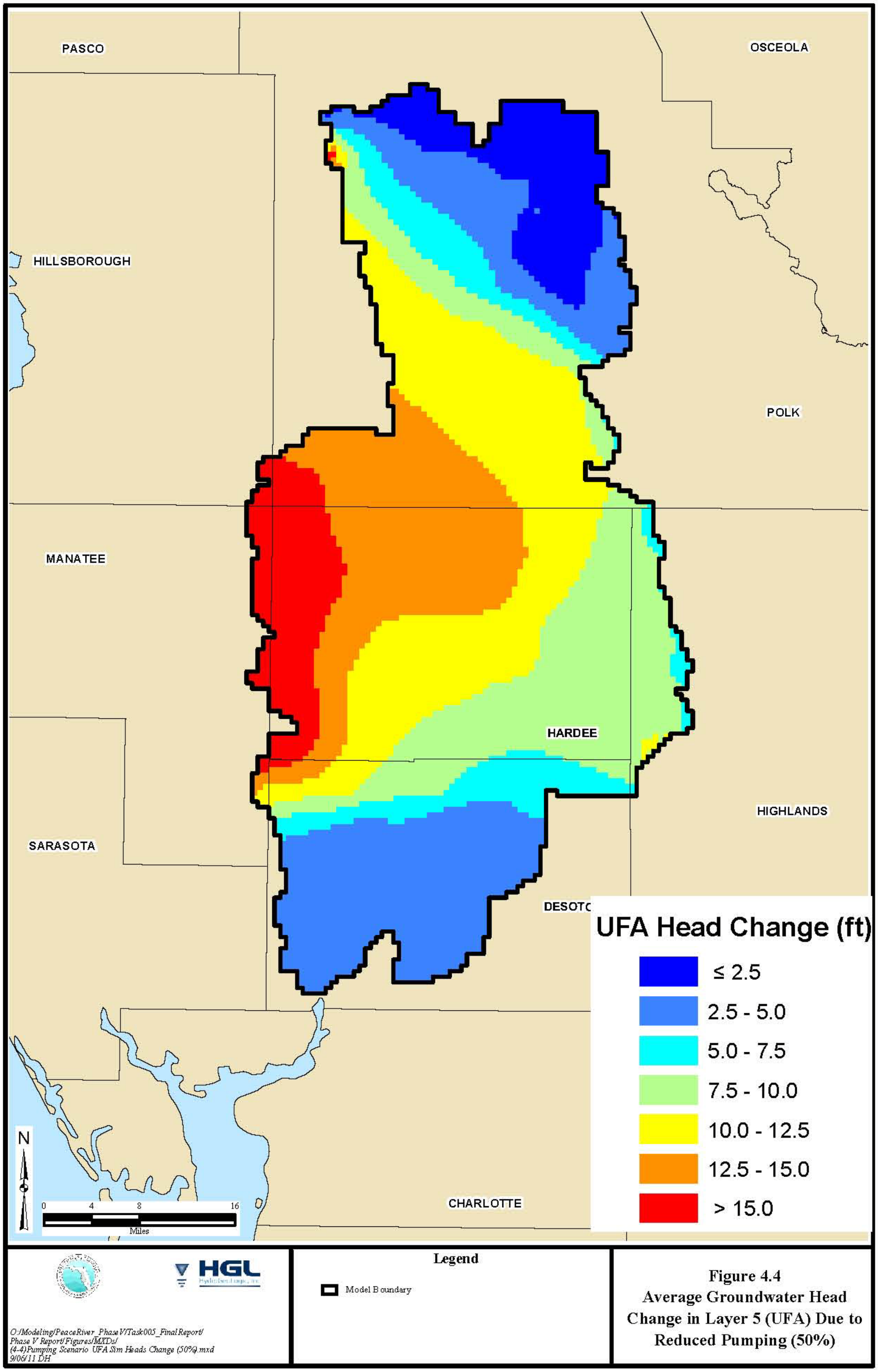


Figure 4.4
Average Groundwater Head Change in Layer 5 (UFA) Due to Reduced Pumping (50%)

4.4 IMPACT OF GROUNDWATER WITHDRAWALS ON WATER BUDGETS

Table 4.3 presents the changes in the basinwide water budgets associated with changes in groundwater withdrawals. The individual sub-basin water budgets are presented in Appendix D. These tables present the water budget components for the Base Case simulation, along with the water budgets for the 75% and 50% withdrawal scenarios, and the percentage change in the water budgets for the two withdrawal scenarios compared to the Base Case simulation. Aside from the obvious change in the groundwater pumping component of the water budgets, the primary effects of changes in groundwater withdrawals are on the lateral groundwater inflow and outflow underneath the basin, and on recharge to the UFA, with reduced groundwater withdrawals resulting in less recharge to the UFA. Basinwide, the changes in groundwater withdrawal have little impact on streamflows. The water budgets for the individual sub-basins in Appendix D confirm that the impacts of the withdrawal scenarios occur primarily in the Upper Peace River basin, with only slight changes in the sub-basins below Zolfo Springs (i.e., Charlie Creek, Horse Creek, Peace at Arcadia, and Joshua Creek).

ET did not change from the Base Case in either of the two Withdrawal Reduction scenarios. The explanation was the automatic reduction in irrigation (GW pumping additions in the water budget tables) associated with the withdrawal reductions would cause a reduction in ET, but in the simulations this was not the case. The likely explanation is that the effect of less irrigation is balanced by the increase in water levels in the SA, so that overall in the simulations there was negligible change in water availability to sustain ET.

Table 4.3
Basinwide Water Budget for Groundwater Withdrawal Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	52.2	52.2	52.2	0	0
GW Pumping Addition	2.1	1.6	1.1	-25	-50
NPDES Discharge	0.8	0.8	0.8	0	0
SW Inflow	0.0	0.0	0.0	0	0
Lateral GW Inflow	2.5	2.2	1.8	-15	-29
TOTAL IN	57.6	56.7	55.8	-2	-3
TOTAL OUT + Δ Storage	58.0	57.1	56.3	-2	-3
ET Loss	38.4	38.3	38.3	0	0
GW Pumping	2.4	1.8	1.2	-25	-50
SW Outflow	13.4	13.4	13.4	0	0
Lateral GW Outflow	4.3	3.9	3.6	-8	-16
Storage Change	-0.3	-0.3	-0.2	-23	-38
UFA Recharge	2.3	1.9	1.6	-15	-29

4.5 EVALUATION OF REDUCED WITHDRAWAL SCENARIOS AGAINST HISTORICAL AQUIFER CONDITIONS

The lowering of the potentiometric surface in the UFA is understood to be a major contributor to the changed hydrologic conditions in the upper Peace River basin, as compared to predevelopment conditions (e.g., Llewelling et al., 1998; Basso, 2003; PBS&J, 2007). These changes include a loss of artesian conditions in the upper part of the basin, which have changed the Peace River from a gaining stream along its entire length to a losing stream north of the boundary between Polk County and Hardee County (Figure 4.5). The 'Average May Surface' shown in this figure represents the potentiometric surface elevation of the UFA during the month of May for the period 1989 – 2000. Associated with the lowering of the groundwater potentiometric surface, springs that historically existed in the upper Peace River basin, most notably Kissengen Spring, have ceased flowing since 1960.

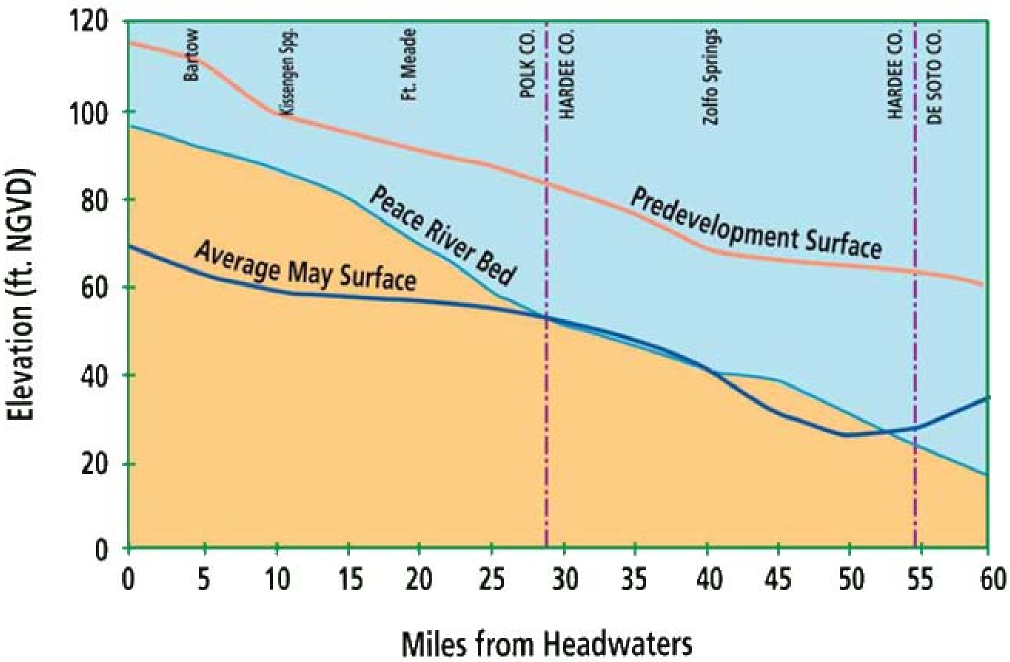


Figure 4.5 Predevelopment and Current Floridan Aquifer Potentiometric Surface along Peace River (from Basso, 2003)

Basso (2003) correlated historical flows at Kissengen Spring with potentiometric heads in the Floridan aquifer, which showed that spring flows declined along with a lowering of the potentiometric surface, and spring flows ending in the 1950s when the Floridan aquifer head fell below the spring outlet elevation. This relationship is depicted in Figure 4.6[1].

[1] Floridan aquifer levels have been updated through 2007 and are the average annual heads from the ROMP 60 monitoring well. Heads prior to the mid-1950s were estimated using a regression relationship with the Sarasota No. 9 well (Basso, personal communication, 2011).

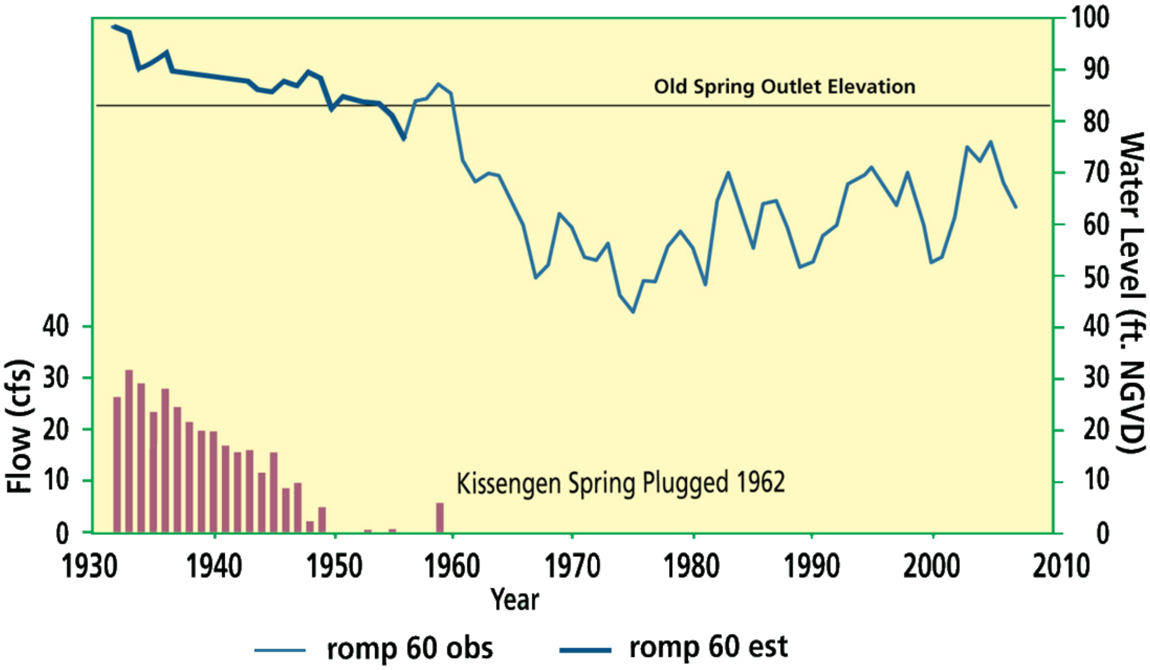


Figure 4.6 Relationship between Flows at Kissengen Spring and Floridan Aquifer Levels (from Basso, 2003).

The present model scenarios offer an opportunity to assess the impacts of reduced groundwater withdrawals on Kissengen Spring flow in a similar manner as the previous analysis of Basso (2003). Figure 4.7 presents a graph of the simulated average May potentiometric heads in the UFA along a north-south cross section of the Peace River, analogous to Figure 4.5. This figure shows the UFA heads for the Base Case scenario, along with the heads for the 75% and 50% withdrawal scenarios. In the Base Case scenario, the UFA head is below the Peace River bed elevation in the upper portion of the basin and intersects the river bed elevation at a point between 20 and 25 miles from the Peace River headwaters. Downstream of this point, the UFA head is higher than the river bed elevation. This pattern is similar to that of the Average May Surface shown in Figure 4.5, although the intersection point is located about 7 miles more upgradient in the simulation results in Figure 4.7 than is depicted in Figure 4.5. These differences may be due to the fact that the average observed May surface in Figure 4.5 reflects data from the period 1989 – 2000, whereas the simulation results in Figure 4.7 are for the 1994 – 2006 period. Figure 4.7 also shows how each increment reduction in withdrawals results in a higher groundwater potentiometric surface. At the 50% reduction, the Upper Floridan head is above the Peace River bed downstream from a point about 4 miles north of Ft. Meade, and the potentiometric surface, if not above, is at least close to the elevation of the river bed upstream of Ft. Meade.

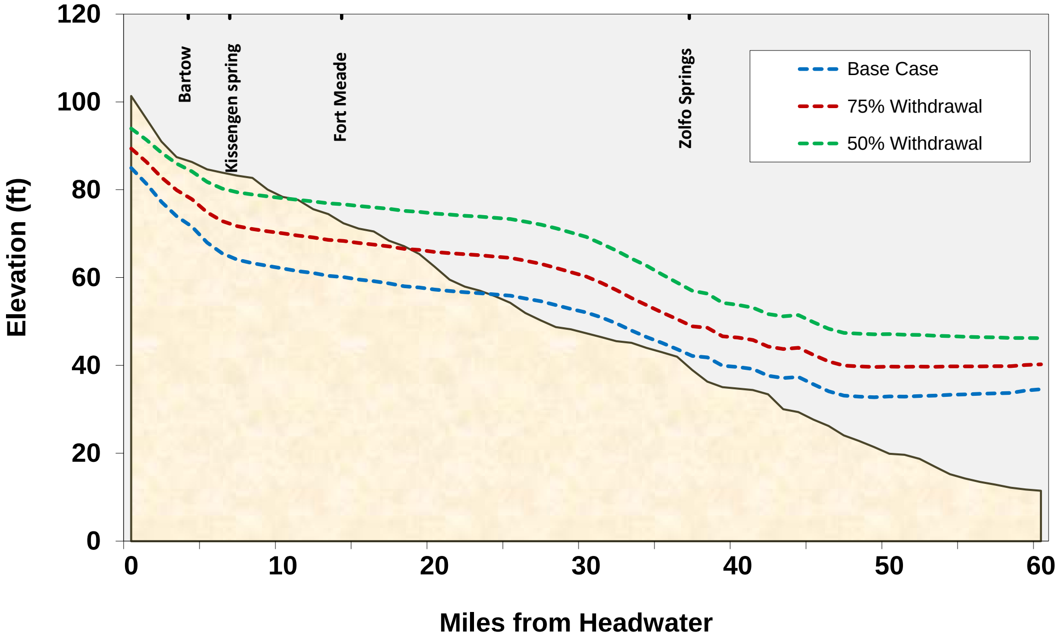


Figure 4.7 North-South Profile of Simulated May UFA Heads versus Peace River Bed Elevation

The impacts of reduced groundwater withdrawals on simulated heads at Kissengen Spring are shown in Figure 4.8. This figure shows simulated UFA heads at Kissengen Spring for the Base Case and the two reduced pumping scenarios. The figure depicts the simulated May heads for the year 1999, which was taken as a representative year because the rainfall for that year was close to the long term average of 50 in/yr (see Figure 2.2). In the Base Case scenario, the simulated UFA head remained from 4 to 27 feet below the spring outlet elevation. In the 75% pumping scenario, the simulated UFA head also remained below the spring outlet elevation during most of the simulation period. When pumping was reduced to 50% however, the simulated UFA head was at or just above the spring outlet elevation during most of the simulation period. Correspondingly, the model produced a slight amount, i.e., less than 1 cfs, of spring discharge for this scenario. Figure 4.9 shows the simulated spring discharge for the 50% Withdrawal scenario. The spring discharge in the simulation is but a small fraction of the historical spring flows, which were between 20 and 30 cfs up to the 1940s (see Figure 4.6). The UFA head in the 50% Withdrawal scenario was also still much lower than historical heads at Kissengen Spring. The highest heads during the simulation were just slightly above the spring outlet elevation of 83.5 feet, whereas pre-development heads were on the order of 98 feet (Basso, 2003).

These head differences in turn are consistent with the magnitude of simulated withdrawals compared to historical conditions. This is illustrated in Figure 4.10 which shows ground water withdrawals in the Southern Water Use Caution Area (SWUCA) from 1950 until the present. This figure indicates that a 50% reduction in water use, would bring withdrawals to about 300 Mgd, which was the water use in 1950 when the spring ceased continuous flow. In contrast, estimated groundwater withdrawals during the 1930s were less than half the 1950 rate (Basso, 2003, Figure 42).

The present analysis of the amount of withdrawal reductions that would be necessary to restore flow at Kissengen Spring is close to the estimates developed by Basso (2003). Based on a combination of graphical and numerical techniques, Basso estimated that a 60% reduction in groundwater withdrawals would be necessary to return continuous flow to Kissengen Spring. Basso's analysis was based on groundwater withdrawals for April and May 1989, whereas the current analysis reflects withdrawals over a much longer, 13-year period, which averages out to lower withdrawal rates than the seasonally highest April-May pumpage. Figure 4.8 also shows that under a 50% withdrawal reduction, continuous flow is not quite achieved at Kissengen Spring. Overall, the results of the withdrawal scenarios are consistent with, and support the analysis of Basso.

