Effects of Phosphate Mining and Other Land Uses on Peace River Flows

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Introduction

During the past twenty years, the Florida phosphate mining industry has made significant improvements in water management and has reduced groundwater withdrawals in the Peace River basin from over 95 mgd in 1980 to less than 20 mgd in 2001. Part of the decrease in withdrawals in the Peace River basin is related to a decrease in the number of active mines operating in the basin. However, most of the decrease is related to water management efforts. Recycled water now accounts for greater than 95 percent of the water used in the mining and beneficiation process. Figure 1 is a graph of groundwater withdrawal for phosphate mining reported as gallons of water per ton of rock produced. A significant reduction in groundwater use is apparent.

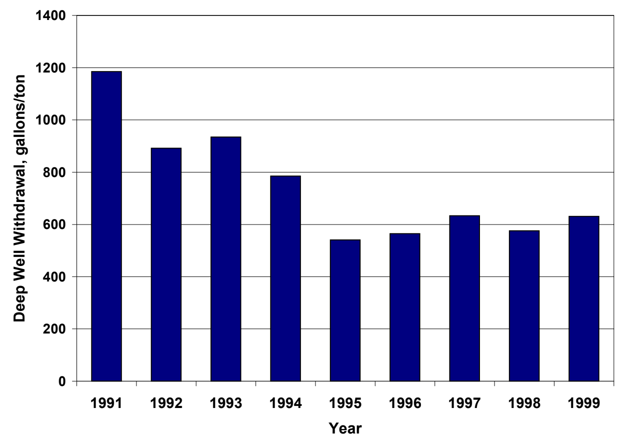

Figure 1. Floridan Aquifer Withdrawals for Phosphate Mining.

Although the phosphate industry has made significant improvements in water management, questions still remain concerning the potential impact of phosphate mining on the flow of the Peace River. The purpose of this report is to address these issues. However, before responding to the specific questions, a brief description of the geological and hydrological setting of the Peace River basin is presented.

Geologic and Hydrogeologic Setting

The geologic system within the Peace River basin consists of thick sequences of carbonate rock overlain by sand and clayey sand deposits. The rock units dip toward and thicken to the south-southwest. Table 1 summarizes information on the geologic formations that make up the hydrostratigraphic column in the Peace River basin.

The phosphorite-rich clastic portion of the Peace River Formation, i.e., the Bone Valley Member, is the stratum mined for phosphate and is locally referred to as “matrix”. The matrix is typically less than 40 feet thick. The soils that make up the matrix were deposited in a beach or alluvial environment between 4 and 6 million years ago.

Because of their clastic nature and relatively high lateral permeabilities, both the overburden and phosphate matrix are considered part of the surficial aquifer system. Depth to the water table is generally less than 5 feet below land surface, but can range from land surface in wetlands to more than 10 feet below land surface in the higher elevation uplands. The water table in the uplands fluctuates seasonally within a 5- to 10-foot range. Lowest levels occur in April or May, while highest levels occur during the wet season into September.

Table 1
Generalized Geologic Setting

<table>
<tr><th>System</th><th>Series</th><th colspan="3">Geologic Formation</th><th>Thickness, feet</th><th colspan="2">Hydrostratigraphic Unit</th></tr>
<tr><td rowspan="2">Quaternary</td><td>Holocene</td><td colspan="3" rowspan="3">Undifferentiated Surficial Soils</td><td rowspan="3">10 to 35</td><td colspan="2" rowspan="4">Surficial Aquifer System (Unconfined)</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td rowspan="8">Tertiary</td><td>Pliocene</td></tr>
<tr><td rowspan="4">Miocene</td><td rowspan="4">HAWTHORN GROUP</td><td colspan="2">Peace River Formation (Bone Valley Member)</td><td>0 to 50</td></tr>
<tr><td rowspan="3">ARCADIA FORMATION</td><td>Undifferentiated</td><td>25 to 200</td><td rowspan="3">INTERMEDIATE AQUIFER SYSTEM</td><td>Confining Bed</td></tr>
<tr><td>Tampa Member</td><td>0 to 200</td><td>Producing Zone</td></tr>
<tr><td>Nocatee Member</td><td>0 to 50</td><td>Confining Bed</td></tr>
<tr><td>Oligocene</td><td colspan="3">Suwannee Limestone</td><td>100 to 300</td><td colspan="2" rowspan="3">Floridan Aquifer System</td></tr>
<tr><td rowspan="2">Eocene</td><td colspan="3">Ocala Group</td><td>200 to 300</td></tr>
<tr><td colspan="3">Avon Park Formation</td><td>400 to 800</td></tr>
</table>

The intermediate aquifer system includes all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. The intermediate aquifer system is comprised of clay, marl, sandstone, and dolomitic limestone. The principal water-producing unit of the intermediate aquifer system is the Tampa limestone. The intermediate aquifer system is the primary source of groundwater in the southern portion of the Peace River basin.

The Floridan aquifer system is comprised of a thick stratified sequence of limestone and dolomite. It is the principal water supply source in the Peace River basin. Groundwater in the Floridan aquifer is under confined conditions throughout the Peace River basin. The potentiometric surface of the Floridan aquifer, i.e., the water level in wells that tap into the aquifer, is highest in the northern part of the basin and lowest in the southern part of the basin.

Recharge and Discharge

The surficial aquifer is recharged by rainfall. The amount of rainfall infiltrating the surficial aquifer in upland areas ranges from approximately 42 inches per year to about 50 inches per year. Most of this water is retained in the root zone within the upper few feet of the soil profile and is consumed through evaporation and plant transpiration. The remainder leaves the surficial aquifer as groundwater outflow to stream systems and as deep recharge to the intermediate and Floridan aquifers.

Surficial groundwater outflow to streams within the Peace River basin ranges from about 3 inches per year to approximately 12 inches per year. Evapotranspiration within the riparian wetland systems along the major streams consumes much, if not most, of the surficial groundwater outflow. That portion of the surficial groundwater outflow that reaches the stream channels provides baseflow to the stream and eventually to the Peace River.

Recharge to the intermediate and Floridan aquifers in the northern part of the Peace River basin can exceed ten inches per year. In the middle and southern portions of the basin, recharge to the intermediate and Floridan aquifers is less than 1 inch per year. Along portions of the Peace River, there are areas where both these artesian aquifers discharge groundwater to the river. This spring flow is another source of baseflow in the Peace River.

Kissengen Springs, which is located about 4 miles southeast of Bartow, formerly discharged as much as 20 million gallons of water per day from the Floridan aquifer to the Peace River. Starting in about 1934, a downward trend in springflow began and by 1950 the spring ceased to flow. This reduction in springflow corresponded to a decrease in the potentiometric surface of the Floridan aquifer. The potentiometric surface decreases primarily as a result of groundwater withdrawals, although decreased recharge can also result in lowered potentiometric levels.

Surface Water

The Peace River watershed covers an area of approximately 2,350 square miles. Its headwaters originate in a number of lakes in northern Polk County. Many of these lakes are linked by canals, some of which flow continually. Fixed or operable control structures have been constructed on many of the lake outlets[1]. The river itself begins at the junction of Saddle Creek and the Peace Creek Drainage Canal near Bartow and flows southward for about 75 miles before discharging into the northeastern portion of Charlotte Harbor. Land surface elevations range from about 200 feet (NGVD) in the headwater areas to sea level in the areas surrounding Charlotte Harbor. The channel of the Peace River is well defined between Bartow and Arcadia. Below Arcadia, the channel becomes braided and the width of the floodplain increases to more than a mile. Tidal influences extend as far north as Fort Ogden. Several areas near the mouth of the river have been channelized for development of waterfront home sites. Seawalls and bulkheads are commonplace[1.]

The Peace River has 5 major tributaries: Payne Creek, Charlie Creek, Joshua Creek, Horse Creek and Shell Creek. The U.S. Geological Survey has collected long-term continuous streamflow data for the Peace River at Bartow, Ft. Meade, Zolfo Springs, and Arcadia and for all 5 of the major tributaries. The long-term average flow of the Peace River at Arcadia is 1075 cfs (695 mgd). The long-term average flow at Charlotte Harbor is 1710 cfs (1,105 mgd).

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[1] Hammett, K.M. (1990). *Land Use, Water Use, Streamflow Characteristics, and Water-Quality Characteristics of the Charlotte Harbor Inflow Area, Florida*. U.S. Geological Survey Water-Supply Paper 2359.

The Peace River Manasota Regional Water Supply Authority (PRMRWSA) has a water intake structure and water treatment facility on the Peace River near Ft. Ogden. Its water use permit allows the Authority to withdraw 10 percent of the streamflow measured at Arcadia provided that the river's flow remains at or above 130 cfs. The intake pump is currently permitted to withdraw an average of 32.7 mgd and a maximum of 90 mgd. After treatment for potable supply, water that is not pumped to the distribution system is pumped to aquifer storage and recovery (ASR) wells. The ASR wells supply water to the distribution system when the river flow cannot support the demand.

Response to Questions Concerning Potential Impacts

This section analyzes and responds to several specific questions concerning the effects of phosphate mining in the Peace River basin. Seven questions are addressed.

Has Mining Funneled Much of the Peace River Flow Underground?

This question arises from one of the statements in Hammett (1990)[2] that reads: *"It is probable that the long-term decline in discharge in the Peace River basin is related to the decline of artesian water levels in the underlying Floridan aquifer system."* To illustrate the long term decreasing trend, Hammett plotted the 5-year moving average discharge for the Peace River at Arcadia. A plot similar to the one presented in Hammett (1990) is presented in Figure 2. A trend line has been added to illustrate the long-term decline in streamflow.

Based on Hammett's work, Lewelling et al(1998)[3] stated that "*along the Peace River, a progressive long-term decline in streamflow has occurred since 1931 due to a lowering of the potentiometric surface of the Floridan aquifer by as much as 60 feet because of intensive groundwater withdrawals for phosphate mining and agriculture."*

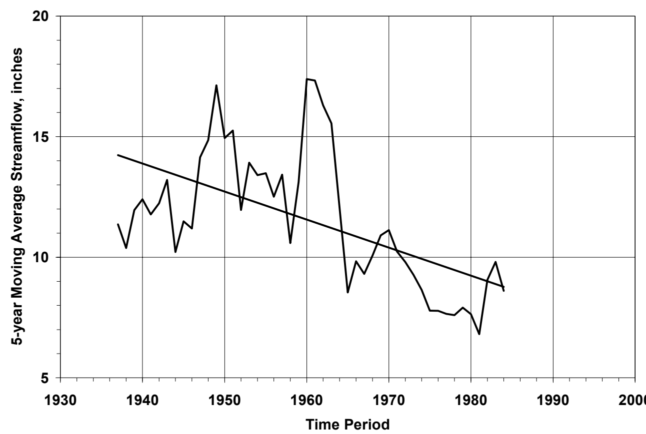

Figure 2. 5-year Moving Average Streamflow in Peace River at Arcadia

The implication of the above conclusions is that the long-term decline in streamflow documented in Figure 2 was caused by groundwater withdrawals.Hammett examined the effect of rainfall on streamflow by comparing plots of cumulative discharge versus cumulative precipitation (double mass curves) for the Myakka River near Sarasota and for the Peace River at Zolfo Springs. The rainfall record used for both the Myakka and Peace River plots was for the Bartow weather station. As shown in Figure 3, the double mass curve for the Myakka River appears to be linear. However, as shown in Figure 4, there is a definite change in the slope of the double mass curve for the Peace River occurring around 1965.

2 Hammett, K.M. (1990) *Land Use, Water Use, Streamflow Characteristics, and Water-Quality Characteristics of the Charlotte Harbor Inflow Area,* U.S. Geological Survey Water Supply Paper 2359.

3 Lewelling, B.R., A.B. Tihansky, and J.L. Kindinger (1998) *Assessment of the Hydraulic Connection Between Ground Water and the Peace River, West Central Florida,* U.S. Geological survey, Water Resources Investigation Report 97-4211.

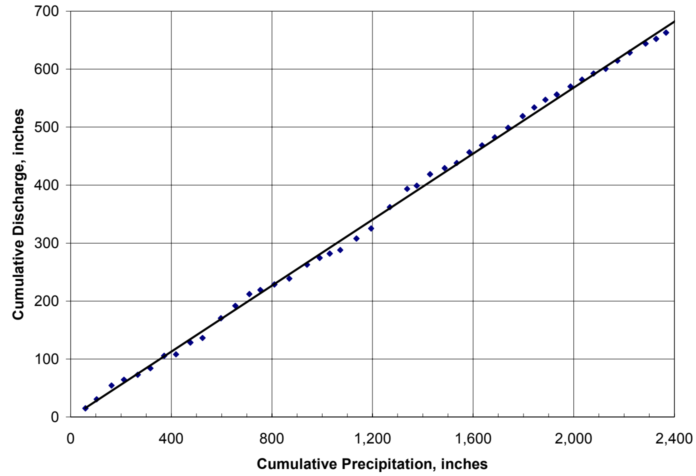

Figure 3. Accumulated Annual Streamflow for Myakka River at Sarasota versus Accumulated Annual Rainfall at Bartow.

Hammett concluded from a comparison of the two plots that *"deficient rainfall between 1961 and 1978 does not appear to be the sole cause of the decline in discharges in the Peace River."*

The relationship between streamflow and rainfall for any watershed is given by the following equation:

Streamflow = Rainfall - (Evapotranspiration + Net Deep Recharge + ΔStorage),

where net deep recharge is the net volume of water that leaves the surface water system as a result of seepage into deeper aquifer systems[4], evapotranspiration is the volume of water that leaves the surface water system through natural evaporation and transpiration (without irrigation), and Δ storage is the change in storage in the basin between the beginning and end of the period of record.

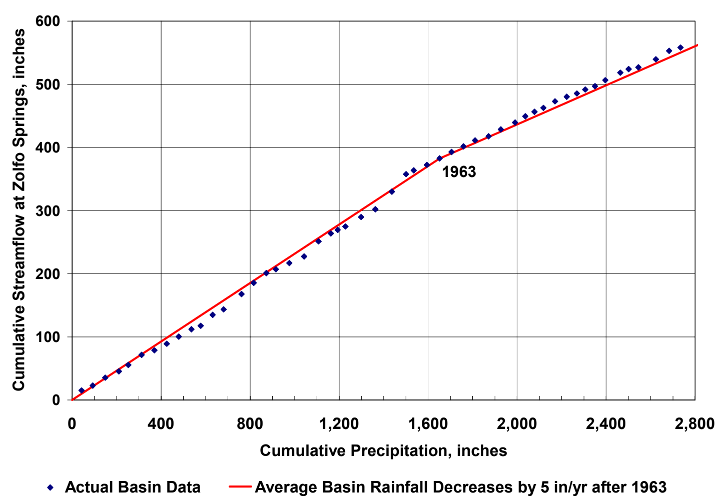

Figure 4 Accumulated Annual Streamflow for Peace River at Zolfo Springs versus Accumulated Annual Rainfall at Bartow, 1934 - 1984.

Hammett reached the conclusion stated above because the two plots shown in Figures 3 and 4 did not show the same change in slope after 1965. However, this conclusion is valid only if: (1) the rainfall in the Myakka River basin during the period of record was identical to the rainfall in the Peace River basin; and (2) there were no anthropogenic effects in the Myakka River basin that could have increased streamflow in the basin after 1963. To test this hypothesis, a hypothetical double mass curve was computed based on the assumption that the only hydrological change that occurred in the Peace River basin after 1963 was a decrease in the average annual rainfall from 55 inches per year to 50 inches per year. The hypothetical double mass curve is shown on Figure 4. As can be seen, the hypothetical curve fits the measured data remarkably well.

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4 It is the difference between the total recharge to the intermediate and Floridan aquifer systems from the surficial aquifer system and the total discharge, e.g., springflow, from the intermediate and Floridan aquifers to the surface water system.