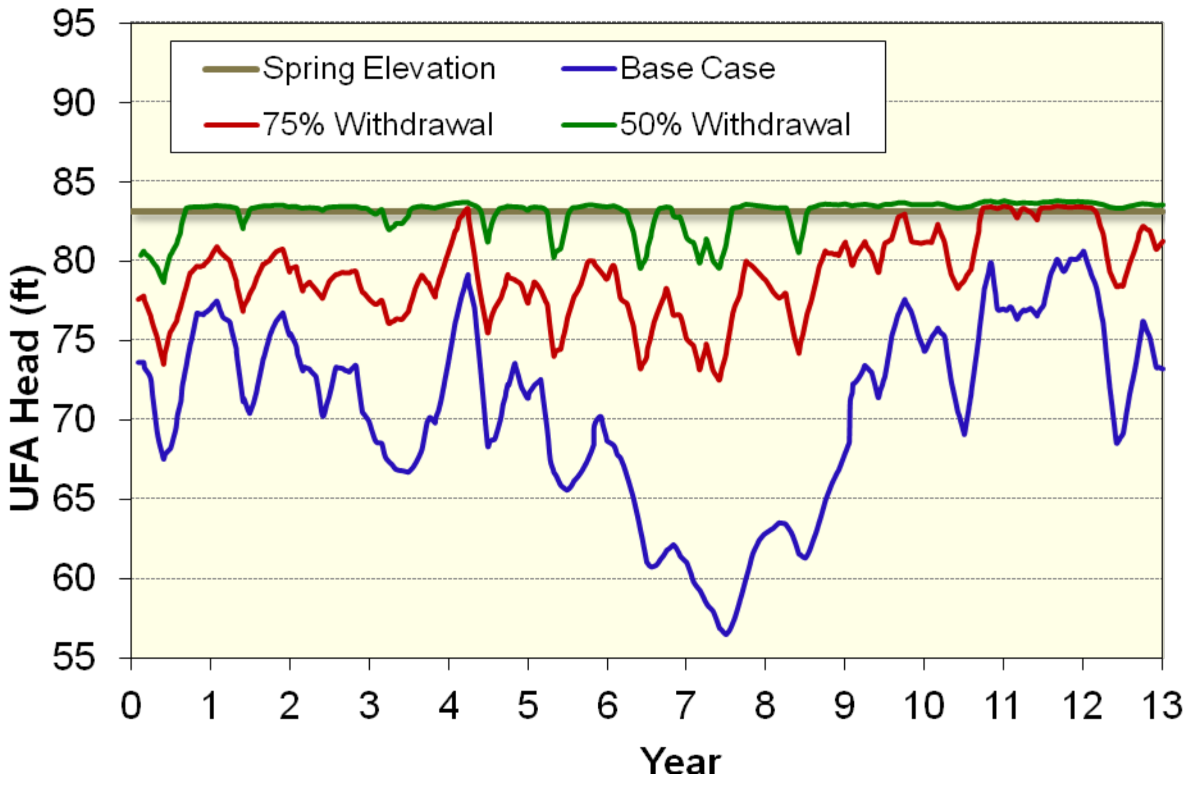


Figure 4.8 Simulated UFA Heads at Kissengen Spring (50% Withdrawal Scenario) for the Reduced Withdrawal Scenarios

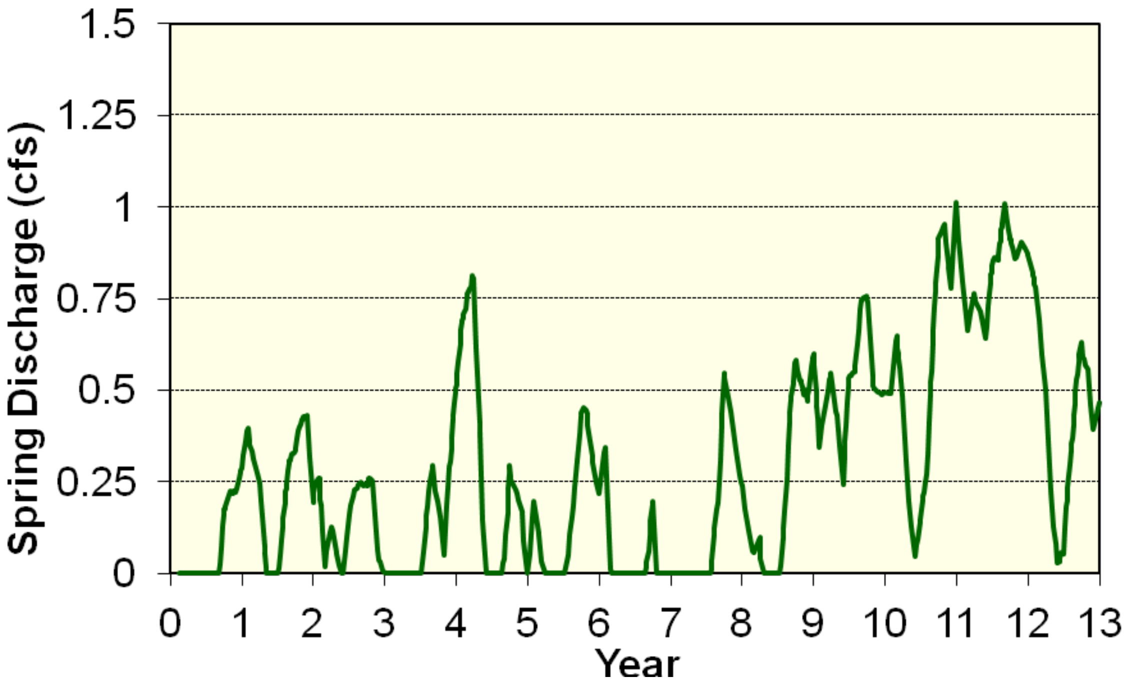


Figure 4.9 Simulated Kissengen Spring Discharge for the 50% Withdrawal Scenario

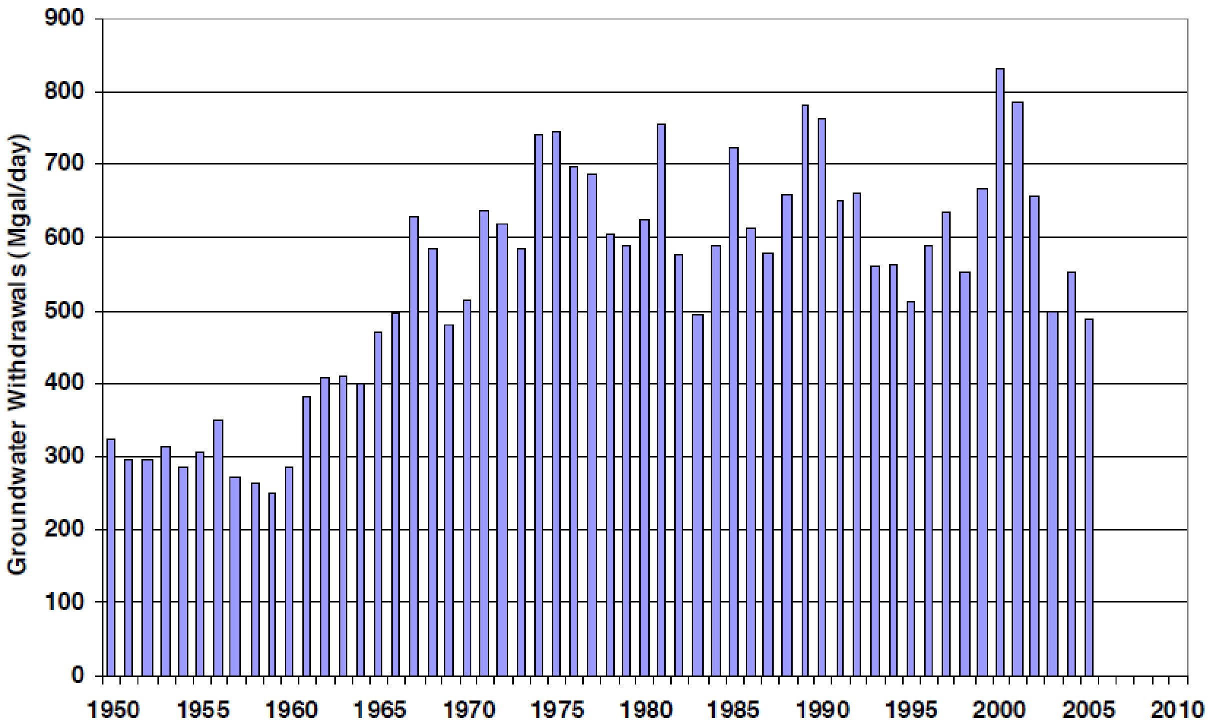


Figure 4.10 Historical Groundwater Use in the SWUCA (from SWFWMD, 2006).

5.0 1940s LAND USE SCENARIO

This scenario evaluated the impacts of land uses changes that have occurred since the 1940s on Peace River flows and other hydrologic characteristics of the basin. The Peace River Cumulative Impact Study (PRCIS) (PBS&J, 2007) identified the following impacts:

- Approximately 343 miles of streams and associated floodplains were lost in the basin from the 1940s through 1999;
- During this same period, the basin sustained a 38.5% reduction in wetland acres, a loss of about 136,000 of the original 355,000 acres; and
- Native upland habitats declined from more than 834,000 acres in the 1940s to fewer than 243,000 acres in 1999, a 71% decrease.

The 1940s Land Use scenario attempted to re-create land use, vegetation, and stream hydrography as it existed during the 1940s to assess the impact of the changes that have occurred since then by comparing the model results for this scenario against the Base Case scenario. The 1940s Land Use scenario utilized information on land use characteristics in the Peace River basin that were assembled as part of the PRCIS (PBS&J, 2007). The process to incorporate this information into the model was as follows: first, land use categories used in the PRCIS were mapped into the corresponding land use categories used in the PRIM; second, the land use related parameters in the PRIM were modified to reflect 1940s land use conditions. Table 5.1 shows the mapping between the PRCIS land use categories and their corresponding PRIM categories.

Table 5.1
1940s Land Use Categories

PRCIS Land Use Categories	Equivalent PRIM Category
Urban	Medium Density Urban
Improved Pasture	Cropland & Pasture
Intensive Agriculture	Row Crops, Tree Crops
Mining	Extractive
Native Upland	Upland Forest
Wetlands	Forested Wetland, Marsh

Each land use category in the PRIM corresponds to a number of model parameters related to ET (root zone depth and crop coefficients), and surface roughness coefficients that affect surface runoff. The specific values of the parameters that were assigned to each land use type are discussed in the PRIM Phase I report (HGL, 2009) and are summarized in Table 5.2. In cases where Table 5.1 lists more than one PRIM land use category, the corresponding model parameters were averaged to construct the 1940s land use characteristics for this scenario. The land use related parameters in the PRIM were then updated based on the 1940s land use map and the relationships in Table 5.1 and 5.2.

Table 5.2
Land Use-Related Parameters for the Primary Land Use Types

Land Use	Root Zone Depth (feet)	ET (Crop) Coefficient	Surface Roughness Coeff.
Wetlands	2.75	1.0	0.1
Upland Forest	6	0.7	0.2
Agriculture	2.5	0.8	0.1
Urban	1.5	0.5	0.06
Mining	1.5	0.7	0.1
Water	N/A	1.3	N/A

Land use in the Peace River basin in the 1940s was substantially different from present-day land use. Table 5.3 summarizes the primary land use types in the 1940s, and current land use based on the 1999 Florida Land Use, Cover, and Forms Classification System (FLUCCS). The latter was used in the PRIM and is incorporated in the Base Case scenario. In the 1940s, wetlands and forests accounted for nearly 84% of the Peace River basin area, and urban and mining together accounted for less than 2% of the basin area. Today, wetlands and forests account for less than 26% of the basin, with agriculture representing the dominant land use, and urban and mining each accounting for about 10% of the basin area. Figure 5.1 shows the 1940s land use map of the basin as developed in the PRCIS project. The predominance of forests and wetlands (dark and light green areas, respectively), is evident in this figure. Some parts of the basin were not covered in the 1940s land use map, including the northernmost portions of Saddle Creek and Peace Creek, and the easternmost portion of Charlie Creek. Those were areas for which no historical aerial photography was available. In creating the 1940s land use distribution for the present modeling scenario, the missing areas were assigned as either wetlands or forest, based on available nearby land use. Ridge areas (e.g., the Lakeland Ridge on the west side of Saddle Creek and the Lake Wales Ridge in Charlie Creek) were assigned as forest areas on the basis that higher elevation ridge areas are not likely to contain marshland.

Table 5.3
Comparison of Major Land Use Categories, 1940s versus Current

Land Use Category	Fraction of Basin Area	
	1940s (PRCIS)	PRIM (1999 FLUCCS)
Wetlands	27%	16%
Upland Forest	57%	10%
Agriculture	11%	42%
Urban	1%	10%
Mining	1%	10%
Water	3%	4%

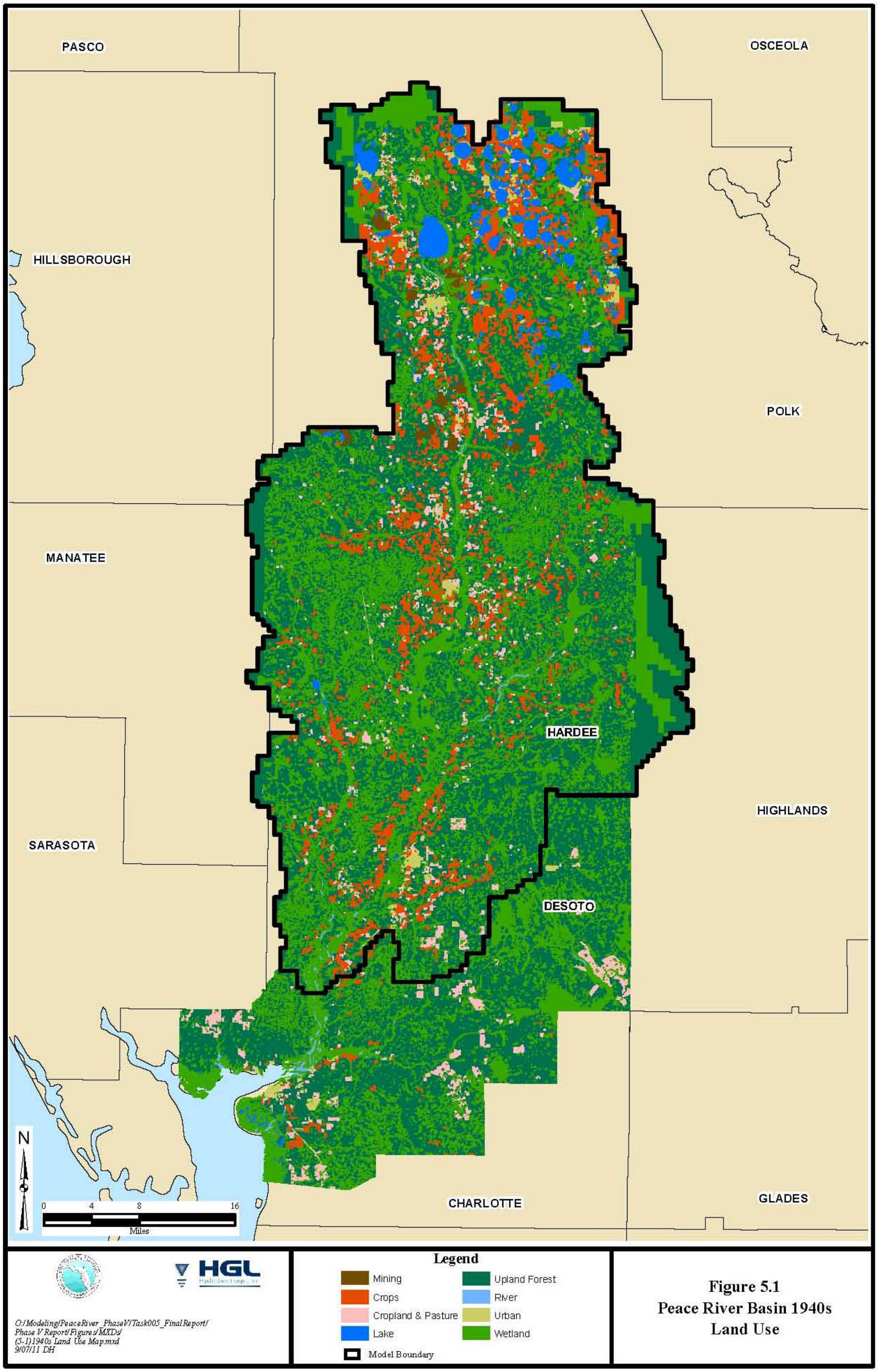


Figure 5.1
Peace River Basin 1940s Land Use

Other major land use related impacts that have occurred in the basin include land alterations associated with drainage improvements such as stream channelization, draining and ditching of agricultural lands, and land alterations associated with phosphate mining. The latter include creation of Clay Settling Areas, sand tailings areas, mine pits, and other modifications to the natural topography and hydrography in mined areas.

Limited information was available to reconstruct 1940s hydrography at the sub-basin scale; accordingly, the PRCIS provides only a single, basinwide hydrography map for the 1940s time period. Reasons for this lack of detail are that before-and-after topography and hydrography are not available for phosphate mining areas and small-scale ditching for agricultural drainage improvements is not mapped. In any case, such small-scale, local modifications also are difficult to capture in the spatial discretization of the PRIM. The modifications that were made to the PRIM were as follows: in the Saddle Creek and Peace Creek sub-basins, the detailed stormwater drainage networks that were incorporated in the PRIM were modified based on information from the PRCIS project, the USGS National Hydrography Dataset (NHD), and other information on historical conditions in the Upper Peace River (McCommons Beck, 1997). Significant stream alterations occurred in the Peace Creek sub-basin in the early twentieth century, including the dredging of Peace Creek to create the Peace Creek Canal and the construction of the Wahneta Farms Canal. These projects were completed prior to the 1940s (McCommons Beck, 1997). These features were, therefore, left unchanged in the model. The node-link drainage networks in the PRIM for Saddle Creek and Peace Creek were modified to match the 1940s hydrography map in the PRCIS and the NHD hydrography, based on visual comparison. This resulted in leaving the major channels intact but removing (inactivating) a number of the drainage nodes and links, with the effect of creating a less dense drainage network. Figure 5.2 shows the modified drainage networks for Saddle Creek and Peace Creek, compared against the Base Case scenario[1]. This comparison shows the much less developed drainage network used in the 1940s Land Use scenario.

The current concrete structures that control flow from lakes in Saddle Creek and Peace Creek were built in the 1960s, and the available descriptions generally state that they replaced previously existing wooden structures. It is not known when the original structures were first built, but for the purposes of the model simulations, the structures that are in the PRIM were left in place for the 1940s land use simulations.

All active phosphate mining areas, as well as clay settling areas and tailings areas located south of Bartow, were removed from the model. This reflects the fact that phosphate mining impacts in the 1940s were limited to the upper most part of the basin in Saddle Creek. While there may have been phosphate mining ongoing in the 1940s, the exact locations and timing of mine operations in this period are not documented and information on mining water use for the period, which is needed to simulate active mining operations in the PRIM (HGL, 2009), is not available. Mining related NPDES surface water discharges were also removed from the model.