To determine if there has been a change in annual rainfall in the Peace River basin after 1963, rainfall data was collected from U.S. Weather Bureau Stations at Arcadia, Bartow, Lake Alfred, Mountain Lake, and Wauchula to create the rainfall graph provided in Figure 5. As shown in Figure 5, there has, in fact, been a decrease of approximately 5 inches per year in the 30-year average annual rainfall in the Peace River basin between the period ending in 1963 and the period ending in 1993. Consequently, the change in slope of the double mass curve for the Peace River at Zolfo Springs can be explained almost entirely by a decrease in rainfall. Also note the nearly 5-inch decrease in average runoff in the Peace River basin for the same period. The unchanged slope of the double mass curve for the Myakka River at Sarasota cannot, therefore, be used to conclude that decreased rainfall is not the primary reason for the change in runoff in the Peace River basin. In fact, a more appropriate conclusion, based on the analyses presented above and assuming that rainfall trends in the Peace River and Myakka River basins are similar, is that changes in the hydrology of the Myakka River basin, e.g., increases in agricultural return flow, have resulted in higher than expected streamflow volumes in the Myakka River basin.

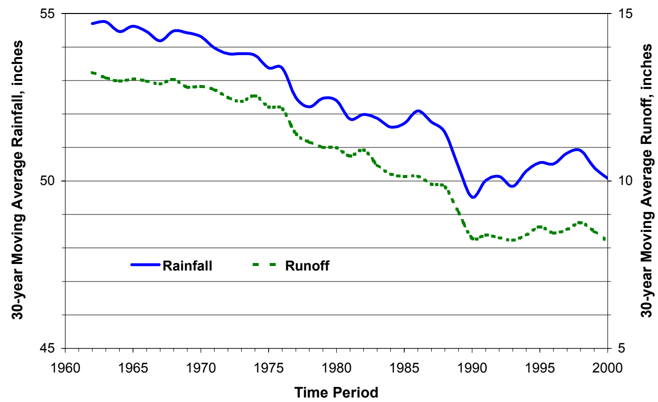

Figure 5. 30-year Moving Average Rainfall and Runoff in Peace River Basin.

It should also be noted that a comparison of a plot of the 5-year moving average rainfall in the Peace River basin, presented here as Figure 6, with the 5-year moving average discharge of the Peace River at Arcadia, presented in Figure 2, leads to the same conclusion as presented above, i.e., the decline in streamflow is primarily a result of the decline in rainfall.

The analysis of long-term rainfall and streamflow data presented above indicates that most, if not all, of the long-term decline in streamflow at the Arcadia gaging station can be explained by the long-term decline in rainfall.

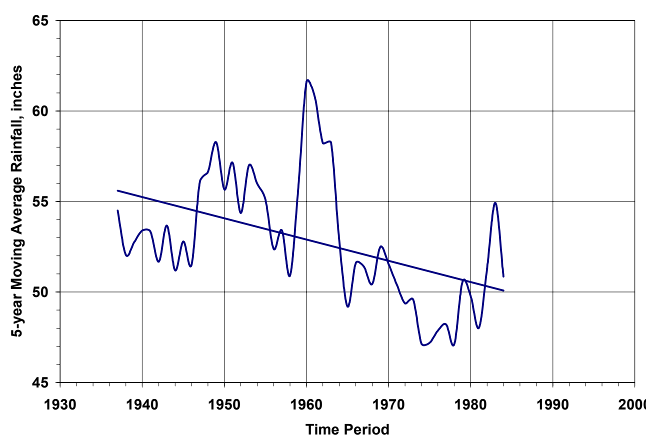

Figure 6. 5-year Moving Average Rainfall in Peace River Basin

Figure 7 compares the average rainfall and streamflow for the Peace River at Arcadia for the periods 1934 to 1963 and 1969 to 1998. The change in runoff between the two periods is greater than the change in rainfall between the two periods by approximately 0.5 inches per year, i.e., the reduction in streamflow at Arcadia resulting from changes in ET plus net deep recharge is approximately 50 cfs out of a total reduction in streamflow of 436 cfs[5].

[5] Note that the conversion from inches per year to cfs for the 1,367-mi^2 Peace River basin above Arcadia is 1 inch per year equals 100.7 cfs. For the 826-mi^2 Peace River basin above Zolfo Springs, the conversion is 1 inch per year equals 60.85 cfs and for the 390-mi^2 Peace River basin above Bartow, the conversion is 1 inch per year equals 28.7 cfs.

In terms of percentage of average annual streamflow, the reduction due to changes in ET plus net deep recharge is approximately 3.8 percent and the reduction due to the decrease in rainfall is approximately 29.4 percent. The average annual streamflow for the period 1934 through 1963 was 1,317cfs.
The change in ET plus net deep recharge between the two periods is a result of both anthropogenic and natural effects, i.e., ET and net deep recharge are affected by changes in both rainfall and land use. During drought periods, natural ET would decrease and natural net recharge would increase.

To determine if there has been a significant change in (ET + Net Deep Recharge + ΔS) within the Peace River basin during the past 60 years, a graph of cumulative difference between rainfall and runoff for the Arcadia gage, the Zolfo Springs gage and the Bartow gage was prepared. The results are presented in Figure 8. The slope of a line between any two points on the curves presented in Figure 8 is the average value of (ET + DR_n + ΔS) for the period between the two points. The average values of (ET + DR_n + ΔS) for the 1934-1963 period and for the 1969-1998 period for the basin areas above Bartow, Zolfo Springs and Arcadia are provided on the figure.

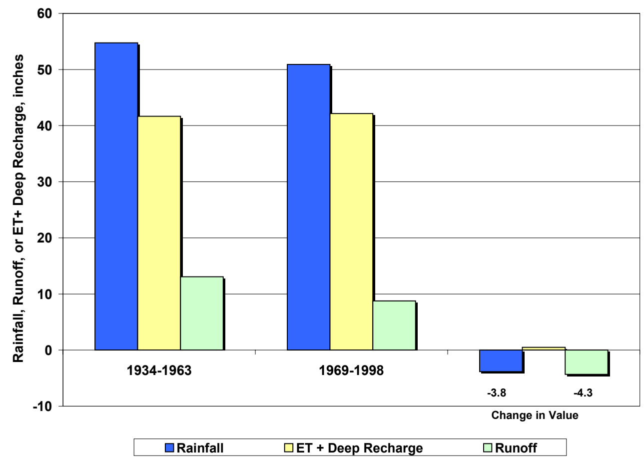

Figure 7. Water Budget for Peace River at Arcadia for Historic and Recent 30-year Periods.

The value of (ET + DR_n + ΔS) is greater for the upper part of the basin because of the higher leakance and higher natural and induced recharge to the intermediate and Floridan aquifers within this portion of the basin. Because 1933 and 1963 as well as 1968 and 1998 were relatively wet years[6], the natural change in storage between the beginning and end of both periods must be relatively small (less than 0.05 in/year). Consequently, the difference in the values of (ET + DR_n + ΔS) between the two periods is approximately equal to the change in average streamflow resulting from ET plus net deep recharge in the basin. The reductions in streamflow resulting from changes in ET plus deep recharge for each of the basin areas evaluated in Figure 8 are summarized in Table 2.

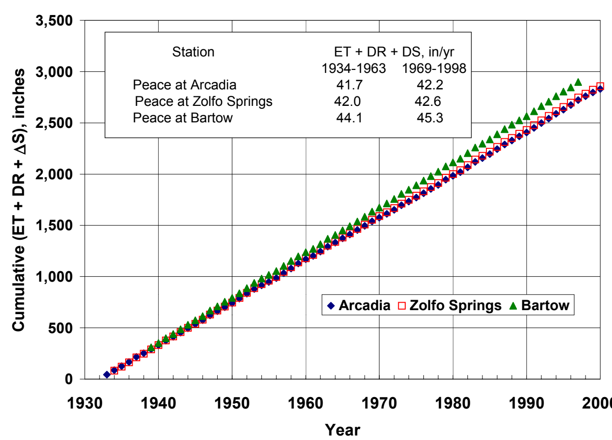

Figure 8. Accumulated difference between Rainfall and Streamflow for Peace River at Arcadia, Bartow, and Zolfo Springs.

[6] The annual rainfall for 1933 was 56.7 in/yr; it was 58.2 in/yr for 1963; 53.4 in/yr for 1968; and 55.7 in/yr for 1998.

Table 2
Reduction in Average Streamflow in
Peace River Basin between 1934-1963 and 1969-1998
due to Changes in ET plus Net Deep Recharge

Location of USGS Gaging Station	Reduction in Average Streamflow (cfs)
Bartow at SR 60	34.4
Zolfo Springs at US 17	35.3
Arcadia at SR 70	49.3

The relatively small reduction in streamflow between Bartow and Zolfo Springs is a result of the return of groundwater back to the Peace River through phosphate mine discharges, irrigation return flow, and domestic wastewater treatment plant discharges along this stretch of the River. The increased reduction in Peace River flow between Zolfo Springs and Arcadia is a result of the increased groundwater withdrawals, primarily for agriculture, that have occurred in this portion of the watershed during the past 30 years. There was no phosphate mining within this portion of the basin between 1969 and 1998.

Although it is not correct to infer that the 49 cfs reduction in streamflow above Arcadia between the two periods is solely the result of increased groundwater withdrawals (i.e., an anthropogenic change in net deep recharge), deep well pumping is certainly responsible for most of the decrease. It is known, for example, that the lowering of the potentiometric surface along the upper Peace River due to groundwater withdrawals has resulted in the cessation of the approximately 30-cfs discharge of Kissengen Springs. Other reductions or cessations in upward seepage along the Peace River basin can probably account for most of the remaining decreased flow.

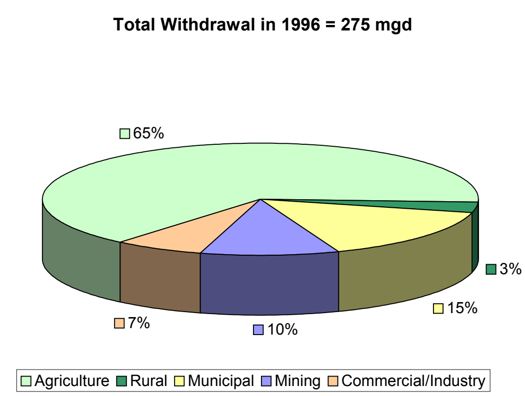

Figure 9. Groundwater Withdrawals in Peace River Basin

It is therefore important to determine the volume of all groundwater withdrawals in the Peace River basin and to allocate the withdrawals by use. The Southwest Florida Water Management District[7] has reported a combined withdrawal from the Floridan and intermediate aquifer systems in the Peace River basin of 274 million gallons per day (mgd). Figure 9 shows a breakdown of the withdrawals by various user groups during 1996. Withdrawals for phosphate mining and beneficiation within the Peace River basin during the past 8 years have averaged less than 25 mgd. During 1996, the average withdrawal was 28 mgd. Current withdrawals (2001) are less than 20 mgd.

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[7] SWFWMD (1999), *The Peace River Comprehensive Watershed Management Plan (Volume I),* July 20, 1999 Draft.

The decrease in the potentiometric surface at Kissengen Springs is a result of all groundwater withdrawals in the Peace River basin as well as groundwater withdrawals in neighboring basins within the Southern Ground Water Basin (SGWB). The boundary of the SGWB encompasses most of Polk and Highlands Counties, the southern half of Hillsborough County and all of Manatee, Hardee, DeSoto, Sarasota, and Charlotte Counties. To compare the impact of the combined withdrawal from all phosphate mines with the impact from other withdrawals within the SGWB, Ardaman & Associates, Inc., obtained a copy of the SWFWMD groundwater flow model[8] for the area and calculated the drawdown at Kissengen Springs from all of the wells within the SGWB and from all of the wells used for phosphate mining in the SGWB. The results are compared in Figure 10. As shown, phosphate mining is responsible for no more than 8.5 percent of the current drawdown of the potentiometric surface at Kissengen Springs. Groundwater withdrawals for phosphate mining actually make up only about 4 percent of the total groundwater withdrawals in the SGWB.

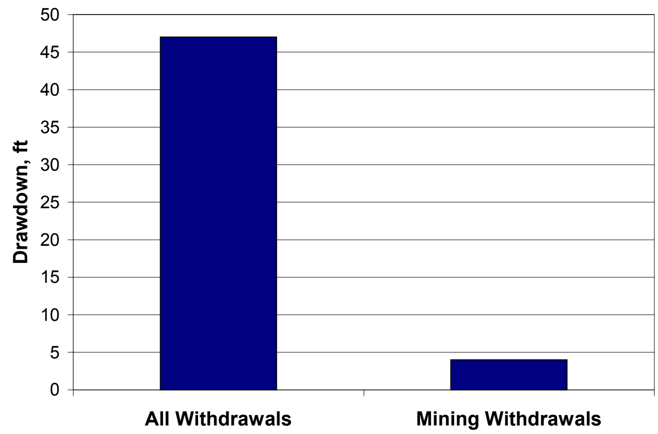

Figure 10. Decrease in Floridan Aquifer Potentiometric Surface at Kissengen Springs.

Does Mining Increase Recharge to the Intermediate and Floridan Aquifers?

The principal sources of this question are Lewelling and Wylie (1993)[9] and Lewelling et al (1998)[10] both of which state that mining and reclamation processes result in alterations in the natural drainage patterns that include: *"...increased recharge to the underlying aquifer system from rainwater that can infiltrate the disturbed overburden and recharge the intermediate aquifer system more readily because the thickness of the upper confining unit (phosphate matrix) has been reduced by mining"*.

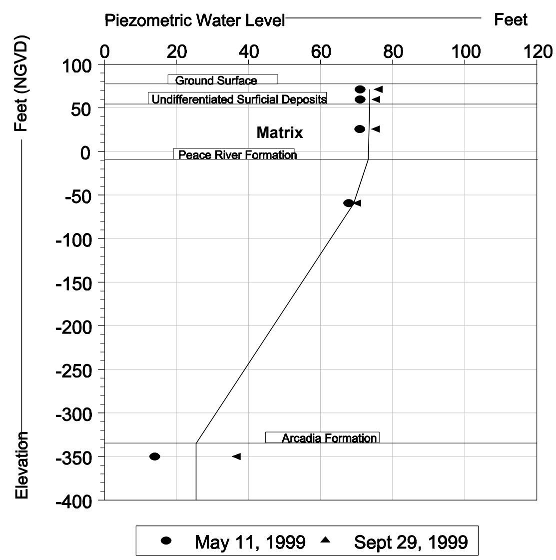

Figure 11. Piezometric Levels versus Depth for Typical Cluster Wells near Ona, Hardee County, Florida.

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8 Barcello, Mark and Ron Basso (1993), *Computer Model of Groundwater Flow in the Eastern Tampa Bay Water Use Caution Area: Southwest Florida Water Management District,* SWFWMD, May, 1993.

9 Lewelling, B.R. and R.W. Wylie (1993), *Hydrology and Water Quality of Unmined and Reclaimed Basins in Phosphate-Mining Areas, West-Central Florida.* U.S.G.S. WRI Report 93-4002.

10 Lewelling, B.R., A.B. Tihansky, and J.L. Kindinger (1998) *Assessment of the Hydraulic Connection Between Ground Water and the Peace River, West Central Florida,* U.S.G.S, WRI 97-4211.

Data collected by Ardaman & Associates and others for the phosphate industry over the past 20 years document that the phosphate matrix provides little, if any, confinement to the intermediate and Floridan aquifer systems and, hydrogeologically, is part of the surficial aquifer system. The confining layer separating the surficial aquifer from the primary producing zone of the intermediate aquifer system begins at the bottom of the phosphate matrix (at the top of the bedclay) and extends to the top of the Tampa limestone. It includes the entire thickness of the undifferentiated Arcadia formation, which varies in thickness from less than 25 feet at the northern boundary of the SGWB in Polk County to greater than 200 feet at the southern boundary in Charlotte County. The decrease in water level with depth across the confining layer for a typical set of clustered wells in Hardee County is illustrated on Figure 11.