[1] Channel segments that appear to cross surface water bodies in the figure are only a visual representation of how drainage links in the model are connected to surface water bodies; in the model these connections are placed at the center of surface water bodies.

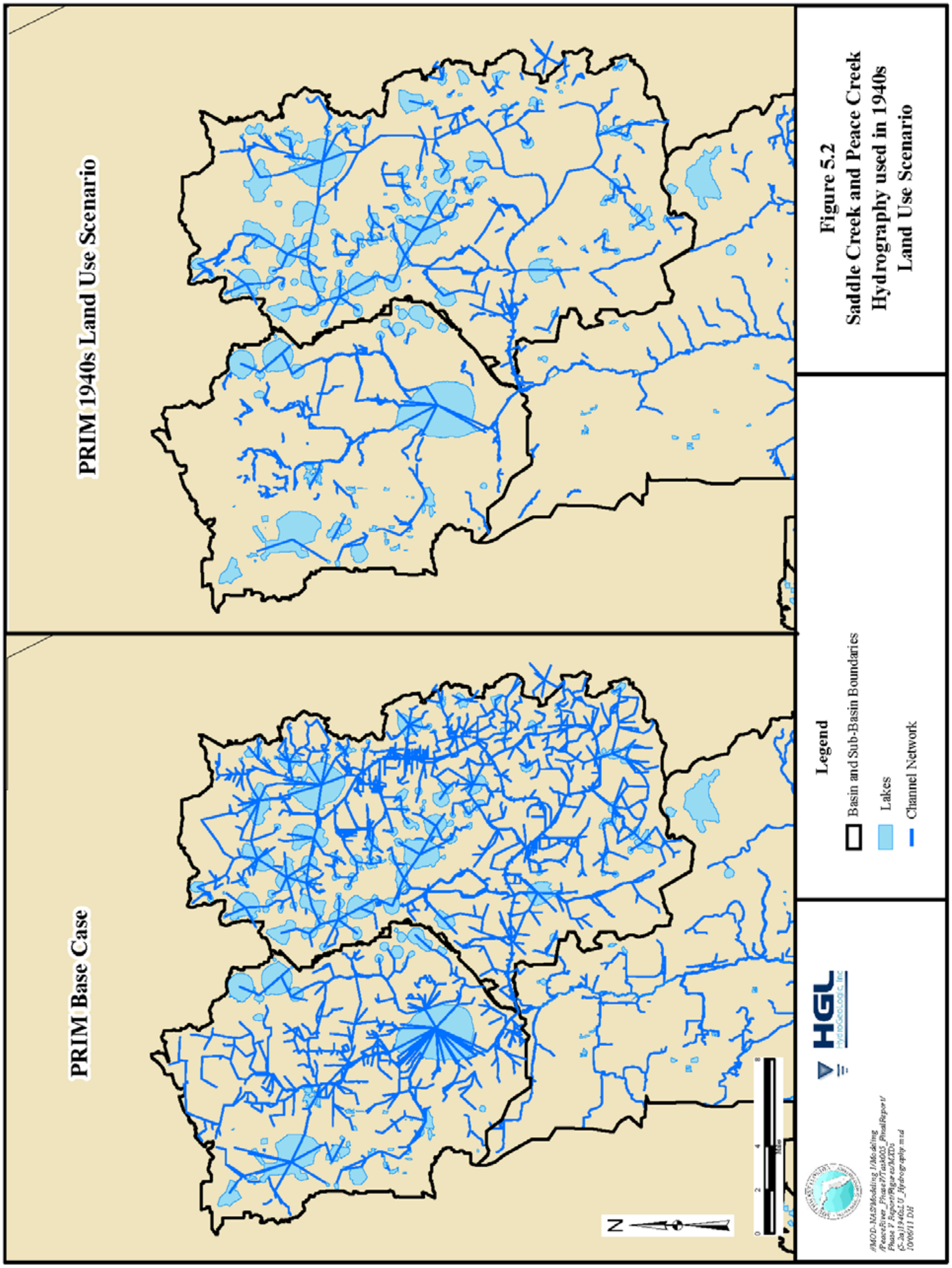


Figure 5.2
Saddle Creek and Peace Creek Hydrography used in 1940s Land Use Scenario

5.1 IMPACT OF LAND USE CHANGES ON STREAMFLOW

Table 5.4 compares the stream flow percentiles for the 1940s Land Use scenario against the Base Case simulation for the main Peace River gages at Bartow, Ft. Meade, Zolfo Springs, and Arcadia. The table also includes the actual average annual flows for the period 1940-1952 at each gage (except the Ft. Meade gage, which didn't exist in this period). The table shows a number of notable patterns:

- Simulated streamflows for the 1940s Land Use scenario are consistently lower than the Base Case.
- This difference is especially pronounced at the Bartow gage, and at lower streamflow percentiles (10^{th} and 50^{th}) at Bartow and Ft. Meade.
- Simulated streamflows for the 1940s Land Use scenario are consistently lower than historical flows for the 1940-1952 period at the Bartow gage and for low (10^{th} percentile) and median (50^{th} percentile) flows at Zolfo.
- Simulated streamflows for the Base Case scenario also are less than the 1940-1952 observed flows under median to low-flow conditions (50^{th} and 10^{th} percentiles) at Bartow, but not under high-flow conditions.
- At the Zolfo gage, simulated Base Case flows are lower than the 1940-1952 observed flows only at 10^{th} percentile flows.
- At the Arcadia gage, simulated flows for 1940s landuse conditions agree well with observed flows for 1940-1952, with a 5% higher simulated flow at the 90^{th} percentile (3469 versus 3290 cfs).

The simulation results agree with observations that impacts of land use changes on streamflows have been most significant in the upper part of the basin, above Zolfo Springs, and are less pronounced in the watershed below Zolfo, but also include some seemingly unexpected results. The reduced streamflow in the 1940s Land Use simulation compared to the Base Case at first appears counter intuitive, because changes in land use, including drainage improvements, are often cited as one of the main factors that have contributed to lower streamflows, especially in the upper portion of the Peace River. However, these results are consistent with the changes that were implemented in the model to represent 1940s land use conditions. Wetlands and forests have greater root zone depths, higher ET (crop) coefficient, and greater surface roughness coefficients than do the agricultural, urban, and mining areas that dominate current land use. Current land use/land cover reduces ET and promotes surface runoff as compared to the pre-development land cover (see Table 5.2). The surface drainage changes that were made in Saddle Creek and Peace Creek to approximate 1940s conditions also would have the effect of reducing runoff, while promoting more surface water storage. In turn, "wetter" watershed conditions, would promote ET losses, thereby reducing the amount of water available for streamflow. Water budgets for this scenario, which are presented in Section 5.4, illustrate these shifts.

Table 5.4
Streamflow Percentiles for the 1940 Land Use Scenario

Gage Name	Streamflow Percentile	Streamflow for Different Land Use Scenarios (cfs)			
		Base Case	1940s Land Use	% Change	1940-1952 Observed
Peace River at Bartow	10th	17	4	-77%	26
	50th	137	35	-74%	166
	90th	889	649	-27%	699
	Average	304	193	-37%	284
Peace River at Ft. Meade	10th	31	18	-43%	NA
	50th	198	93	-53%	NA
	90th	1100	848	-23%	NA
	Average	391	276	-30%	NA
Peace River at Zolfo Springs	10th	94	90	-4%	116
	50th	392	283	-28%	370
	90th	2040	1974	-3%	1680
	Average	766	678	-12%	732
Peace River at Arcadia	10th	140	140	0%	135
	50th	607	516	-15%	507
	90th	3511	3469	-1%	3290
	Average	1334	1261	-5%	1266

The higher 90th percentile flows (Table 5.4) in the basin above Zolfo Springs in the Base Case scenario compared to the 1940-52 observed streamflows are consistent with the development that has occurred in the watershed. Drainage improvements and increases in impervious land surfaces associated with urban development increase surface runoff and contribute to higher peak flows while reducing baseflow.

While the average streamflow response of the 1940s Land Use scenario is consistent with the changes made to the model for this scenario, a more puzzling aspect of the model results is the very low 10th percentile streamflow at Bartow. The aforementioned factors that led to higher watershed storage under historical as compared to current conditions would be expected to manifest themselves in more sustained streamflow in dry conditions. The loss of this watershed storage is commonly cited as one of the reasons that parts of the upper Peace River has lost flow in recent dry periods (PBS&J, 2007). Inspection of the results in Table 5.4 for the 1940s Land Use scenario shows that the model does not reproduce this behavior. Table 5.5 shows a summary of the ratios between 10th and 50th percentile flows at the four Peace River gages. By normalizing the 10th percentile flows against the median (50th percentile) flow value, the difference in streamflow magnitude between the scenario simulations and historical (1940-1952) streamflows is removed or at least minimized, and the ratio represents a more direct measure of the relative contribution of baseflow.

Table 5.5
Ratios between 10th and 50th Percentile Streamflows

Gage Name	Scenario		
	Base Case	1940 Land Use	1940-52 Observed
Bartow	0.12	0.11	0.16
Ft. Meade	0.16	0.19	NA
Zolfo Springs	0.24	0.32	0.32
Arcadia	0.23	0.27	0.27

Table 5.5 indicates that, except for the Bartow gage, the streamflow ratios for the 1940s Land Use scenario are indeed somewhat higher than they are for the Base Case scenario; however, for both of the model scenarios, the values are lower than the ratios calculated from observed 1940-1952 streamflows. The difference is the most pronounced for the 1940s Land Use scenario at the Bartow and Zolfo Springs gage locations (i.e., in the upper portion of the Peace River basin). At the Arcadia gage, the difference is much smaller.

Part of the explanation for the differences between the results of the model scenario and observed 1940s streamflows may be the model's inability to fully capture the hydrologic effects of land use changes. Another key issue, however, is that the model scenarios evaluated the effects of individual factors but did not consider the interactions and complementary effects of multiple changes that have occurred in the basin since the 1940s. The 1940s Land Use scenario did not use historical rainfalls and, probably more importantly, did not include groundwater withdrawals of the 1940s. Instead, the scenario used 1994-2006 pumping rates, which are much higher than withdrawals during the 1940s. Peek (1951) estimated that annual groundwater withdrawals in southwest Polk County were 22 Mgd in 1940 and increased to 90 Mgd by 1950. Currently, groundwater withdrawals in Polk and Hardee Counties are between 300 and 400 Mgd (Basso, 2003). Because of the much reduced groundwater withdrawals, the groundwater potentiometric surface in the 1940s was significantly higher than it is currently, resulting in gaining stream conditions along the entire length of the Peace River. The groundwater withdrawal scenario discussed in the preceding section showed that reduced groundwater extraction and the associated higher groundwater levels caused a pronounced increase in low flows in the upper portion of the basin (Table 4.1).

5.2 IMPACT OF LAND USE CHANGES ON LAKE LEVELS

Table 5.6 provides a summary of the effects of land use changes on lake levels for selected lakes in Saddle Creek and Peace Creek. The impacts are expressed in terms of the changes in the lake level, at selected percentiles over the 13-year simulation period, between the Base Case scenario and the 1940s Land Use scenario. Positive values mean a higher lake level in the 1940s Land Use scenario compared to the Base Case. Instances where the magnitude of the change was less than 0.1 feet are indicated in the table using a dash (-) symbol. The table shows that the impacts on lake levels fall into two groups: the larger group of lakes (13 out of 19) showed relatively little effect of land use changes and generally showed lower lake levels in the 1940s scenario, which can be attributed to the greater ET losses in this scenario compared to the Base Case. A smaller group of lakes—Lake Parker, Lake Arietta, Eagle Lake, Lake Alfred and Lake Garfield—showed higher lake levels and the magnitude of the change for these lakes was distinctly higher than for the first group. The second group of lakes represents the increased watershed storage that is associated with the less well-developed drainage network in the 1940s Land Use scenario. The water levels in these lakes increased because hydraulic links that facilitated drainage in the Base Case scenario were removed, in combination with higher groundwater levels.

Table 5.6
Effect of Land Use Changes on Lake Levels for Selected Lakes

Lake	Lake Level Change (feet)[1)]			
	10th Percentile	50th Percentile	90th Percentile	Mean
Lake Hancock	-1.1	-0.1	-	-0.3
Lake Parker	+2.1	+3.9	+3.6	+3.4
Lake Arietta	+0.4	+2.1	+1.8	+1.6
Lake Ariana	+0.1	-	+0.1	-
Lake Lena	-0.6	-	-	-0.2
Spirit Lake	-0.2	-0.1	-	-0.1
Eagle Lake	-1.3	+2.5	+4.0	+1.8
Lake Alfred	+2.4	+2.3	+2.6	+2.3
Lake Conine	-0.2	-	-0.2	-0.1
Lake Haines	-0.2	-	-0.2	-0.1
Lake Smart	-0.2	-	-0.2	-0.1
Lake Fannie	-0.9	-0.5	-0.2	-0.5
Lake Hamilton	-0.4	-0.1	-0.5	-0.2
Lake Howard	-0.2	-	-0.1	-0.1
Lake Shipp	-0.2	-	-0.1	-0.1
Lake Annie	-1.5	-1.9	-3.5	-2.1
Lake Myrtle	-0.1	-0.2	-0.3	-0.2
Lake Garfield	-0.2	+0.5	+1.5	+0.7
Surveyors Lake	-0.1	-	+0.1	-

+ indicates higher lake level compared to Base Case, - indicates lower lake level

It should be kept in mind that the exact drainage network that existed in the 1940s is not well known, and there was degree of subjectivity involved in modifying the drainage network for the 1940s Land Use scenario. The results, therefore, should not be taken to represent the exact impact on the individual lakes but rather as a more general indication of how drainage changes can affect watershed storage, including lake levels. Lake level hydrographs for a number of the lakes are presented in Appendix E. The plots in this Appendix illustrate how some lakes showed relatively little impact from land use changes (e.g., Lake Howard, Lake Hamilton), while other lakes (e.g., Lake Parker) show much more dramatic changes.

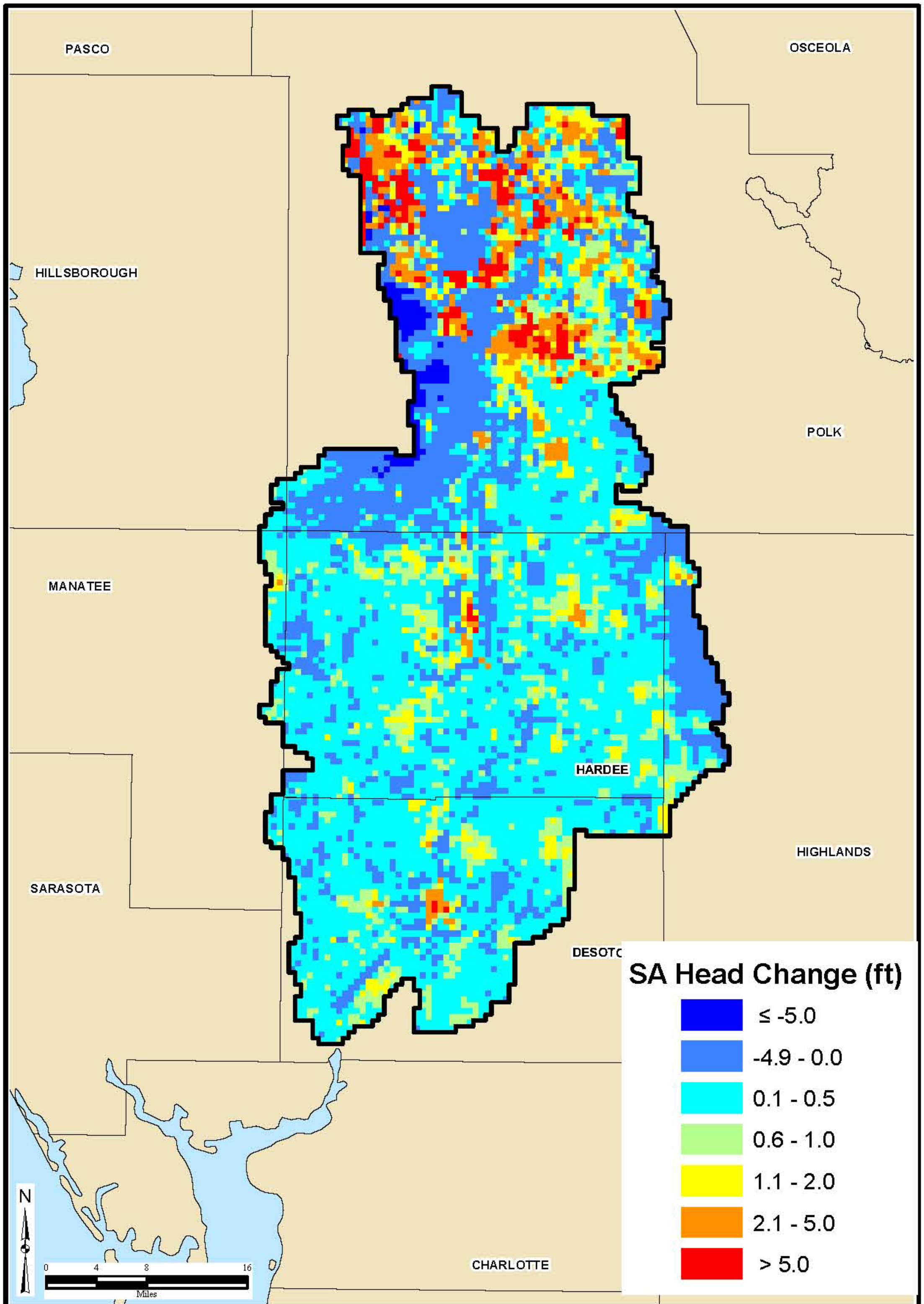
The hydrographs plots furthermore show a difference in how initial conditions were handled between the 1940s Land Use scenario, and the preceding rainfall and withdrawal scenarios. In the latter scenarios, all model simulation runs were started from the same initial condition, which were assigned from a steady-state model run with long-term average rainfall. All lake level plots in Appendices A and C, therefore, started from the same initial lake level. In the 1940s Land Use scenario however, it was not feasible to do this because of the modifications made to the channel network, represented by the MODHMS CHF package. Because of changes in the number and configuration of channel segments, it was no longer feasible to map the heads from the original initial condition run onto the revised CHF network. Instead, the 1940s model was used in a steady state run with long-term average rainfall to regenerate initial conditions for the transient 1940s simulation. Owing to the changes in the model, the steady state run produced a different initial model state than the Base Case scenario; these differences are reflected in the graphs in Appendix E.