A relatively constant piezometric water level with depth across the matrix is evidence that the matrix does not provide much, if any, of the confinement between the surficial aquifer and the Floridan aquifer. Figure 12 compares the difference in the piezometric level between the water table and the piezometric level near the base of the matrix to the total difference in piezometric water level between the water table and the potentiometric surface of the Floridan aquifer for 12 cluster well locations in the southern half of Polk County and the northern half of Hardee County. As shown, the difference in piezometric level across the matrix is essentially non existent at nine of the locations and very small compared to the total head difference between surficial and Floridan aquifers at the other three locations. Removal of the matrix would have essentially no effect on vertical recharge to the Floridan aquifer at nine of the locations and would have relatively little effect (less than 10 percent increase) at the other three locations.

Neither of the U.S.G.S. reports raising the issue at hand present data that suggest that the drop in water level across the phosphate matrix provides any significant confinement to the intermediate and Floridan aquifers. Because matrix layers provide relatively little, if any, confinement to the intermediate and Floridan aquifer systems, and because the groundwater level in the reclaimed surficial aquifer system returns to essentially the same level that existed prior to mining, removal of the matrix will not increase recharge to the deeper aquifer systems.

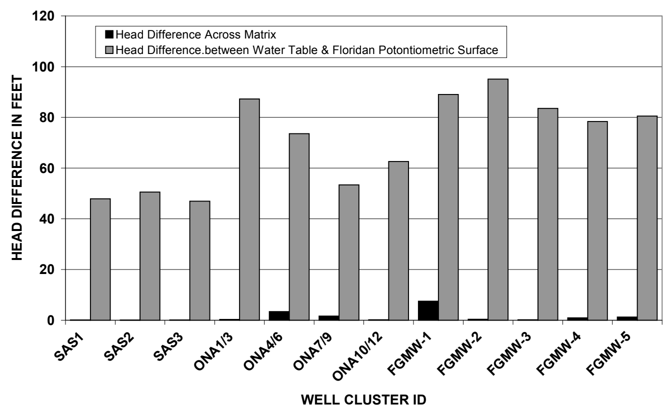

Figure 12. Comparison of Head Difference Across Matrix with Head Difference between Surficial and Floridan Aquifers.

Has Mining Significantly Reduced Baseflow to the Peace River?

The principal source of this question is Lewelling et al (1998) which includes the statement that phosphate mining and reclamation processes have *"...reduced or eliminated baseflow"*. The basis for this conclusion is the work reported in Lewelling and Wylie (1993). Lewelling and Wylie measured the runoff from three small unmined basins, two reclaimed clay settling areas, one reclaimed sand-clay mix area, one reclaimed overburden fill area, and one reclaimed sand tailings fill area. The areas varied in size from 90 to 460 acres. They measured no groundwater outflow to the shallow swales located on the surfaces of either the clay or sand-clay mix areas. This is not surprising considering the relatively low hydraulic conductivity of the clay and sand-clay mix and the fact that the measured groundwater levels within the clay and sand-clay mix areas were typically below the bottom of the swale.

Although reclaimed clay and sand-clay mix areas after completion of consolidation do not provide much groundwater outflow to the surface water system[11], this does not mean that mining and reclamation have reduced or eliminated baseflow to the Peace River or any other stream system. Provided the area of sand tailings fill between the clay areas and the surface water system is wide enough and high enough to capture sufficient rainfall, post-reclamation groundwater outflow can remain reasonably similar to pre-mining groundwater outflow.

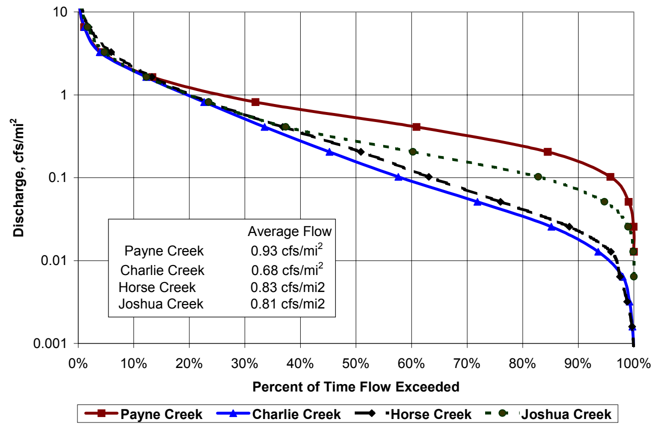

Figure 13. Comparison of Flow-Duration Curves for Mined and Unmined Creeks in the Peace River Basin.

In fact, measured streamflow data from the USGS gaging station on Payne Creek indicate that baseflow is greater in areas that have been and are being mined for phosphate than in similar unmined basins. Mining in the Payne Creek watershed has occurred since the 1930's. More than 70 percent of the land within the basin has been mined and much of it has been reclaimed. Yet, total runoff and, more importantly, baseflow in the Payne Creek basin is greater than total runoff and baseflow for similar unmined watersheds with nearly identical rainfall nearby. Figure 13 contains flow-duration curves with flow plotted as cfs/mi^2 for Payne, Charlie, Joshua and Horse Creeks for the period between January 1980 and October 1999. As can be seen, for at least 70 percent of the time, when streamflow is primarily baseflow, the streamflow is higher in the Payne Creek basin than in any of the unmined basins.

Has Mining Permanently Reduced the Replenishment of the Peace River?

The source of this question is also Lewelling and Wylie (1993) and Lewelling et al (1998) both of which conclude that there is *"... reduced surface runoff in mined and reclaimed areas where overland flow is impounded in pits and surface depressions"* and natural surface drainage is replaced *"...by a system of reclaimed ditches, swales, and modified topography".*

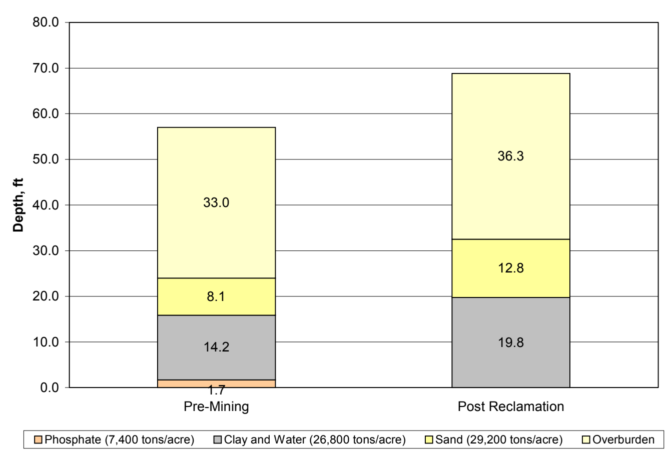

Figure 14. Comparison of Average Thickness of Soil Profile Before and After Mining.

Although mine pits and clay settling areas associated with active phosphate mining do capture and temporarily store surface water, phosphate mining does not create permanent voids in the land surface that capture surface water after reclamation. The void created by removal of phosphate rock from the property is more than offset by the swelling of the overburden, sand, and clay that occurs during the mining and

11 During the consolidation process, which may take 30 or more years, substantial groundwater outflow does occur from the clay and sand/clay mix areas. Water release rates for some of the deeper clay areas during the early period following reclamation may exceed several feet per year. Much of the water which is released is probably lost through evapotranspiration. However, some of the water becomes surface water and ground water outflow. The consolidation model indicates that approximately twenty percent of the consolidation water leaves through the bottom of the clay deposits.

beneficiation process. Figure 14 compares the average thicknesses of the various components of the soil profile affected by mining for the pre-mining and post-reclamation condition. Instead of creating a depression or void, phosphate mining actually results in an increase in the average thickness of the post-reclamation soil profile because the reclaimed deposits are not as dense as the natural deposits.