5.3 IMPACT OF LAND USE CHANGES ON GROUNDWATER HEADS

Figures 5.3 and 5.4 show the effect of the 1940s Land Use changes on potentiometric heads, averaged over the 13-year simulation period, in the SA and UFA, respectively. The figures depict the change in head compared to the Base Case scenario, i.e. ($h_{1940s} - h_{Base\_Case}$). Positive values in the figure mean that the average head in the 1940s Land Use scenario was higher than the head in the Base Case scenario. The effect on SA heads (Figure 5.3) is a complex pattern of both head increases and decreases, especially in the portion of the basin above the Polk – Hardee County line. The greatest increases in SA heads occurred in urban and in phosphate mining areas. These areas are represented as red colors in Figure 5.3. The urban areas include Lakeland in northwestern Saddle Creek, Winter Haven and Haines City in Peace Creek. In the southern portion of the basin, the location of the town of Arcadia can be distinguished. Removing phosphate mines from the model resulted in increases of simulated SA heads in the corresponding model locations. As discussed in the PRIM Phase I report (HGL, 2009), mine cells were assigned a fixed surficial aquifer recharge value of 2 inches/year. This value was based on available mine water budget studies. In the 1940s Land Use scenario simulation, mine features were removed and all model cells were active. One of the results was a greater recharge to the SA in the mine locations with a corresponding increase in the SA heads.

Other land use related changes that affected the SA were the increased watershed storage in the 1940s simulation, which increased groundwater recharge and thereby groundwater levels, and changes in ET. The increased ET associated with historical land cover types tended to lower groundwater levels. These multiple factors combined to produce the complex pattern seen in Figure 5.3 for the SA.

The impacts on the UFA potentiometric surface (Figure 5.4) show a much simpler spatial pattern because the localized effects seen in the SA are smoothed out in the UFA. The simulated land use effects on the UFA were small except for an increase in UFA heads in the northern portion of the basin in Saddle Creek and Peace Creek, which resulted from higher recharge from the SA to the UFA in this portion of the basin that has good vertical hydraulic



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Phase V Report/Figures/MXDs/
(5-3)Land Use Scenario SA Sim Heads Change.mxd
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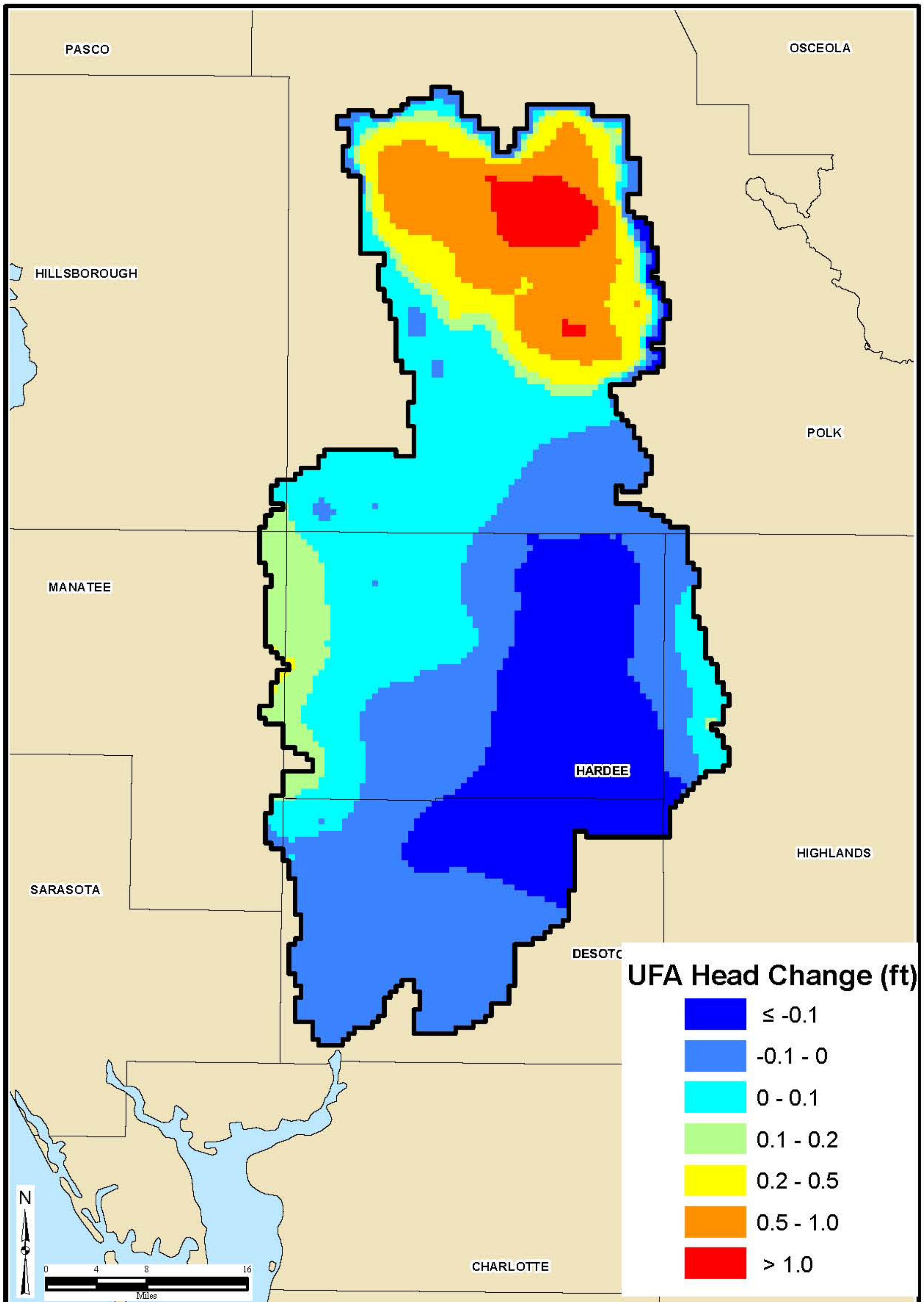
Legend

Model Boundary

Figure 5.3
Average Groundwater Head Change in Layer 1 (SA) Due to the Land Use Change (1940s)



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Phase V Report/Figures/MXDs/
(5-4)Land Use Scenario UFA Sim Heads Change.mxd
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Legend

Model Boundary

Figure 5.4
Average Groundwater Head Change in Layer 5 (UFA) Due to the Land Use Change (1940s)

connectivity between the aquifers. It should be noted that the scale of head changes in Figure 5.4 is different from other figures in this report that show UFA impacts, in order to accentuate head differences in Figure 5.4. Also notable in this figure are the distinct model boundary effects. Because UFA heads around the model perimeter were set to the same values in the 1940s simulation as in the Base Case scenario (because groundwater withdrawals in the two scenarios were kept the same), the head change at the model boundary was also forced to be zero.

The impact of land uses changes on the UFA is similar to that of increasing rainfall; both tend to increase recharge in the Upper Peace River basin, and result in similar patterns of head changes, as can been seen by comparing Figure 5.4 with Figure 3.5. However, the magnitude of the changes associated with the 1940s land use conditions is greater than that of the Wet versus Dry rainfall scenario. The greatest increase in UFA heads in the 1940s Land Use scenario is 2 feet, whereas the greatest UFA head impact for the Wet versus Dry rainfall scenario was just under 1.3 feet (Figure 3.5), and the area where the UFA head increases exceeded 1 foot was smaller in the rainfall scenario as compared to the 1940s Land Use scenario.

5.4 IMPACT OF LAND USE CHANGES ON WATER BUDGETS

Tables 5.7 and 5.8 summarize the water budget in the 1940s Land Use scenario compared to the Base Case simulation. Table 5.7 presents the changes in the basinwide water budget. As discussed already, the primary differences are in stream flow, ET and groundwater recharge, and the impacts are the greatest in the upper portion of the basin, above Zolfo Springs. Table 5.8 shows a summary of the surface water outflow, ET and recharge components of the basinwide and sub-basin water budgets that illustrates these changes. The table shows that a basinwide reduction in streamflow that is offset by an increase in ET and UFA recharge. These basinwide impacts are caused primarily by changes in the uppermost portion of the Peace River, as shown by the much greater shifts in the water budgets in the Saddle Creek and Peace Creek basins as compared to other sub-basins. The table indicates there is little or no change in the Horse Creek and Charlie Creek basins, two sub-basins that have been least affected by human influences and still retain much of their original land use/land cover.

To facilitate comparisons between the 1940s Land Use scenario and the Base Case simulation, the water budget summaries in Tables 5.7 and 5.8 were calculated in terms of the same model area as used in the Base Case scenario, i.e., the area of the inactive model cells in the Base Case simulation was also not included in the water budgets shown in the tables for the 1940s Land Use scenario, even though the inactive cells representing phosphate mining areas were not present in the 1940s Land Use simulations. The complete water budgets for each subbasin in the 1940s Land Use scenario are presented in Appendix F. Because the summaries in Table 5.7 and 5.8 were calculated using somewhat different areas, close inspection of Appendix F will show some differences with Table 5.8 for those subbasins that included inactive cells in the Base Case, primarily the Peace River at Zolfo and the Payne Creek subbasins.

Garlanger (2002) compared water budgets of the Peace River basin above Arcadia for the period 1934 to 1963 against budgets the period from 1969 to 1998. Although he evaluated analytical water budgets in which many of the water budget components were estimated, and his analysis also considered different time periods, his conclusions were qualitatively similar to the findings of the current analysis, Garlanger concluded that the increase in impervious surfaces associated with urbanization in the Upper and Lower Peace River basin resulted in an increase in streamflow, and decrease in ET. He also noted the increased in groundwater recharge due to the lowering of the UFA potentiometric surface. However, Garlanger's estimated magnitude of these changes on the water budget was considerably greater than the present analysis indicates. The water budget presented by Garlanger included a 1 inch/year decrease in ET, from 38.8 in/yr to 37.8 in/yr between the 1934 to 1963 and the 1969 to 1998 periods. He also estimated an increase in recharge to the UFA (deep recharge) from 3.4 in/yr to 6.3 in/yr, for the Peace River basin above Arcadia. These latter values especially are very high. The water budget analyses performed for the PRIM project do not support basin-wide UFA recharge of more than 3 in/yr (see Table 5.7).

Table 5.7
Basinwide Water Budget for 1940s Land Use Scenario (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	52.2	52.2	0
GW Pumping Addition	2.1	2.1	0
NPDES Discharge	0.8	0.8	0
SW Inflow	0.0	0.0	0
Lateral GW Inflow	2.5	2.5	0
TOTAL IN	57.6	57.4	0
TOTAL OUT + Δ Storage	58.0	57.8	0
ET Loss	38.4	38.9	1
GW Pumping	2.4	2.4	0
SW Outflow	13.4	12.4	- 7
Lateral GW Outflow	4.3	4.4	+ 2
Storage Change	-0.3	-0.3	0
UFA Recharge	2.3	2.4	+ 4

Table 5.8
Water Budget Summary for the 1940s Land Use Scenario against the Base Case Scenario

		Surface Water Out Flow (in/yr)	ET (in/yr)	Recharge to SA (in/yr)	Recharge to UFA (in/yr)
Basin-Wide	Base Case	13.4	38.4	3.8	2.3
	1940s LU	12.4	38.9	4.0	2.4
Saddle Creek	Base Case	11.2	38.4	8.8	7.0
	1940s LU	7.1	41.3	9.8	7.5
Peace Creek	Base Case	8.2	38.9	11.9	9.3
	1940s LU	5.2	41.3	12.6	9.8
Payne Creek	Base Case	19.8	32.1	2.1	1.0
	1940s LU	18.0	32.9	2.1	1.0
Horse Creek	Base Case	15.5	38.7	1.5	0.5
	1940s LU	15.5	38.6	1.6	0.5
Charlie Creek	Base Case	13.6	39.9	2.1	0.5
	1940s LU	13.7	39.8	2.1	0.5
Joshua Creek	Base Case	16.6	40.8	1.8	-0.2
	1940s LU	17.3	40.0	2.0	-0.2
Peace At Zolfo Springs	Base Case	32.8	34.0	2.8	1.4
	1940s LU	26.5	35.0	2.8	1.3
Peace At Arcadia	Base Case	91.2	42.3	1.0	0.2
	1940s LU	81.6	41.5	1.1	0.2

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6.0 DISCUSSION

The scenarios analyzed in this report confirm that the Peace River below Zolfo Springs is hydrologically a relatively straightforward system. Streamflows respond primarily to rainfall: higher rainfall increases streamflow and lower rainfall reduces streamflow. Peace River flows below Zolfo Springs are not much affected by changes in groundwater pumping. Land use changes that have occurred since the 1940s have some impact on streamflows. Notably, changing land use and vegetation to 1940s conditions caused some reduction in streamflows, but much of this can be attributed to lower inflows from the Peace River above Zolfo Springs. The impact of land use/vegetation changes in the basin below Zolfo Springs on streamflows does not appear to be significant. Groundwater levels in the SA underlying the Peace River basin below Zolfo Springs are affected by rainfall as well as watershed changes that have occurred since the 1940s, but due to the confined nature of the UFA in this area, UFA heads are affected only by groundwater withdrawals, with little or no impact from variations in rainfall or land use changes.

Under conditions of median flows and above, streamflows in the Upper Peace River basin above Zolfo Springs are also controlled by differences in rainfall. However, under low flow conditions, the hydrologic response of the Upper Peace river basin is considerably more complex, and none of the factors analyzed in this report can fully explain the observed long-term changes in Peace River flows by itself. However, the scenario analyses do provide insights into the interactions and combined impacts of changes in rain fall, groundwater withdrawals and land use changes that have occurred in the basin.

The more significant findings include:

- Increasing rainfall had a dramatic effect on simulated streamflows in the Upper Peace River. Model-predicted flows at the Bartow and Ft. Meade gages approximately doubled between the Dry and the Wet scenario;
- However, under low-flow conditions, the simulated flows at Bartow for both Wet and Dry rainfall periods were still significantly less than the actual historical flows for the same time periods;
- The most likely explanation for this discrepancy are the contributions from industrial, mining and WWTP discharges that historically augmented Peace River flows, but which were significantly reduced in the 1980s as a result of water conservation and water quality regulations, and which are not accounted for in the model;
- Conversely, under high-flow conditions (90^{th} percentile), simulated flows at all gages matched or exceeded observed flows. This held true for the Wet and Dry rainfall scenarios and for the Base Case scenario versus observed 1940s streamflows;
- The greater peak streamflows can be attributed to development and drainage improvements in the basin which have reduced watershed storage and promote surface runoff;

- The impacts of reducing groundwater withdrawals were most pronounced at the Bartow and Ft. Meade gages under low flow conditions. In the 50% withdrawal scenario, 10^{th} percentile flows at the Bartow gage were nearly 20% higher than the Base Case and they were nearly 40% higher at the Ft. Meade gage;
- Reductions in groundwater withdrawals increased the UFA heads throughout the entire basin. Average UFA heads increased by 10 feet or more underneath much of the central and western parts of the basin in the 50% Withdrawal reduction scenario, with the greatest head increase occurring along the western boundary of the basin in the area where drawdown was the greatest under Base Case pumping conditions;
- Heads in the SA also increased in the Reduced Withdrawal scenarios, but heads in the SA were much less sensitive to changes in groundwater withdrawals, with head increases less than 0.5 feet in most of the basin, even in the 50% Withdrawal Reduction scenario. The relative insensitivity of heads in the SA to changes in pumping can be attributed the limited vertical hydraulic connection between the SA and UFA in much of the basin, with effective leakances of 10^{-5}/day or less, except in the Saddle Creek and Peace Creek sub-basins, in combination with the reduced recharge contribution from irrigation in the Withdrawal reduction scenarios. Reduced recharge from irrigation will tend to cause lower SA heads and therefore counteract the effect of higher heads in the UFA;
- Land use/vegetation changes that more closely approximate pre-development conditions did not increase streamflows; instead, they decreased streamflows, with the greatest reductions occurring in the sub-basins that have seen the most man-made alterations. i.e., Saddle Creek and Peace Creek;
- The impact of land use changes on streamflows can be attributed to the greater ET loss, increased watershed storage, and increased groundwater recharge associated with 1940s versus modern land use characteristics. Drainage improvements and increased areas of impervious surfaces associated with urban development in the Saddle Creek and Peace Creek subbasins promote more surface runoff and higher peak flows as compared to historical, 1940s conditions;
- It was expected that the 1940s simulation would show a greater contribution of baseflow, because of the changes that have occurred in the watershed. However, the simulations did only partially reproduced this behavior. While base flow (expressed as the ratio between 10^{th} and 50^{th} percentile flows) was higher in the 1940s simulation than the Base Case scenario at the Fort Meade, Zolfo and Arcadia gages, this was not the case for simulated flows at the Bartow gage. Simulated base flows in the model simulations were consistently lower than actual flows in the 1940 – 1952 period (Table 5.5);
- Lake levels showed slight sensitivity to rainfall. The average increase in the mean lake level in the Wet versus Dry scenario was 0.8 feet; however for the majority of the lakes the increase was 0.3 feet or less;
- Lake levels showed little or no sensitivity to changes in groundwater withdrawals. While this lack of sensitivity was not expected, it is consistent with the limited effect

of changes in withdrawals on SA, since lake levels closely follow heads in the SA. Additionally, less surface runoff caused by lower irrigation return flows in the Withdrawal Reduction scenarios, will tend to counteract lake level rise caused by higher groundwater heads.

The overall conclusions from the scenario analyses are: (1) rainfall is the most important factor controlling streamflow (2) a confirmation that the overall impact on streamflows from all changes that have occurred in the Upper Peace River basin has mainly been on low flows; and (3) that for the same rainfall conditions, the lowering of the groundwater potentiometric surface caused by groundwater withdrawals is probably the single most important cause of the reduced low flows. Whereas historically, groundwater discharges helped sustain baseflow in the upper portion of the basin river during dry periods, the portion of the basin above Fort Meade (see Figure 4.5) now loses water to groundwater. The comparison of observed flows at Bartow for the Base Case period of 1994 to 2006 against the historically dry period of 1969 to 1981 (Figure 3.6), supports the concept that prior to the 1980s the loss of groundwater discharge on flows was masked by flow augmentations from mining and waste water discharges.

Water budget calculations for Saddle Creek and Peace Creek in Appendix D indicate that the basin above Bartow loses about four to five inches per year to groundwater recharge after adjusting the UFA recharge in the water budgets for GW Pumping Additions. In other words, the net loss to groundwater recharge is [UFA Recharge – GW Pumping Addition]; the GW Pumping Addition is subtracted because it is a transfer from groundwater to surface water. In the 50% Withdrawal scenario, the net loss to groundwater recharge is reduced by 0.6 inch/year in Saddle Creek and 0.3 inch/year in Peace Creek. For both sub-basins, the reduction in recharge translates almost directly into an equivalent increase in surface water outflow.

The scenario analyses that were conducted in this phase on the PRIM project addressed the impacts of individual factors. This approach is useful to understand the effects of individual factors, and can also provide practical insights to assess the potential impacts of alternative management strategies. For example the SWFWMD is currently evaluating strategies to increase lake (e.g., Lake Hancock) and watershed storage in the Upper Peace River basin. Such alternatives can be readily incorporated into the PRIM. However, the single factor approach is limited with regard to gaining a full understanding of the aggregate effects that have occurred in the basin over time. The 1940s Land Use scenario presented in this report produced some results, such as reduced low flows in the Upper part of the basin, that are counterintuitive and opposite from the actual historical record. While this may point to inherent limitations of the model to fully reproduce a complex system, the simulation scenario considered land use changes in isolation from other factors. The likely most important issue is that the historical land use scenario used current day ground water extraction rates which are much higher than actual withdrawal rates in the 1940s. A recommended next step in the scenario analyses would be simulate a combination of the 1940s land use with contemporaneous groundwater withdrawals and rainfall inputs.

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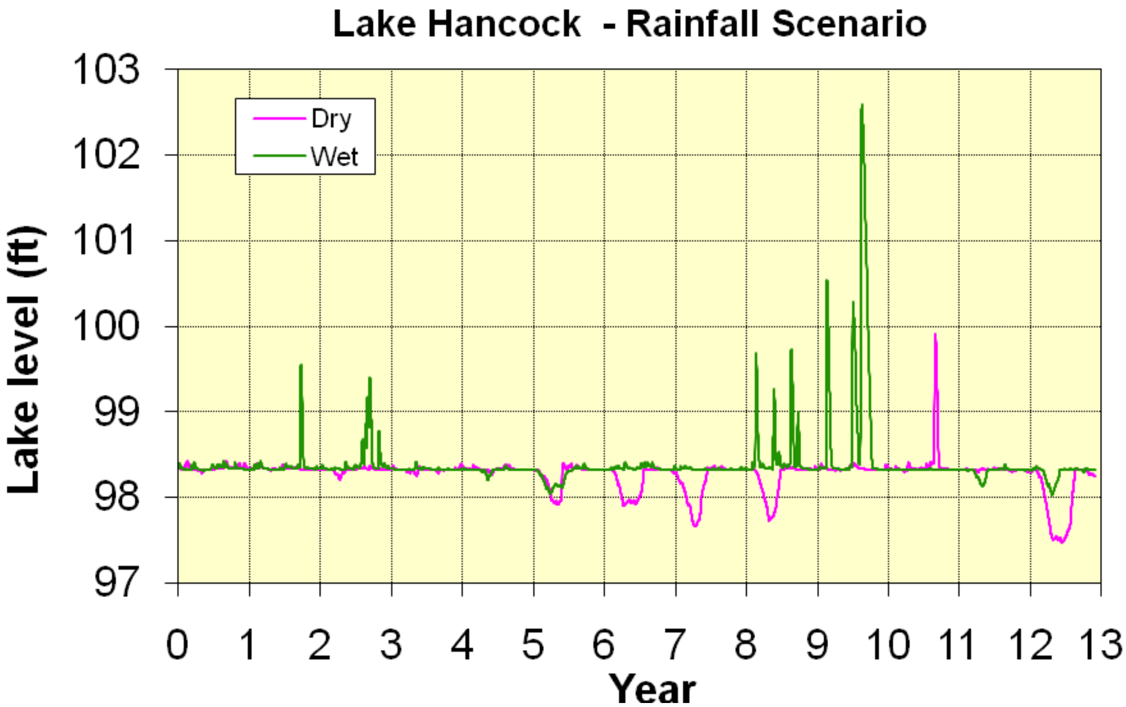
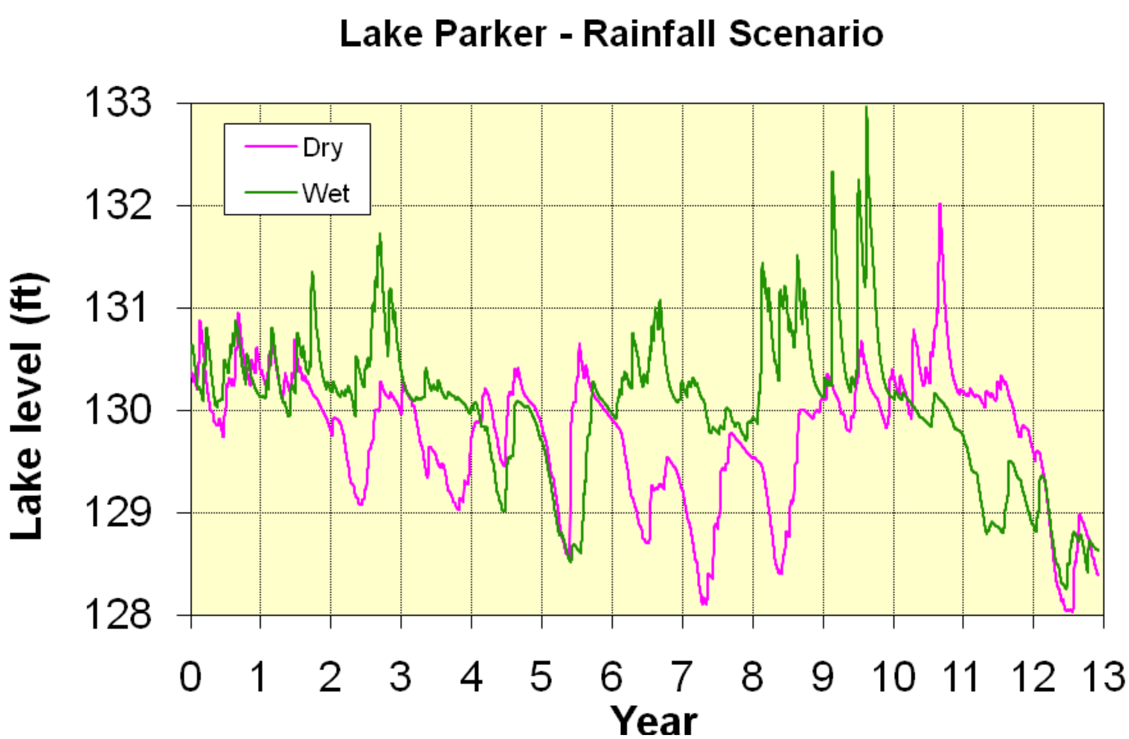
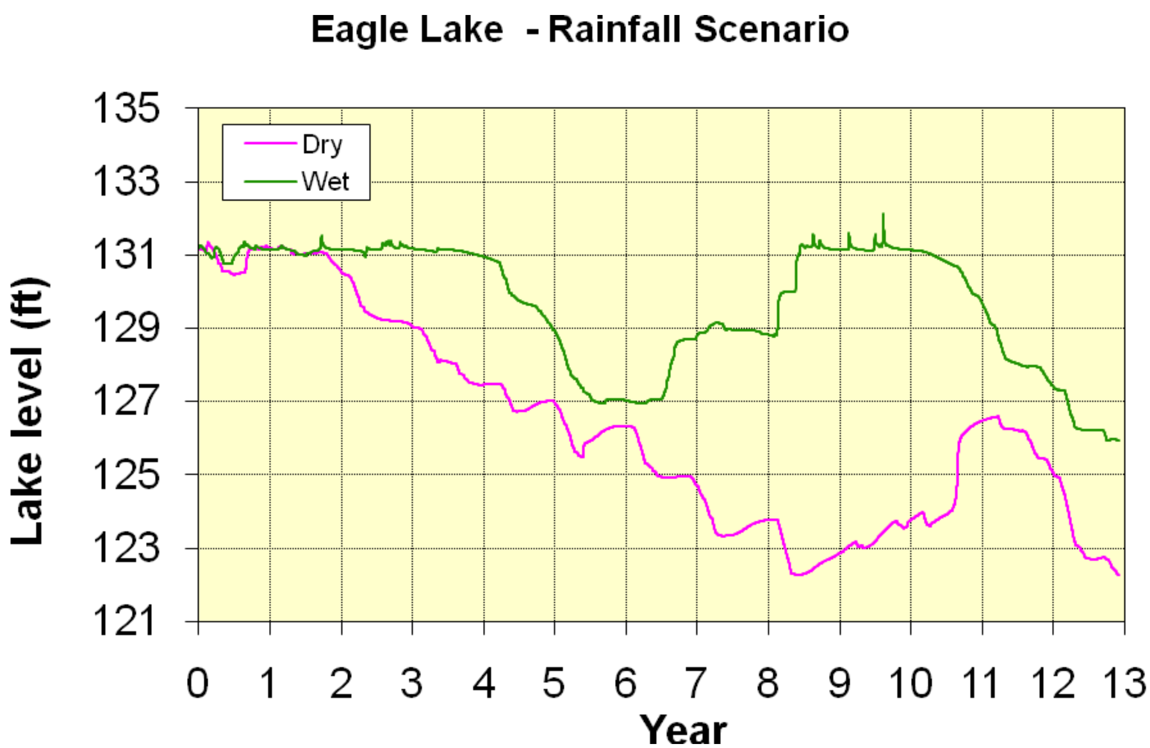
APPENDIX A

LAKE LEVELS FOR RAINFALL SCENARIOS

APPENDIX A
LAKE LEVELS FOR RAINFALL SCENARIOS






Eagle Lake - Rainfall Scenario
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Wet
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133
131
129
127
125
123
121
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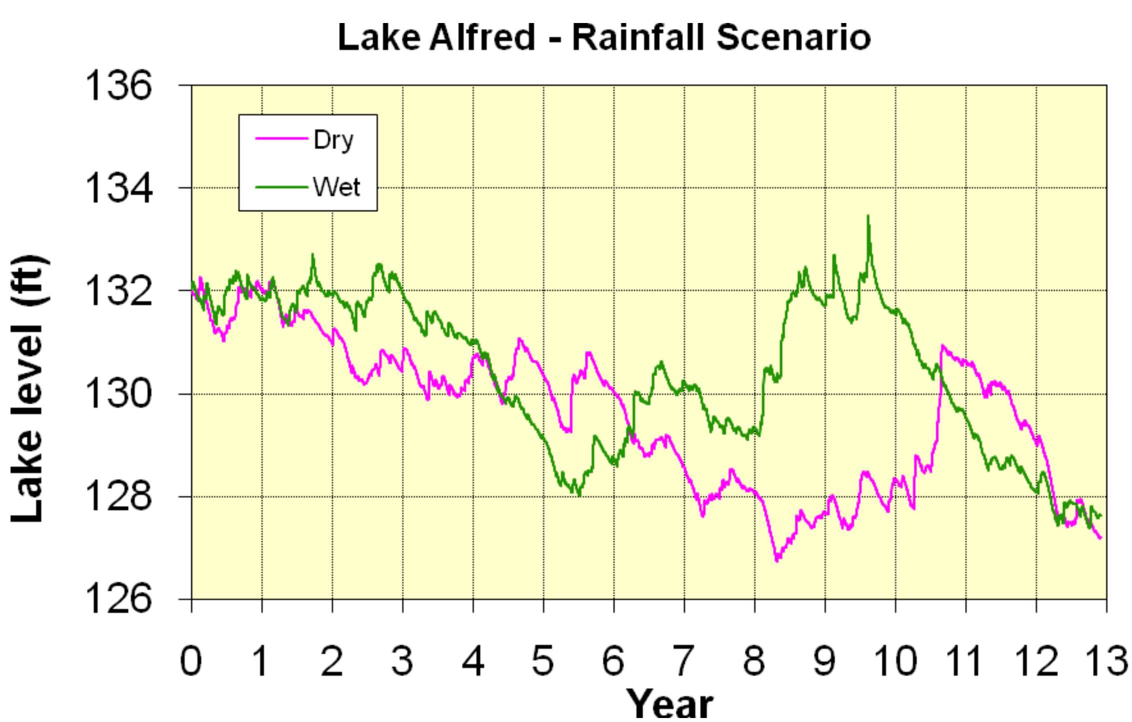
Year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Dry
Wet
Lake level (ft)
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134
132
130
128
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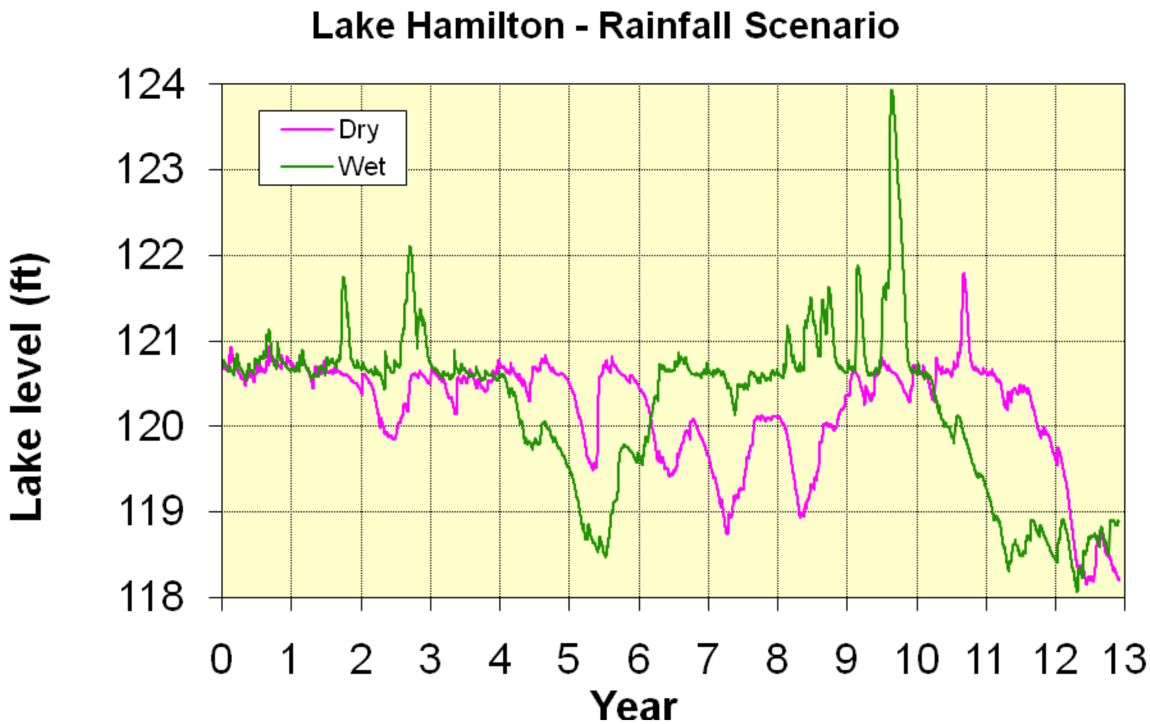
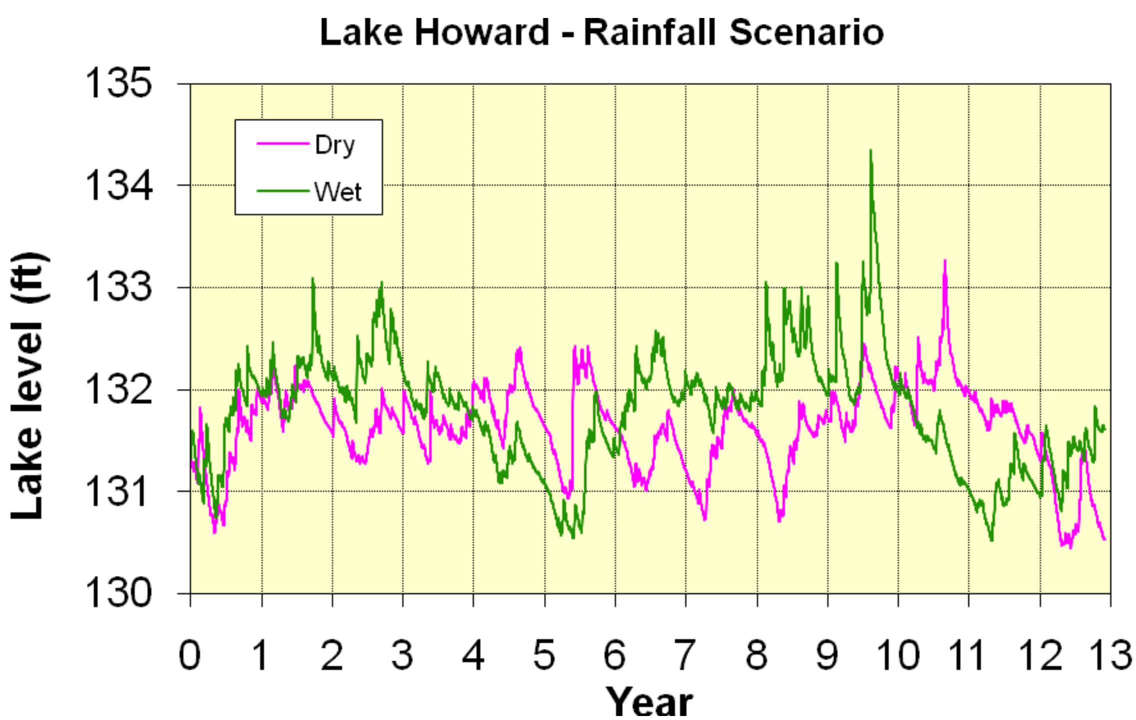
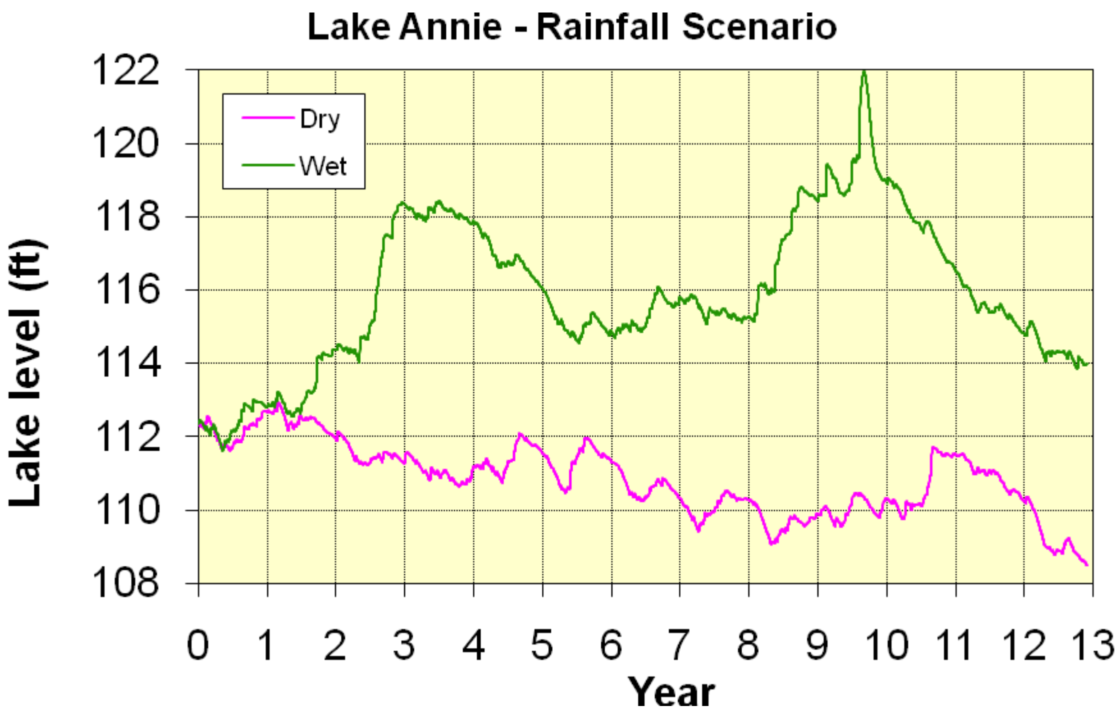
Year


Lake Hamilton - Rainfall Scenario
Dry
Wet
Lake level (ft)
124
123
122
121
120
119
118
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year


Lake Howard - Rainfall Scenario
Dry
Wet
Lake level (ft)
135
134
133
132
131
130
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year


Lake Annie - Rainfall Scenario
Dry
Wet
Lake level (ft)
122
120
118
116
114
112
110
108
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year

APPENDIX B

SUB-BASIN WATER BUDGETS FOR RAINFALL SCENARIOS

APPENDIX B
SUB-BASIN WATER BUDGETS FOR THE WET VERSUS DRY RAINFALL SCENARIO[1]

Table B.1
Saddle Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	% Change
Rainfall	53.6	47.7	12
GW Pumping Addition	2.9	2.9	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.3	0.2	41
Lateral GW Inflow	8.1	8.3	-2
TOTAL IN	64.8	59.0	10
TOTAL OUT + Δ Storage	65.4	59.3	10
ET Loss	38.9	38.3	1
GW Pumping	2.9	2.9	0
SW Outflow	10.5	5.9	79
Lateral GW Outflow	13.2	12.7	4
Storage Change	-0.1	-0.5	-85
UFA Recharge	6.3	5.8	8

Table B.2
Peace Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	% Change
Rainfall	54.7	48.1	14
GW Pumping Addition	3.8	3.8	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.2	0.1	75
Lateral GW Inflow	2.6	2.7	-3
TOTAL IN	61.3	54.7	12
TOTAL OUT + Δ Storage	61.9	55.2	12
ET Loss	39.9	38.6	3
GW Pumping	3.8	3.8	0
SW Outflow	7.9	3.8	108
Lateral GW Outflow	10.7	9.9	8
Storage Change	-0.5	-1.1	-53
UFA Recharge	9.1	8.7	5

[1] The sub-basin water budgets are based on the active model cells. In the Payne Creek and Peace at Zolfo sub-basins, a number of land surface model cells were set as inactive to represent operational phosphate mining areas. The inactive cells account for 23% of the sub-basin area in Payne Creek and 17% in the Peace at Zolfo sub-basin. Rainfall and ET in the water budgets for these sub-basins are, therefore, low by the same percentages.