Both the shallow depressions left in the reclaimed landform to support wetlands and reclaimed lakes are purposely created as part of an approved reclamation plan. These wetlands and lakes fill naturally with water while they are still within the mine recirculation system. The only retention storage created within these reclaimed landforms after they are released from the mine recirculation system is a result of evapotranspiration and net groundwater outflow, the same processes that create retention storage in the pre-mining landform.

It is probable that mining and reclamation has increased evapotranspiration (ET) above that which existed on the same land prior to mining. Lakes, wetlands, and reclaimed clay settling areas all have higher ET than pine-flatwoods or sand scrub. However, the reduction in streamflow resulting from increased evapotranspiration has been more than offset by the increased runoff from residential and commercial development in the Peace river watershed.

Mining has occurred on approximately 150,000 acres within the 1,500,000-acre Peace River watershed. A reasonable estimate of the increased magnitude of ET from mined land is between 0.5 and 1 inch per year. Converting the increased ET to decreased streamflow results in a range of decreased streamflow between 8.5 and 17 cfs.

The impervious area in the Peace River Basin above Arcadia, estimated from the SWFWMD 1995 Land Use map and percent impervious values for different land uses based on Ardaman & Associates experience, is approximately 43,000 acres. The increase in runoff from impervious surfaces is approximately 30 inches per year. The increase in streamflow above Arcadia resulting from the total increase in impervious surfaces, then, is approximately 160 cfs. The net effect of anthropogenic changes in ET in the Peace River basin (considering both mining and urbanization) is an estimated increase in streamflow of approximately 145 cfs.

Has Mining Reduced Groundwater Supplies?

As stated above, withdrawals for phosphate mining during the last ten years account for less than 10 percent of the total groundwater withdrawal in the Peace River basin. These withdrawals compare with approximately 15 percent withdrawn for potable supply and approximately 65 percent withdrawn for agricultural irrigation.

Have Groundwater Withdrawals for Phosphate Mining Affected Flow in the Peace River?

The impact of groundwater withdrawals on the potentiometric surface and the cessation of the spring flow at Kissengen Springs was discussed above. Groundwater withdrawals also reduce streamflow by inducing additional deep recharge to the intermediate and Floridan aquifers. The SWFWMD groundwater flow model for the SGWB was used to estimate the increase in deep recharge from all groundwater withdrawals and from phosphate mining withdrawals only. The results for current withdrawals are summarized in the following table[12].

Table 3
Recharge Induced by Current Groundwater Withdrawals in Peace River Basin

Scenario	Induced Recharge, cfs	
	Peace River Basin above Arcadia	Peace River Basin above Charlotte Harbor
All Withdrawals	430	460
Mining Withdrawals	26	28

The decrease in streamflow in the Peace River basin resulting from groundwater withdrawals (increased net deep recharge) is the difference between total induced recharge and total groundwater returned to the river as surface water discharges or irrigation losses (total return flow). For current phosphate mining operations, most of the groundwater withdrawn is consumed, i.e., evaporated, transported with the product, or entrained in the sand and clay used to backfill the reclamation areas. A large percentage of the groundwater currently withdrawn for irrigation is also consumed, i.e., evaporated or transpired. Table 4 summarizes where water is consumed in the mining and reclamation process.

Table 4
Disposition of Water for Typical Phosphate Mine

Consumer	Water Consumed (gal/ton)
Evaporation	60
Clay Entrainment	450
Sand Entrainment	100
Overburden Refill	60
Product Moisture	30

The total water consumed during the mining and reclamation activities at a typical phosphate mine is typically less than 700 gal per ton of phosphate rock produced. This is a reasonable estimate based on average mine conditions for the first 20 years of mine life. The consumption varies with time and also with changes in the matrix density and clay content and average solids content in the clay settling areas. As shown in Figure 1, the amount of water supplied by groundwater withdrawals from the Floridan aquifer averages about 600 gal/ton for the phosphate mining industry. The remainder of the water, i.e., approximately 100 gal/ton is supplied by rainfall captured within

12 Withdrawals for phosphate mining account for only about 4 percent of the total groundwater withdrawal in the Southern Ground Water Basin, but because of the location of the withdrawal points, they are responsible for about 6 percent of the induced recharge in the Peace River basin.

the mine recirculation system. The decrease in runoff in the Peace River resulting from 100 gal/ton of surface water capture by existing mines is approximately 5 cfs.

Because of improved water management practices and significantly reduced groundwater withdrawals, only a small fraction of the water withdrawn from the Floridan aquifer by the phosphate mining industry during the past five years has been discharged to the Peace River. However, during most of the 30-year period between 1969 and 1998, much of the water withdrawn for phosphate mining and beneficiation in the Peace River basin was discharged to the River. For example, in 1980, the phosphate mining industry returned approximately 60 percent of its 95-mgd groundwater withdrawal to the River. During the same year, it is estimated that agriculture returned approximately 45 percent of its 116-mgd irrigation withdrawal, industrial/commercial users returned approximately 65 percent of their 50-mgd process water withdrawal, and municipal wastewater treatment plants and septic tank drain fields returned most, if not all, of the 40-mgd withdrawal for public and rural water supply back to the Peace River[13]. The cumulative effect of groundwater withdrawals on streamflow in 1980 would have been a decrease of approximately 120 mgd or 185 cfs.

The cumulative impact on streamflow from anthropogenic effects can be obtained by subtracting the increase in streamflow caused by the net decrease in ET in the basin (145 cfs) from the decrease in streamflow caused by groundwater withdrawals in the basin (185 cfs). The result is a predicted reduction in average streamflow of approximately 40 cfs.

A comparison of the average annual water budget in the Peace River basin for the 1934-1963 period and the 1969-1998 period is summarized in Table 5.

Table 5
Comparison of Average Annual Water Budgets
Peace River Basin above Arcadia

Parameter	Quantity, in/year	
	Period from 1934 to 1963	Period from 1969 to 1998
Rainfall	54.75	50.90
Evapotranspiration	38.8	37.8
Deep Recharge	3.37	6.3
Return Flow	0.5	1.95
Δ Storage	0.0	0.0
Streamflow	13.08	8.75

The values provided in Table 5 for rainfall and streamflow are measured quantities. The reduction in streamflow resulting from the measured decrease in rainfall is 3.75 in/year (388 cfs). The values for ET, deep recharge and return flow are estimated quantities based on the results of the preceding analyses and the measured reduction in streamflow caused by the change in ET plus net deep recharge of 0.48 in/year (48 cfs) . Clearly, the most significant change to the water budget is the increased net deep recharge within the basin. Although groundwater withdrawals for phosphate mining are expected to remain constant through 2020[14], continued growth in

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13 For many years, the City of Lakeland Wastewater Treatment Plant discharged treated effluent back to the Peace River. For the past ten or more years, the treated effluent has been discharged to a wetland treatment system located on a former clay settling area that discharges to the Alafia River. The permitted discharge is approximately 20 cfs.

14 SWFWMD (2000). Southwest Florida Water Management District *Regional Water Supply Plan* (Draft)

groundwater withdrawals for potable supply and irrigation, even with current conservation efforts, is expected to increase net deep recharge in the future. Increased impervious area associated with continued urbanization in the upper and lower Peace River basin will continue to lower ET. The future effect of increasing urbanization and net deep recharge on streamflow is unknown. However, as shown in Table 5, past experience indicates that streamflow will decrease as groundwater withdrawals and urbanization increase with time.

Has Mining Permanently Reduced the Replenishment of the Floridan Aquifer?

The probable source of this question is Lewelling and Wylie (1993) which includes the following statement concerning reclaimed clay and sand-clay mix areas: *"...The depth to the water table in the surficial aquifer in these three reclaimed basins generally was much greater than that in the unmined basins and in the reclaimed basins backfilled with overburden, and the recharge from the surficial aquifer to the underlying intermediate aquifer system was greatly reduced."* In the same report, the authors state *"...The phosphate matrix, which formed the upper confining unit of the intermediate aquifer system, and the overburden were removed during mining and were replaced by a thick layer of clay during reclamation. This clay restricts ground-water recharge and limits the hydraulic connection between the surficial and intermediate aquifer systems."*

Most reclaimed clay areas contain remnant overburden piles that cover most, if not all, of the base of the area, as described in Lewelling and Wylie (1993). Recharge to the intermediate and Floridan aquifer beneath clay settling areas will not, therefore, change significantly either during mining or after reclamation. Figure 15 is a cross section through a clay settling area. Note that the clay is separated from the top of the confining layer by a layer of cast overburden. The cast overburden typically varies from 20 to 30 feet thick and has a hydraulic conductivity in the range of $5x10^{-4}$ to $5x10^{-3}$ cm/sec (1.5 to 15 feet per day). During filling, the piezometric level in the overburden layer will be higher than the pre-mining water table in the surficial aquifer. At the end of filling, the percent solids (density) of the clay is such that the effective vertical hydraulic conductivity of the clay is greater than 4.8×10^{-6} cm/sec (60 inches/year). The hydraulic conductivity at the end of filling is plotted as a function of depth in Figure 16. Downward seepage into the overburden at the end of filling for the settling area shown in Figure 15 is in excess of 8.5 inches per year.

After filling, the clay will continue to consolidate yielding water to both the surface of the clay and to the underlying overburden layer. Figure 17 is a plot of the settlement of the clay surface as a function of time. Note that because the clay is saturated, one inch of water must be released to result in one inch of settlement. An examination of Figure 17 indicates that for at least 20 years after reclamation, continued consolidation of the clay will provide between one inch and 20 inches of water annually to the surface and ground water systems. The amount of consolidation water entering the overburden layer is more than enough to satisfy a downward recharge rate of 1 inch per year. Any excess consolidation water entering the overburden layer will flow laterally toward the perimeter of the area where it will provide a portion of the groundwater outflow to an adjacent riparian system.

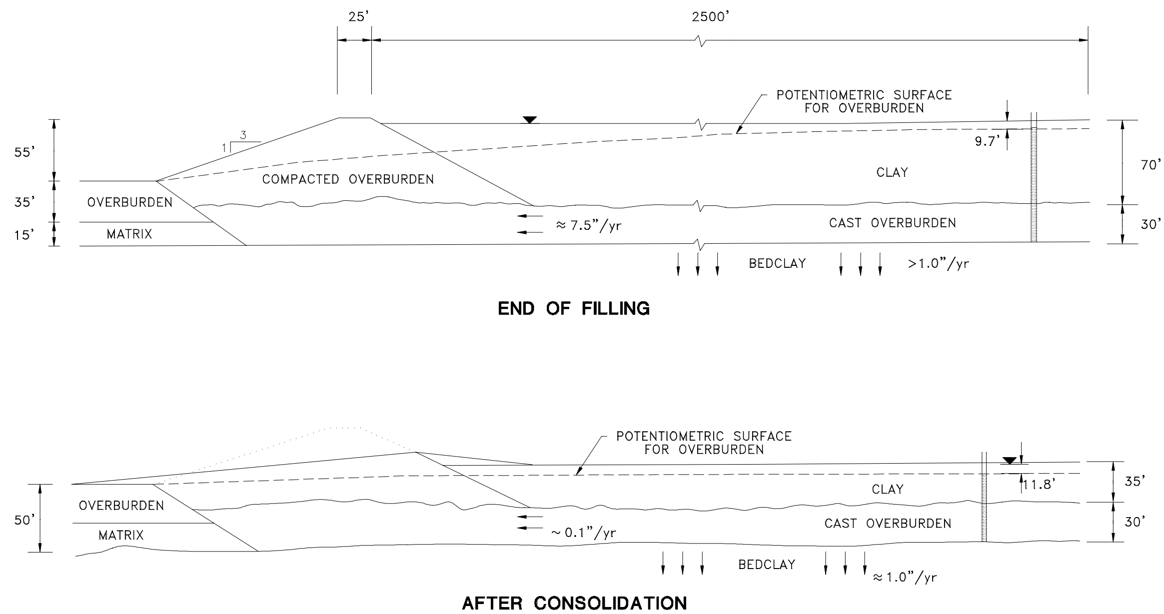

Figure 15. Cross Section through Clay Settling Area

The variation of vertical hydraulic conductivity of the clay with depth after consolidation is complete is also shown on Figure 16. The effective vertical hydraulic conductivity at the end of consolidation is 3.4 x 10^{-7} cm/sec (4.3 inches/year). For the conditions shown in Figure 15, the computed recharge through the consolidated clay into the overburden layer is about 1.4 inches per year. The computed lateral flow is approximately 0.2 inches per year and the downward flow to the deeper aquifer systems is greater than 1.0 inch per year.

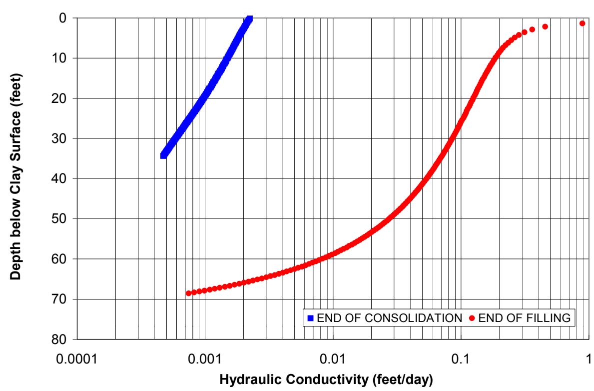

Figure 16. Hydraulic Conductivity versus Depth for Typical clay Settling Area.

Because the natural recharge to the Floridan aquifer in the phosphate mining areas is approximately 1 inch per year, the analysis presented above demonstrates that recharge to the intermediate and Floridan aquifers does not decrease beneath a clay settling area. This is consistent with the water level data obtained from piezometers installed in the reclaimed clay settling areas investigated by Lewelling and Wiley (1993)[15]. In all cases, the piezometric levels in the settling areas were greater than the pre-mining water table.

15 Lewelling, B. R. and Wylie, R. W. (1993). *Hydrology and Water Quality of Unmined and Reclaimed Basins in Phosphate-Mining Areas, West Central Florida*", U.S. Geological Survey, Water-Resources Investigations Report 93-4002

It should also be noted that a groundwater level lower than the reclaimed clay surface is not surprising if the clay surface is elevated above the surrounding ground surface as is usually the case.

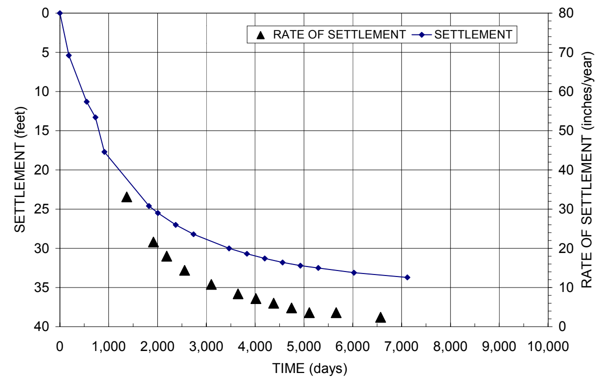

Figure 17.Settlement and Rate of Settlement vs Time for Typical Clay Settling Area.

What Effect Has Phosphate Mining Had on the Timing of Streamflow in the Peace River?

As discussed in previous sections of this report, phosphate mining captures surface water in its recirculation system during runoff events, induces recharge to the Floridan aquifer as a result of groundwater withdrawals, and increases evapotranspiration as a result of increased lake and wetland areas in the reclaimed landform. Prior to 1995, most of the surface water captured within the mine recirculation systems and much of the water withdrawn from Floridan aquifer wells was discharged to the Peace River. The effect of capturing surface water during runoff events and releasing it along with unconsumed groundwater during and after runoff events was illustrated in Figure 13. Peak flow was decreased relative to other streams in the Peace River basin and both total flow and baseflow increased. For downstream water users, this provides additional water during low flow periods and decreases flooding during high flow periods.