Table B.3
Peace at Zolfo Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	% Change
Rainfall	48.8	42.4	15
GW Pumping Addition	1.7	1.7	0
NPDES Discharge	1.9	1.9	0
SW Inflow	17.8	10.7	66
Lateral GW Inflow	6.7	6.7	1
TOTAL IN	76.9	63.4	21
TOTAL OUT + Δ Storage	77.4	63.8	21
ET Loss	34.5	33.9	2
GW Pumping	2.5	2.5	0
SW Outflow	32.7	20.3	61
Lateral GW Outflow	7.4	7.2	3
Storage Change	0.4	-0.1	-458
UFA Recharge	1.5	1.4	5

Table B.4
Peace at Arcadia Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	%Change
Rainfall	56.3	49.0	15
GW Pumping Addition	2.2	2.2	0
NPDES Discharge	0.0	0.0	0
SW Inflow	80.2	49.4	62
Lateral GW Inflow	4.5	4.5	0
TOTAL IN	143.1	105.1	36
TOTAL OUT + Δ Storage	141.2	105.0	35
ET Loss	42.6	42.1	1
GW Pumping	2.2	2.2	0
SW Outflow	92.9	57.7	61
Lateral GW Outflow	3.9	3.8	1
Storage Change	-0.3	-0.8	-58
UFA Recharge	0.2	0.2	1

Table B.5
Payne Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	%Change
Rainfall	46.0	40.2	14
GW Pumping Addition	1.1	1.1	0
NPDES Discharge	7.2	7.2	0
SW Inflow	0.9	0.5	92
Lateral GW Inflow	9.1	9.2	0
TOTAL IN	64.3	58.1	11
TOTAL OUT + Δ Storage	64.4	58.2	11
ET Loss	32.6	31.9	2
GW Pumping	2.6	2.6	0
SW Outflow	19.7	14.5	35
Lateral GW Outflow	9.6	9.6	0
Storage Change	0.0	-0.4	-92
UFA Recharge	1.0	1.0	1

Table B.6
Horse Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	%Change
Rainfall	53.6	47.2	14
GW Pumping Addition	1.0	1.0	0
NPDES Discharge	0.0	0.0	0
SW Inflow	1.2	0.6	105
Lateral GW Inflow	9.5	9.5	0
TOTAL IN	65.3	58.3	12
TOTAL OUT + Δ Storage	65.7	58.7	12
ET Loss	39.2	38.7	1
GW Pumping	1.2	1.2	0
SW Outflow	15.6	9.5	65
Lateral GW Outflow	9.9	9.9	0
Storage Change	-0.2	-0.6	-60
UFA Recharge	0.4	0.4	1

Table B.7
Charlie Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

	Wet	Dry	% Change
Rainfall	54.3	47.7	14
GW Pumping Addition	1.9	1.9	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.7	0.3	107
Lateral GW Inflow	2.9	2.9	-1
TOTAL IN	59.7	52.9	13
TOTAL OUT + Δ Storage	59.9	52.9	13
ET Loss	40.4	39.8	2
GW Pumping	1.8	1.8	0
SW Outflow	14.3	8.6	66
Lateral GW Outflow	3.7	3.4	9
Storage Change	-0.3	-0.7	-53
UFA Recharge	0.3	0.3	8

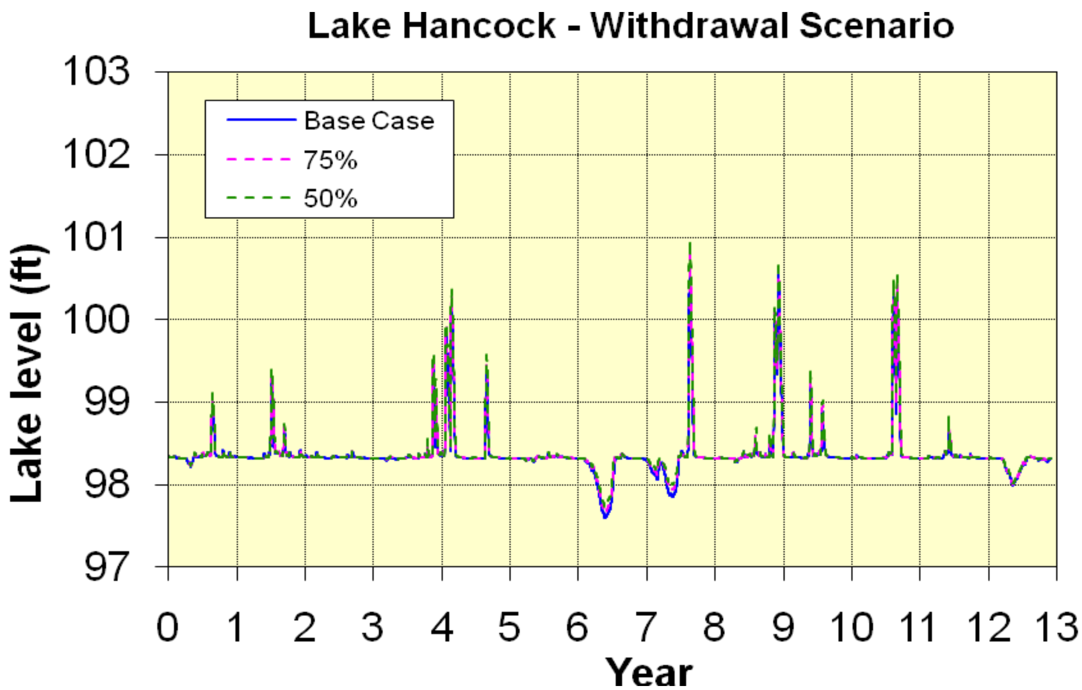
Table B.8
Joshua Creek Water Budget for Wet and Dry Rainfall Scenarios (in/yr)

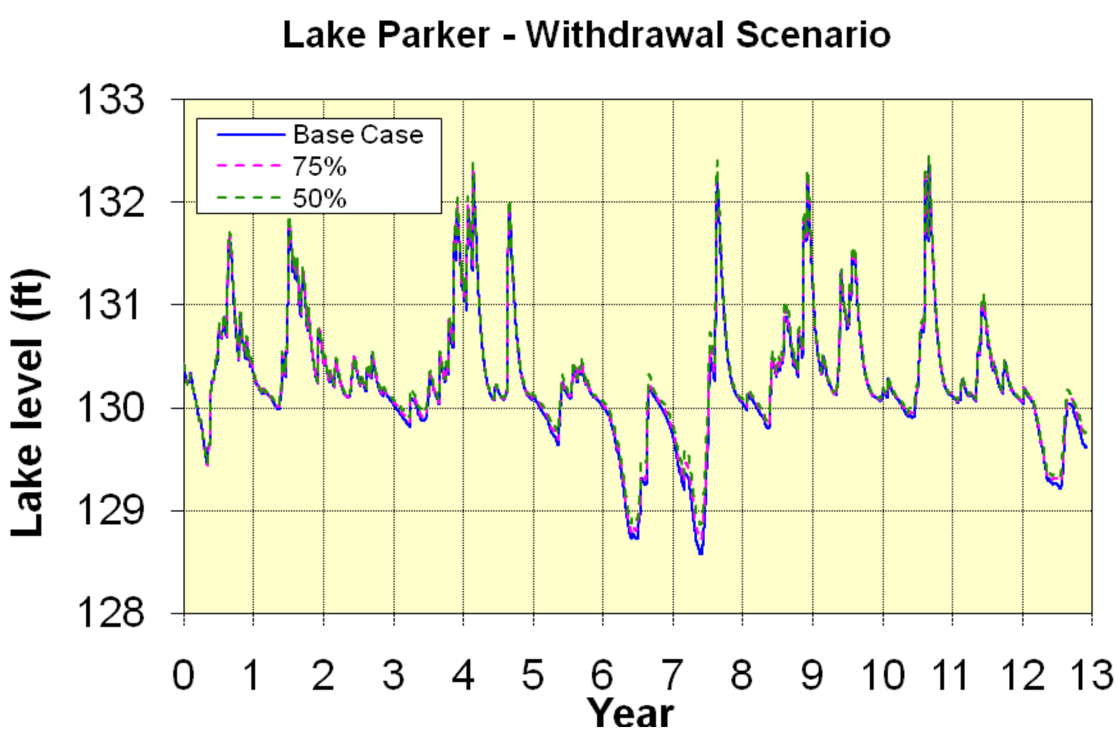
	Wet	Dry	% Change
Rainfall	57.2	50.0	14
GW Pumping Addition	2.7	2.7	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.6	0.4	69
Lateral GW Inflow	11.0	11.1	0
TOTAL IN	71.6	64.2	12
TOTAL OUT + Δ Storage	71.5	64.1	12
ET Loss	41.6	40.6	2
GW Pumping	2.7	2.7	0
SW Outflow	17.2	11.1	55
Lateral GW Outflow	10.3	10.2	0
Storage Change	-0.2	-0.5	-54
UFA Recharge	-0.1	-0.1	-11

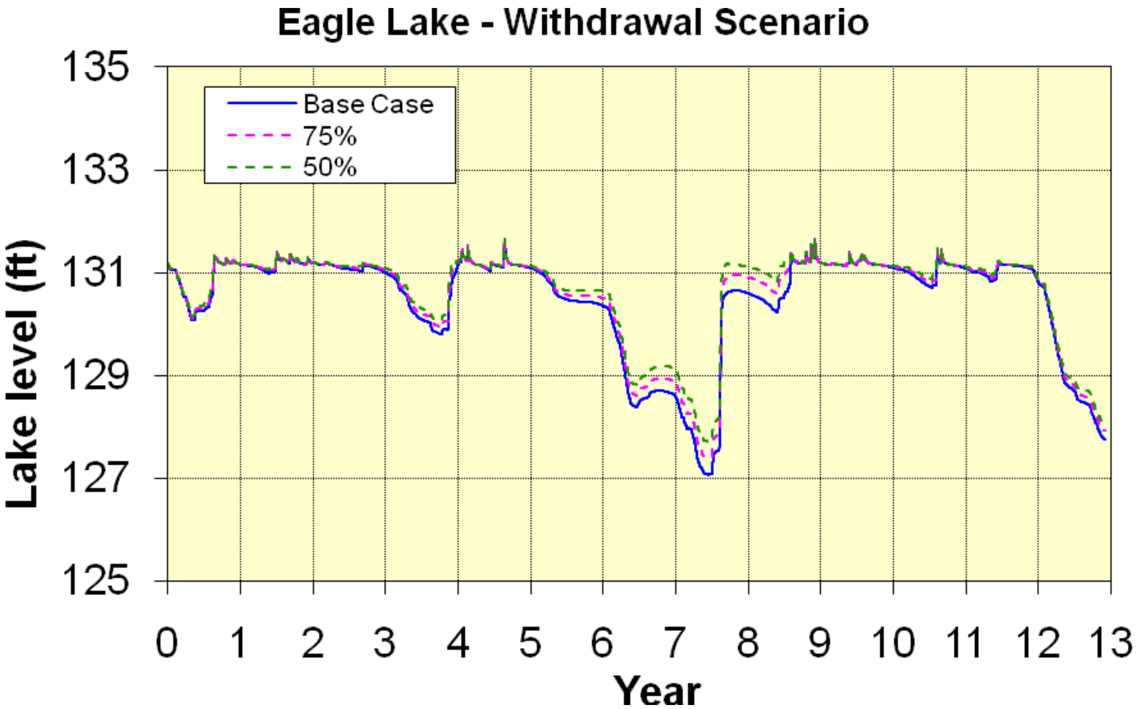
APPENDIX C

LAKE LEVELS FOR WITHDRAWAL SCENARIOS

APPENDIX C
LAKE LEVELS FOR WITHDRAWAL SCENARIOS






Eagle Lake - Withdrawal Scenario
Base Case
75%
50%
Lake level (ft)
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133
131
129
127
125
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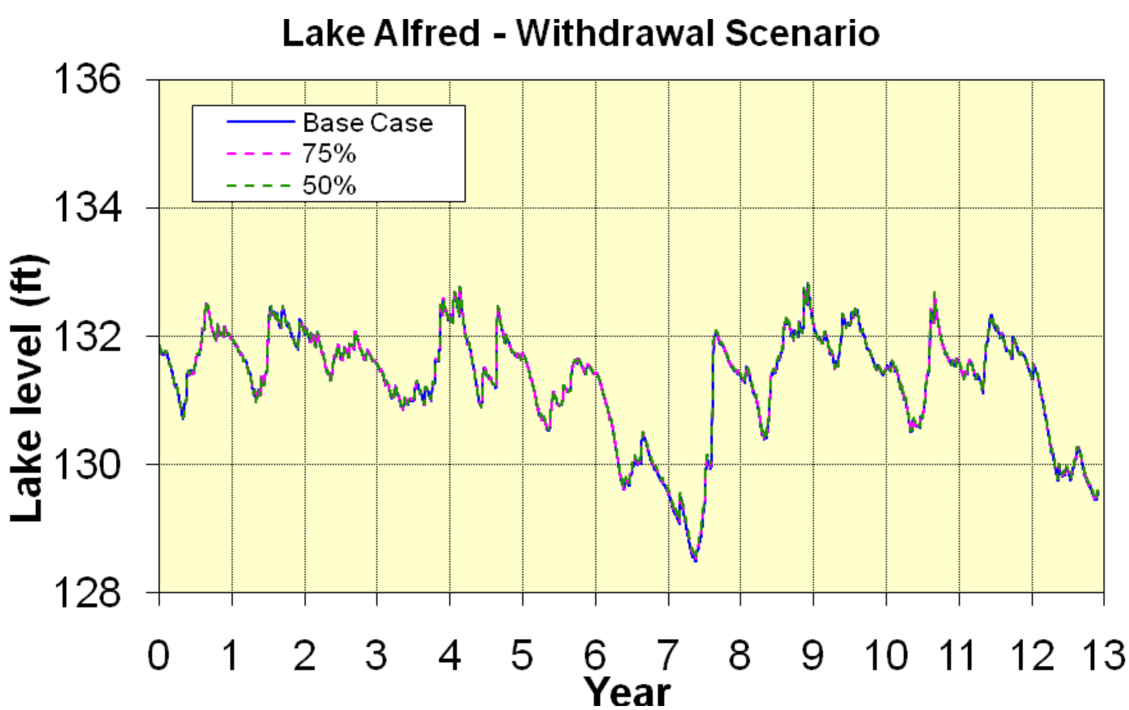
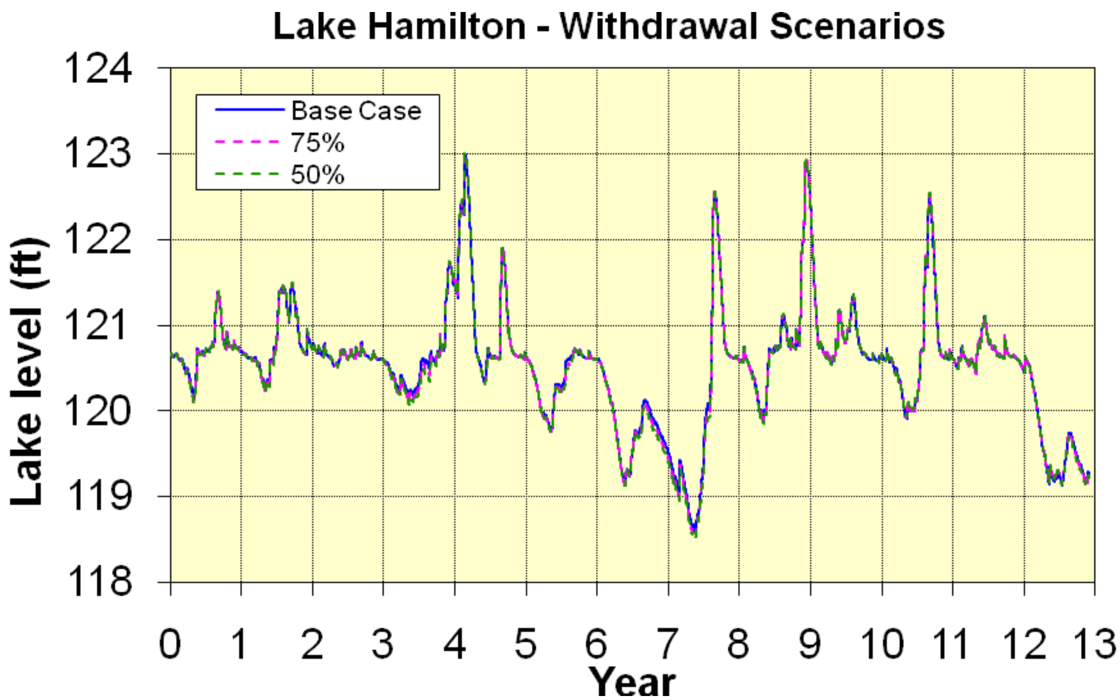
Year


Lake Alfred - Withdrawal Scenario
Base Case
75%
50%
Lake level (ft)
136
134
132
130
128
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year



Lake Hamilton - Withdrawal Scenarios
Base Case
75%
50%
Lake level (ft)
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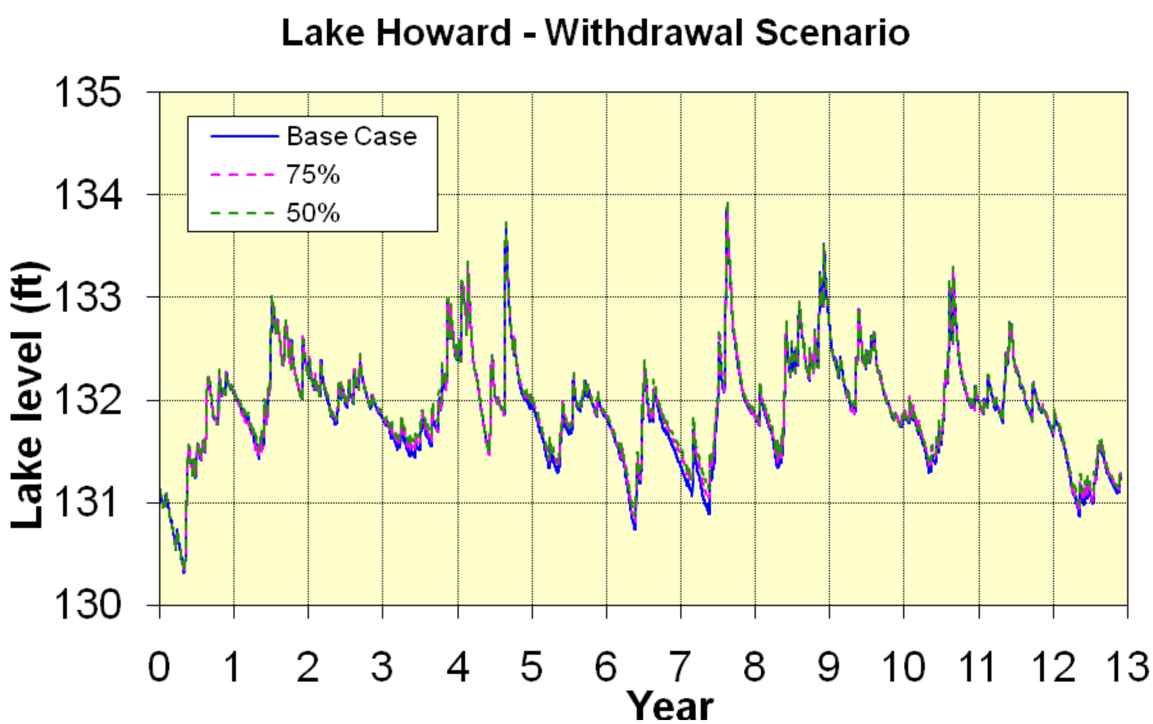
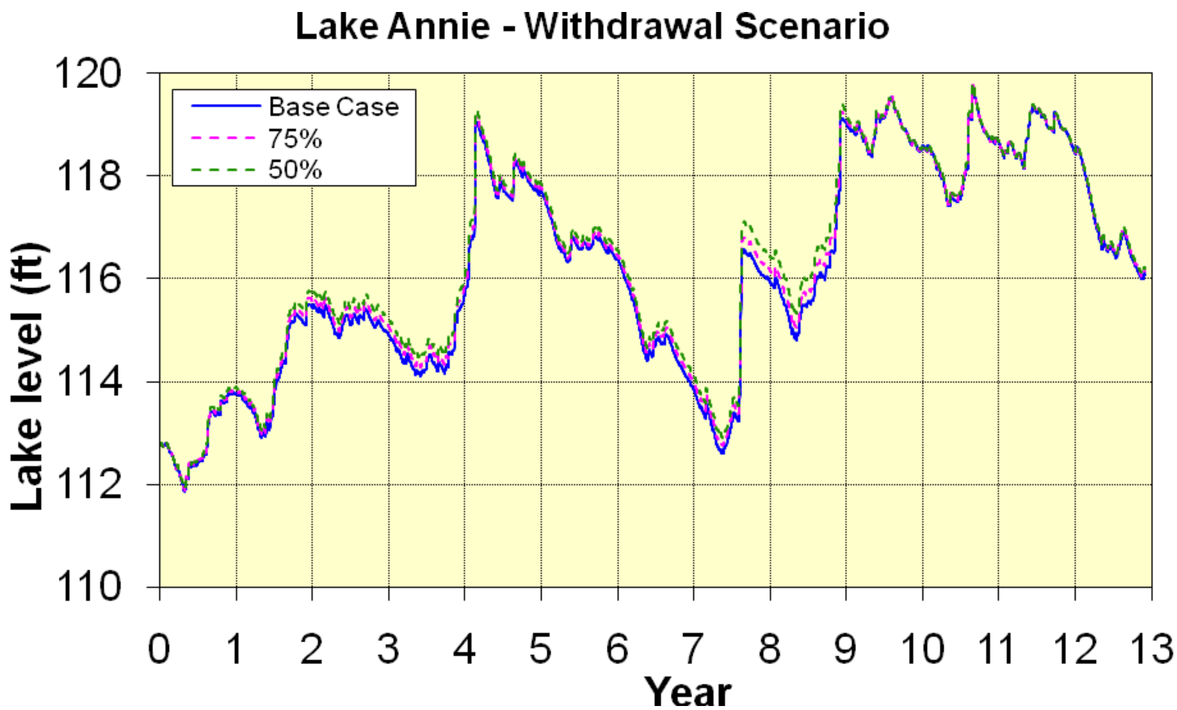
123
122
121
120
119
118
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year



Lake Howard - Withdrawal Scenario
Base Case
75%
50%
Lake level (ft)
135
134
133
132
131
130
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year


Lake Annie - Withdrawal Scenario
Base Case
75%
50%
Lake level (ft)
120
118
116
114
112
110
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Year

APPENDIX D

SUB-BASIN WATER BUDGETS FOR WITHDRAWAL SCENARIOS

APPENDIX D
SUB-BASIN WATER BUDGETS FOR GROUNDWATER WITHDRAWAL SCENARIOS[1]

Table D.1
Saddle Creek Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	54.3	54.3	54.3	0	0
GW Pumping Addition	2.9	2.2	1.4	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	0.3	0.3	0.2	-6	-12
Lateral GW Inflow	7.7	6.7	5.7	-13	-27
TOTAL IN	65.2	63.4	61.7	-3	-5
TOTAL OUT + Δ Storage	65.9	64.1	62.4	-3	-5
ET Loss	38.4	38.4	38.4	0	0
GW Pumping	2.9	2.2	1.4	-25	-50
SW Outflow	11.2	11.6	11.9	3	6
Lateral GW Outflow	13.5	12.1	10.7	-11	-21
Storage Change	-0.2	-0.1	-0.1	-29	-53
UFA Recharge	7.0	6.0	4.9	-15	-29

Table D.2
Peace Creek Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	54.3	54.3	54.3	0	0
GW Pumping Addition	3.8	2.9	1.9	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	0.2	0.2	0.2	-10	-17
Lateral GW Inflow	2.2	2.0	1.8	-10	-19
TOTAL IN	60.5	59.3	58.2	-2	-4
TOTAL OUT + Δ Storage	61.1	60.0	58.8	-2	-4
ET Loss	38.9	39.0	39.1	0	0
GW Pumping	3.8	2.9	1.9	-25	-50
SW Outflow	8.2	8.4	8.6	2	5
Lateral GW Outflow	10.5	9.9	9.4	-5	-10
Storage Change	-0.4	-0.3	-0.2	-28	-51
UFA Recharge	9.3	8.2	7.1	-12	-24

[1] The sub-basin water budgets are based on the active model cells. In the Payne Creek and Peace at Zolfo sub-basins, a number of land surface model cells were set as inactive to represent operational phosphate mining areas. The inactive cells account for 23% of the sub-basin area in Payne Creek and 17% in the Peace at Zolfo sub-basin. Rainfall and ET in the water budgets for these sub-basins are, therefore, low by the same percentages.

Table D.3
Peace at Zolfo Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	47.3	47.3	47.3	0	0
GW Pumping Addition	1.7	1.3	0.8	-25	-50
NPDES Discharge	1.9	1.9	1.9	0	0
SW Inflow	18.4	18.7	19.1	2	4
Lateral GW Inflow	6.2	5.5	4.9	-10	-20
TOTAL IN	75.5	74.8	74.1	-1	-2
TOTAL OUT + Δ Storage	76.1	75.4	74.8	-1	-2
ET Loss	34.0	34.0	34.0	0	0
GW Pumping	2.5	1.8	1.2	-25	-50
SW Outflow	32.8	33.1	33.5	1	2
Lateral GW Outflow	6.5	5.9	5.4	-9	-17
Storage Change	0.3	0.5	0.6	59	100
UFA Recharge	1.4	1.1	0.8	-23	-45

Table D.4
Peace at Arcadia Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	54.7	54.7	54.7	0	0
GW Pumping Addition	2.2	1.6	1.1	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	79.1	79.5	80.0	0	1
Lateral GW Inflow	4.9	4.2	3.8	-13	-21
TOTAL IN	140.9	140.0	139.6	-1	-1
TOTAL OUT + Δ Storage	139.2	138.4	138.0	-1	-1
ET Loss	42.3	42.2	42.2	0	0
GW Pumping	2.2	1.6	1.1	-25	-50
SW Outflow	91.2	91.4	91.8	0	1
Lateral GW Outflow	4.2	3.7	3.5	-12	-17
Storage Change	-0.6	-0.6	-0.5	-12	-17
UFA Recharge	0.2	0.1	0.1	-22	-41

Table D.5
Payne Creek Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	45.0	45.0	45.0	0	0
GW Pumping Addition	1.1	0.8	0.5	-25	-50
NPDES Discharge	7.2	7.2	7.2	0	0
SW Inflow	0.9	0.9	0.9	0	0
Lateral GW Inflow	10.0	9.2	8.4	-8	-16
TOTAL IN	64.3	63.3	62.2	-2	-3
TOTAL OUT + Δ Storage	64.4	63.4	62.3	-2	-3
ET Loss	32.1	32.1	32.1	0	0
GW Pumping	2.6	1.9	1.3	-25	-50
SW Outflow	19.8	19.9	19.9	0	0
Lateral GW Outflow	10.2	9.7	9.2	-5	-10
Storage Change	-0.3	-0.2	-0.2	-22	-35
UFA Recharge	1.0	0.9	0.7	-12	-24

Table D.6
Horse Creek Water Budget for Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	53.0	53.0	53.0	0	0
GW Pumping Addition	1.0	0.8	0.5	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	1.2	1.2	1.2	0	0
Lateral GW Inflow	8.7	7.5	6.4	-14	-26
TOTAL IN	63.9	62.5	61.1	-2	-4
TOTAL OUT + Δ Storage	64.3	62.9	61.5	-2	-4
ET Loss	38.7	38.7	38.7	0	0
GW Pumping	1.2	0.9	0.6	-25	-50
SW Outflow	15.5	15.5	15.5	0	0
Lateral GW Outflow	9.4	8.1	7.0	-13	-26
Storage Change	-0.5	-0.4	-0.3	-24	-37
UFA Recharge	0.5	0.4	0.3	-20	-40

Table D.7
Charlie Creek Water Budget Pumping Scenarios (in/yr)

	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	52.8	52.8	52.8	0	0
GW Pumping Addition	1.9	1.4	0.9	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	0.6	0.6	0.6	-1	-2
Lateral GW Inflow	2.4	2.1	2.0	-9	-16
TOTAL IN	57.7	57.0	56.3	-1	-2
TOTAL OUT + Δ Storage	57.8	57.1	56.5	-1	-2
ET Loss	39.9	39.8	39.8	0	0
GW Pumping	1.8	1.4	0.9	-25	-50
SW Outflow	13.6	13.4	13.3	-1	-2
Lateral GW Outflow	3.2	3.1	3.1	-2	-2
Storage Change	-0.6	-0.6	-0.6	0	1
UFA Recharge	0.5	0.4	0.3	-17	-33

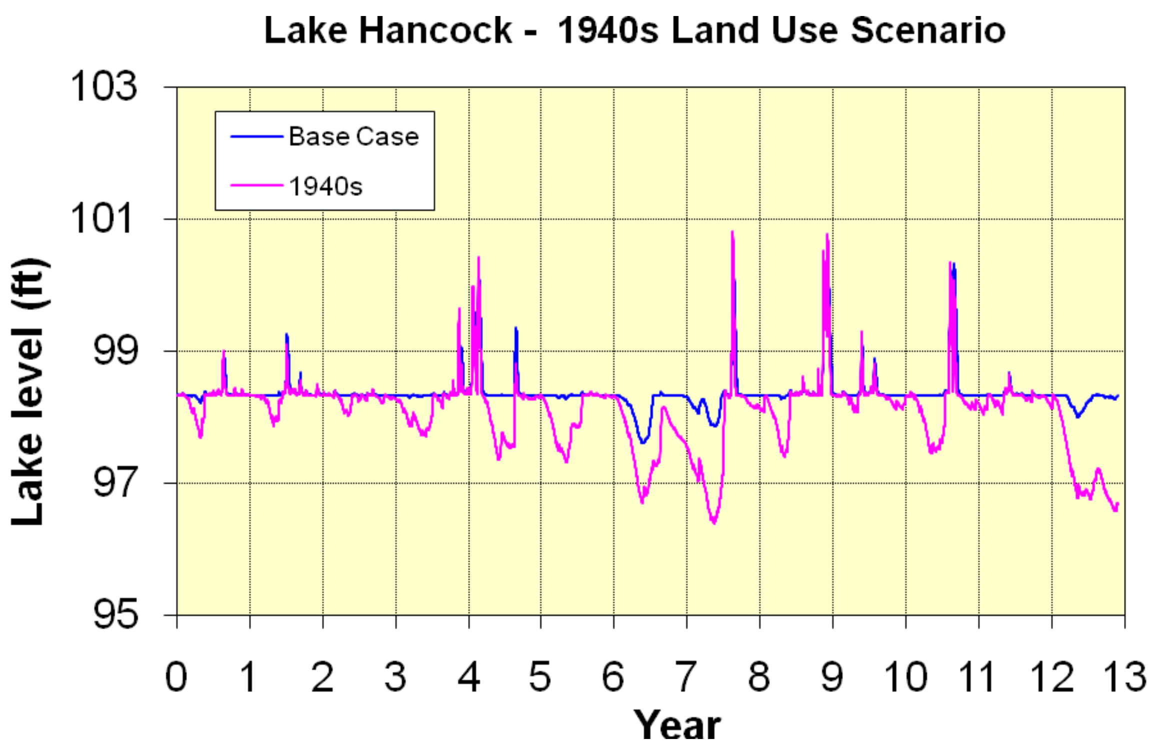
Table D.8
Joshua Creek Water Budget for Pumping Scenarios (in/yr)

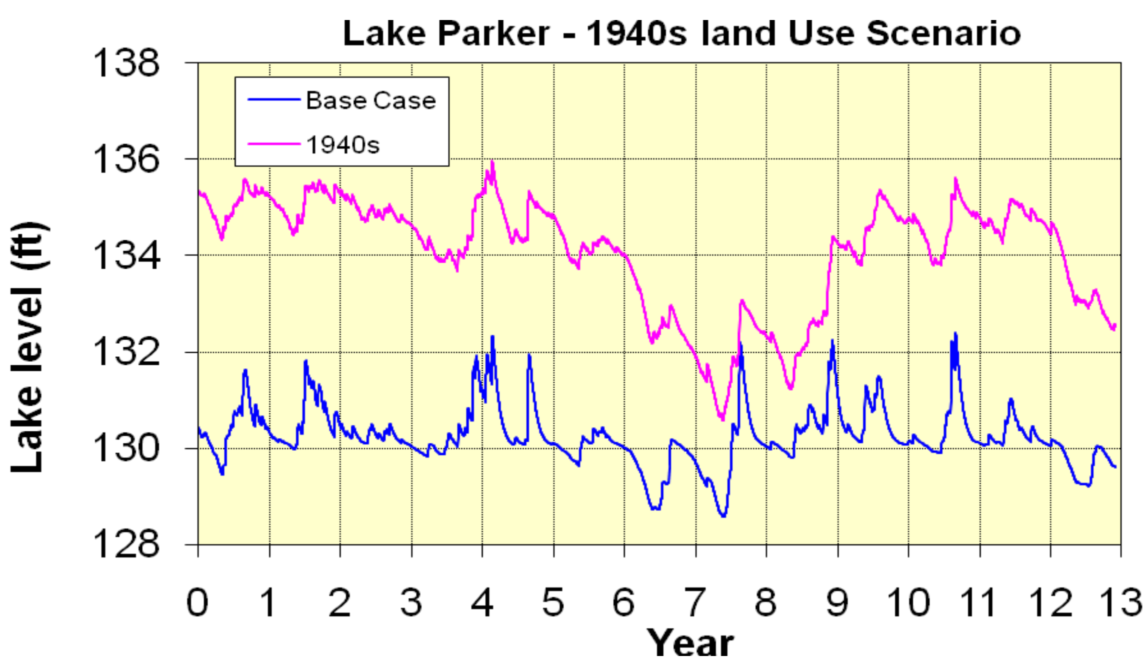
	Base Case	75% Pumping	50% Pumping	75% Pumping Change (%)	50% Pumping Change (%)
Rainfall	55.8	55.8	55.8	0	0
GW Pumping Addition	2.7	2.0	1.3	-25	-50
NPDES Discharge	0.0	0.0	0.0	0	0
SW Inflow	0.6	0.6	0.6	-2	-4
Lateral GW Inflow	11.0	9.3	7.9	-16	-28
TOTAL IN	70.1	67.7	65.7	-3	-6
TOTAL OUT + Δ Storage	70.1	67.7	65.6	-3	-6
ET Loss	40.8	40.7	40.6	0	-1
GW Pumping	2.7	2.0	1.4	-25	-50
SW Outflow	16.6	16.3	16.0	-2	-4
Lateral GW Outflow	10.4	9.1	8.1	-13	-22
Storage Change	-0.4	-0.5	-0.5	2	3
UFA Recharge	-0.2	-0.2	-0.3	22	43