Figure 18 compares the flow duration curves for a hypothetical watershed before and after increased groundwater withdrawals have doubled the deep recharge. The natural recharge in the simulation was 2.8 inches per year. Return flow for both the baseline and increased withdrawal case was 40 percent of the groundwater withdrawal. As shown, the effect of increasing withdrawals is to slightly decrease streamflow during high flow periods because of increased storage and significantly increase streamflow during low flow periods as return flow is released to the system.

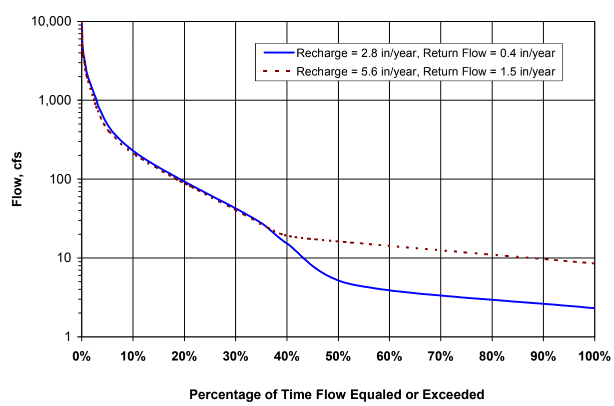

Figure 18. Effect of Increasing Deep Recharge on Flow- Duration Curve for Hypothetical Watershed.

It was demonstrated above that the effect of increased evapotranspiration resulting from increased lake and wetland areas in the reclaimed landform was more than offset by the effect of decreased evapotranspiration resulting from increased urbanization within the basin. The effect of increased urbanization in the basin on the timing of flow in the Peace River is illustrated on Figure 19, which compares the flow-duration curves for the same hypothetical watershed described above before and after adding 5 percent impervious area. As can be seen, adding impervious area to the watershed results in higher streamflow for all flow periods, but is particularly effective in increasing low flows.

The combined effect of doubling the deep recharge and increasing the impervious area within the simulated watershed by 5 percent is shown in Figure 20. For the conditions modeled, the effect of combining increased groundwater withdrawals with increased impervious areas significantly increases low flows and returns the high flows to near baseline conditions.

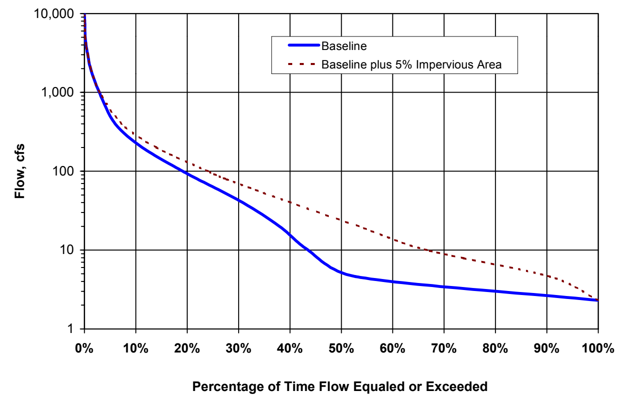

Figure 19. Effect of Adding 5 Percent Impervious Area on Flow-Duration Curve for Hypothetical Watershed.

Has Phosphate Mining Reduced the Safe Yield of the Peace River/Manasota Regional Water Supply Facility at Fort Ogden?

The average flow of the Peace River at Arcadia for the period between 1933 and 1999 is in excess of 1,000 cfs. The Peace River/Manasota Regional Water Supply Authority is permitted to withdraw an average of 50 cfs from the River. Pumping is limited to 10 percent of the measured flow at Arcadia when the flow is greater than 130 cfs. The small reduction in flow during high flow periods associated with phosphate mining does not affect the safe yield of the PRMRWSA's production facility at Fort Ogden. In fact, by releasing this water after peak events when only a small fraction of the flow can be withdrawn by the facility's intake structure, more water is made available to the Authority.

The safe yield of the facility can be impacted only if there is an increase in the number of days when streamflow is below 130 cfs. Mining and reclamation do not increase the number of low flow days. The available data (Figure 13) and the analyses presented above both indicate that mining and reclamation generally result in increased baseflow.

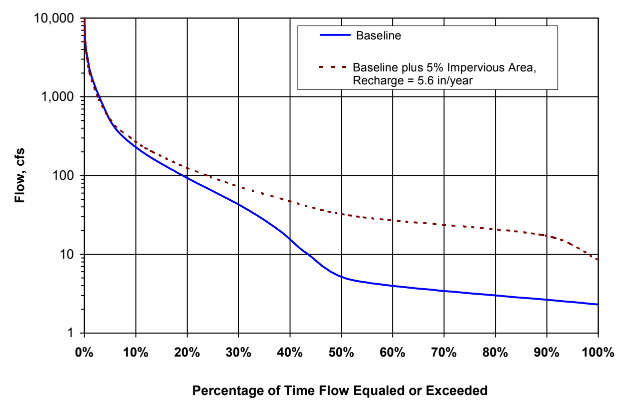

Figure 20. Effect of Adding 5 Percent Impervious Area and Doubling Deep Recharge on Duration Curve for Hypothetical watershed.

Conclusions

- Groundwater withdrawals by the phosphate mining industry account for approximately 10 percent of the total groundwater pumping in the Peace River basin. Withdrawals for agricultural pumping and municipal supply account for 65 percent and 15 percent, respectively. Industrial and commercial withdrawals account for approximately 7 percent of the withdrawals.

- Average annual streamflow measured at the US Geological Survey gauging station on the Peace River at Arcadia has decreased from 1,317 cfs for the 30-year period ending in 1963 to 881 cfs for the 30-year period ending in 1998. The decrease in average annual streamflow at Arcadia caused by the difference in average annual rainfall between the two 30-year periods ending in 1963 and 1998 is 387 cfs. The decrease in average annual streamflow at Arcadia resulting from the cumulative effect of all man-made activities in the basin and all natural changes in ET plus deep recharge for the same two periods is 49 cfs.

- The decrease in the potentiometric surface of the Floridan aquifer resulting from groundwater pumping in the Southern Groundwater Basin has resulted in a drawdown of more than 45 feet at the location of the former Kissengen Springs. Withdrawals by the phosphate mining industry account for not more than 8.5 percent of this drawdown.

- The decrease in the potentiometric surface of the Floridan aquifer resulting from groundwater pumping in the Southern Groundwater Basin has increased recharge to the Floridan aquifer within the Peace River basin by approximately 460 cfs. Withdrawals for phosphate mining account for approximately 6 percent of the increased recharge.

- The phosphate matrix provides little, if any, retardation to vertical flow between the surficial and Floridan aquifer systems. Clay and sand-clay mix disposal areas are permeable enough to support the approximately 1 inch per year of natural recharge to the intermediate and Floridan aquifers typical of the current mining area. The piezometric levels at the top of the intermediate aquifer system beneath reclaimed phosphate mines are essentially at the same level as existed prior to mining.

- Mining has not significantly reduced baseflow in the Peace River basin. The evidence suggests that baseflow in tributary basins to the Peace River is greater in basins where extensive mining has occurred than it is in similar basins where little or no mining has occurred.

- The increase in evapotranspiration in the Peace River basin resulting from the increased area of wetlands, lakes, and clay soils associated with phosphate mining and reclamation may have resulted in a decrease in streamflow in the range of 8.5 to 17 cfs. This reduction in streamflow from increased ET is more than offset by the increased runoff, estimated at 160 cfs, resulting from the paved and roofed areas associated with commercial and residential development in the basin.

- Phosphate mining does not reduce the safe yield of the Peace River Manasota Regional Water Supply Authority facility at Fort Ogden. By capturing water during peak storm events and releasing it later when more of the water can be withdrawn by the water production facility, phosphate mining increases the water available to the facility. The long-term average flow of the Peace River is in excess of 1,000 cfs. At their permitted capacity, the Authority will withdraw less than 5 percent of the average flow of the river.