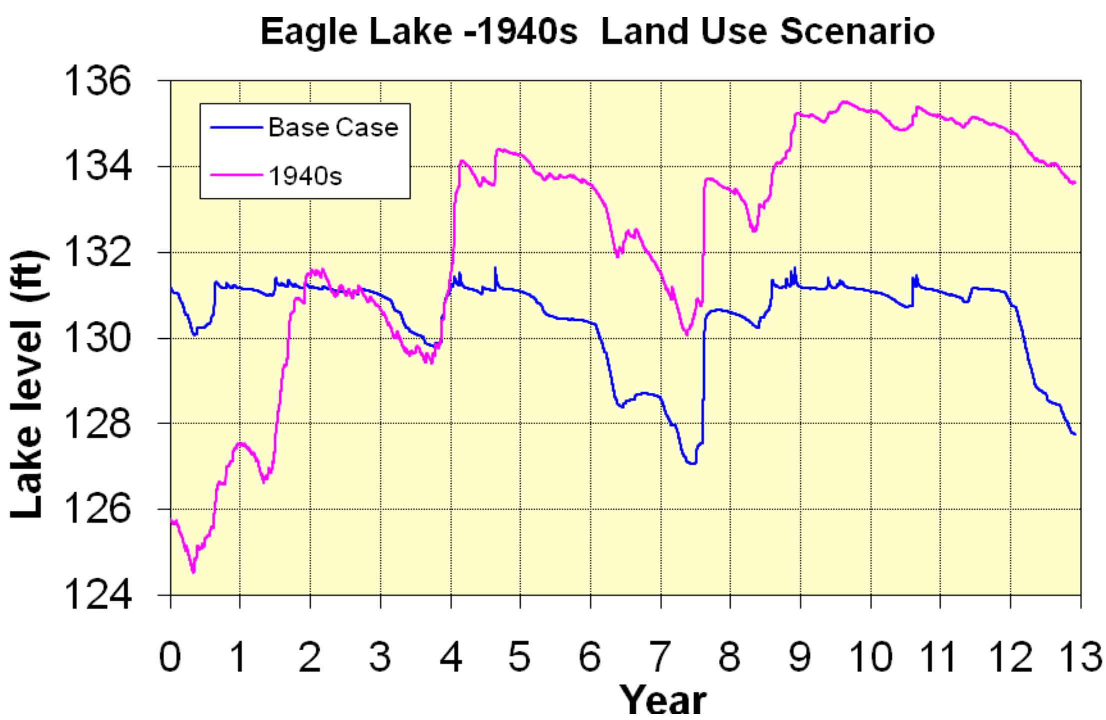
APPENDIX E

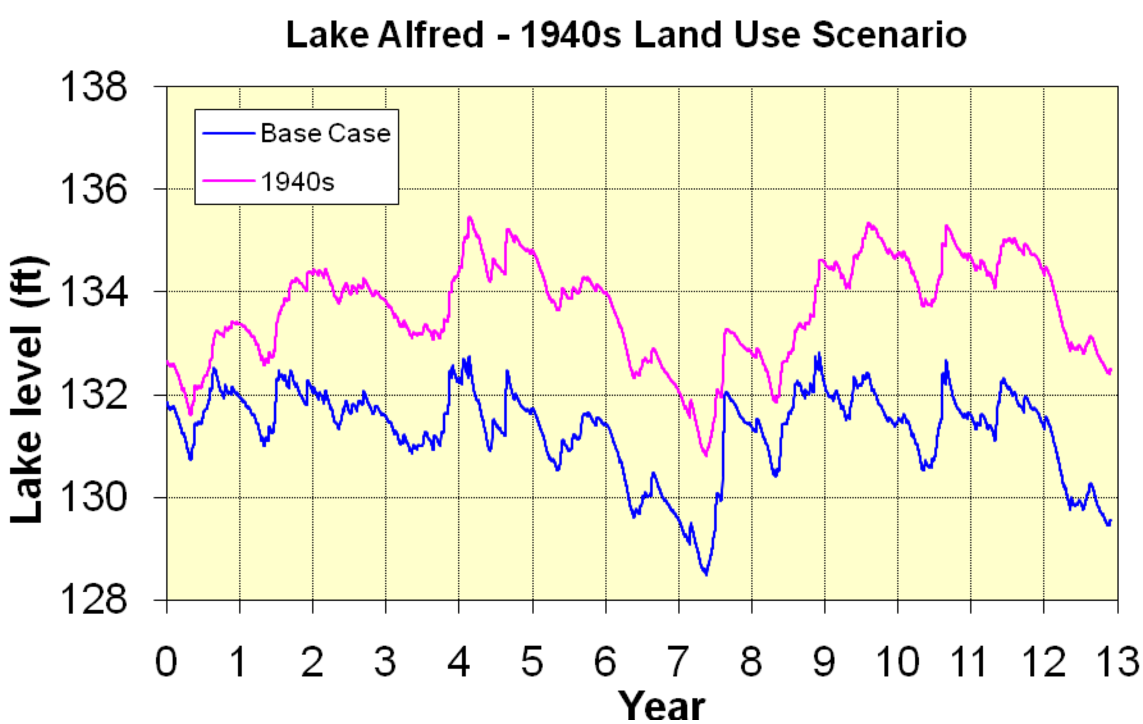
LAKE LEVELS FOR 1940s LAND USE SCENARIO

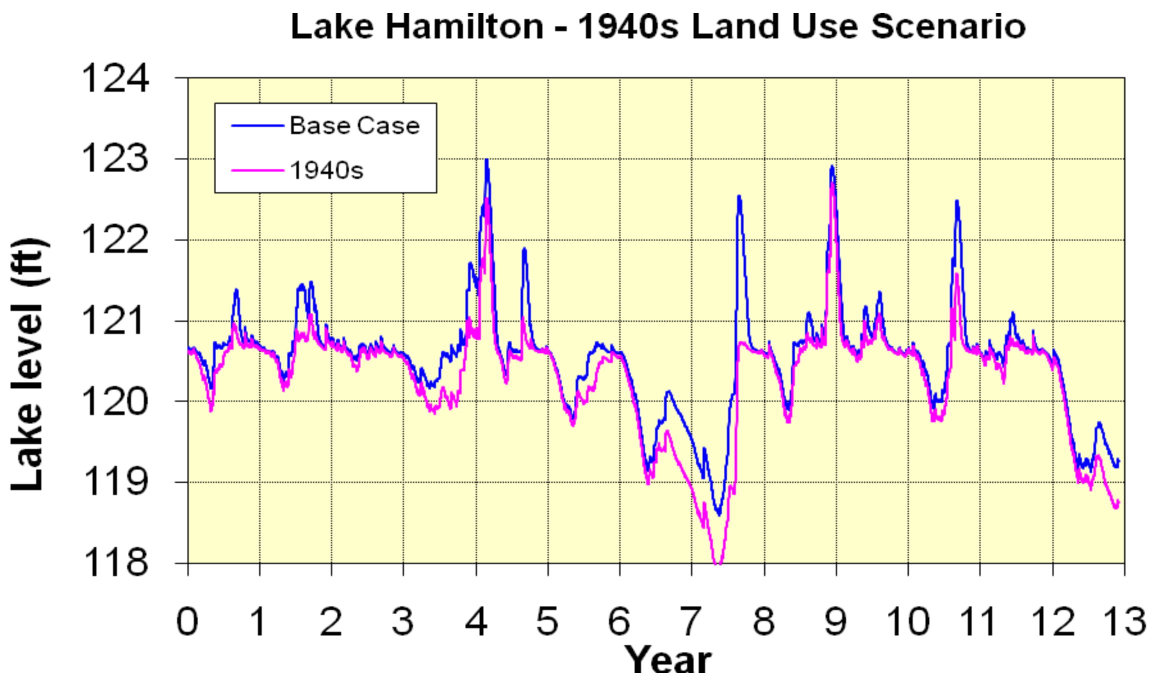
APPENDIX E
LAKE LEVELS FOR 1940s LAND USE SCENARIO

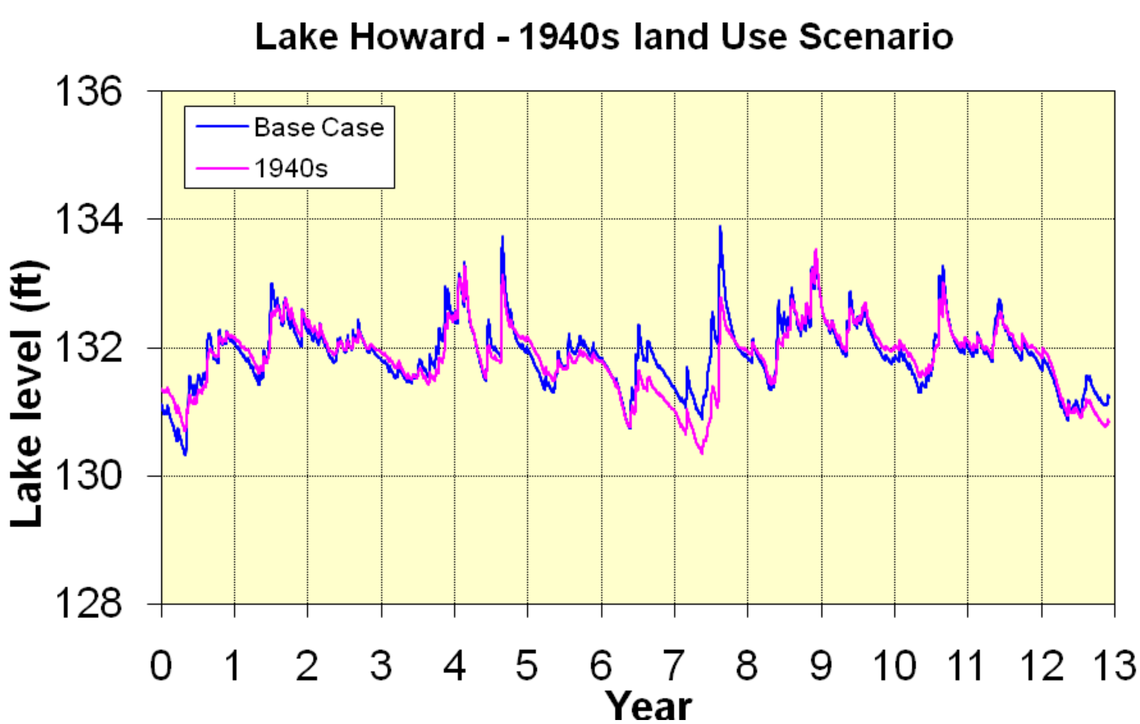


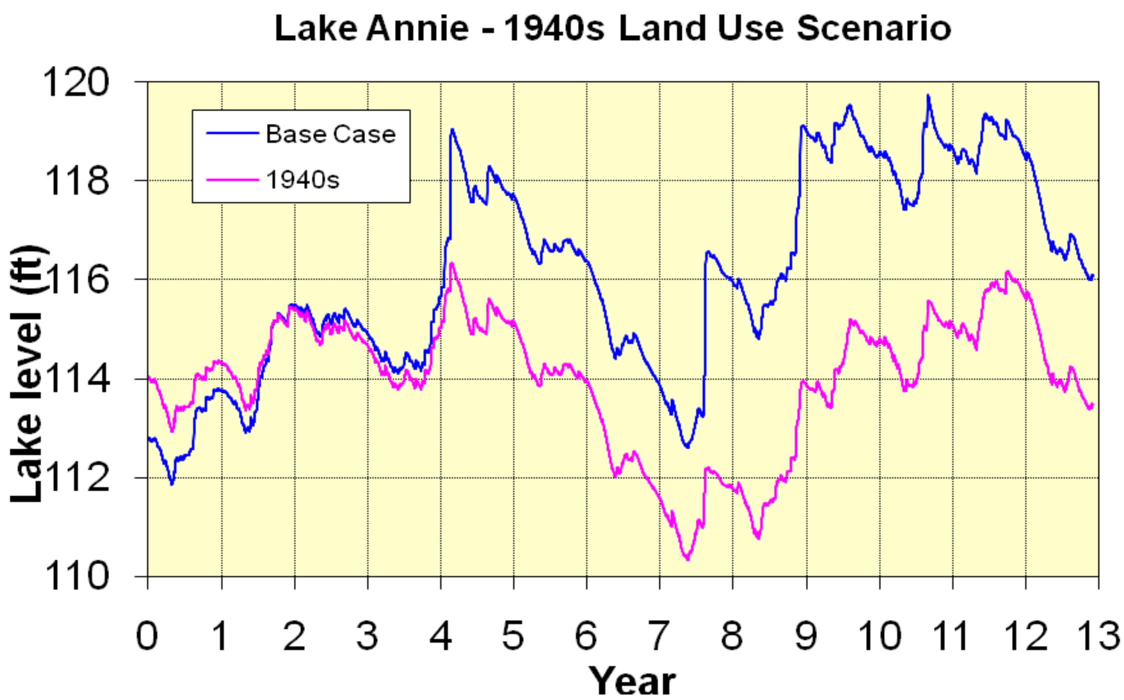



Eagle Lake -1940s Land Use Scenario
Base Case
1940s
Lake level (ft)
136
134
132
130
128
126
124
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year


Lake Alfred - 1940s Land Use Scenario
Base Case
1940s
Lake level (ft)
138
136
134
132
130
128
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Year


Lake Hamilton - 1940s Land Use Scenario
Base Case
1940s
Lake level (ft)
124
123
122
121
120
119
118
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Year


Lake Howard - 1940s land Use Scenario
Base Case
1940s
Lake level (ft)
136
134
132
130
128
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Year


Lake Annie - 1940s Land Use Scenario
Base Case
1940s
Lake level (ft)
110
112
114
116
118
120
Year
0
1
2
3
4
5
6
7
8
9
10
11
12
13

APPENDIX F

SUB-BASIN WATER BUDGETS FOR 1940s LAND USE SCENARIO

APPENDIX F
SUB-BASIN WATER BUDGETS FOR 1940S LAND USE SCENARIO

Table F.1
Saddle Creek Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	54.3	54.3	0
GW Pumping Addition	2.9	2.9	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.3	0.1	-46
Lateral GW Inflow	7.7	7.5	-3
TOTAL IN	65.2	64.9	-1
TOTAL OUT + Δ Storage	65.9	65.5	-1
ET Loss	38.4	41.3	7
GW Pumping	2.9	2.9	0
SW Outflow	11.2	7.1	-37
Lateral GW Outflow	13.5	14.1	4
Storage Change	-0.2	0.2	-190
UFA Recharge	7.0	9.0	28

Table F.2
Peace Creek Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	%Change
Rainfall	54.3	54.6	1
GW Pumping Addition	3.8	3.9	1
NPDES Discharge	0.0	0.0	0
SW Inflow	0.2	0.3	10
Lateral GW Inflow	2.2	2.1	-7
TOTAL IN	60.5	60.7	0
TOTAL OUT + Δ Storage	61.1	61.4	0
ET Loss	38.9	41.5	7
GW Pumping	3.8	3.8	0
SW Outflow	8.2	5.3	-35
Lateral GW Outflow	10.5	11.1	6
Storage Change	-0.4	-0.4	17
UFA Recharge	9.3	9.3	0

Table F.3
Peace at Zolfo Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	47.3	54.9	16
GW Pumping Addition	1.7	2.1	24
NPDES Discharge	1.9	1.4	-25
SW Inflow	18.4	14.8	-20
Lateral GW Inflow	6.2	6.2	1
TOTAL IN	75.5	79.5	5
TOTAL OUT + Δ Storage	76.1	79.9	5
ET Loss	34.0	40.8	20
GW Pumping	2.5	2.5	0
SW Outflow	32.8	29.6	-10
Lateral GW Outflow	6.5	6.5	1
Storage Change	0.3	0.5	76
UFA Recharge	1.4	2.4	72

Table F.4
Peace at Arcadia Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	54.7	54.7	0
GW Pumping Addition	2.2	2.2	0
NPDES Discharge	0.0	0.0	0
SW Inflow	79.1	73.7	-7
Lateral GW Inflow	4.9	4.9	0
TOTAL IN	140.9	135.5	-4
TOTAL OUT + Δ Storage	139.2	133.6	-4
ET Loss	42.3	41.5	-2
GW Pumping	2.2	2.2	0
SW Outflow	91.2	86.3	-5
Lateral GW Outflow	4.2	4.2	0
Storage Change	-0.6	-0.6	-13
UFA Recharge	0.2	0.2	0

Table F.5
Payne Creek Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	45.0	56.2	25
GW Pumping Addition	1.1	1.1	2
NPDES Discharge	7.2	6.3	-12
SW Inflow	0.9	1.2	22
Lateral GW Inflow	10.0	10.0	0
TOTAL IN	64.3	74.7	16
TOTAL OUT + Δ Storage	64.4	74.8	16
ET Loss	32.1	41.2	29
GW Pumping	2.6	2.6	0
SW Outflow	19.8	21.1	6
Lateral GW Outflow	10.2	10.3	0
Storage Change	-0.3	-0.3	5
UFA Recharge	1.0	1.2	20

Table F.6
Horse Creek Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	53.0	54.6	3
GW Pumping Addition	1.0	1.0	1
NPDES Discharge	0.0	0.0	0
SW Inflow	1.2	1.2	0
Lateral GW Inflow	8.7	8.7	0
TOTAL IN	63.9	65.4	2
TOTAL OUT + Δ Storage	64.3	65.9	2
ET Loss	38.7	39.7	3
GW Pumping	1.2	1.2	0
SW Outflow	15.5	16.0	3
Lateral GW Outflow	9.4	9.4	0
Storage Change	-0.5	-0.4	-10
UFA Recharge	0.5	0.5	4

Table F.7
Charlie Creek Water Budget 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	52.8	52.8	0
GW Pumping Addition	1.9	1.9	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.6	0.6	0
Lateral GW Inflow	2.4	2.4	0
TOTAL IN	57.7	57.7	0
TOTAL OUT + Δ Storage	57.8	57.8	0
ET Loss	39.9	39.8	0
GW Pumping	1.8	1.8	0
SW Outflow	13.6	13.7	1
Lateral GW Outflow	3.2	3.1	-2
Storage Change	-0.6	-0.6	-1
UFA Recharge	0.5	0.5	0

Table F.8
Joshua Creek Water Budget for 1940s Land Use Scenarios (in/yr)

	Base Case	1940s Land Use	% Change
Rainfall	55.8	55.8	0
GW Pumping Addition	2.7	2.7	0
NPDES Discharge	0.0	0.0	0
SW Inflow	0.6	0.6	-8
Lateral GW Inflow	11.0	11.0	0
TOTAL IN	70.1	70.1	0
TOTAL OUT + Δ Storage	70.1	70.0	0
ET Loss	40.8	40.0	-2
GW Pumping	2.7	2.7	0
SW Outflow	16.6	17.3	4
Lateral GW Outflow	10.4	10.4	0
Storage Change	-0.4	-0.4	-8
UFA Recharge	-0.2	-0.2	0