Cumulative Risk of Decreasing Streamflows in the Peace River Basin

Prepared for

Charlotte County,
Lee County,
and the
Peace River/Manasota Regional Water Supply Authority

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by

GROUND-WATER CONSULTANTS SM

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1.0 INTRODUCTION

The lifeblood of Charlotte Harbor is freshwater, and one of the major sources of this freshwater inflow is the Peace River Basin. Over the past 40 years, the streamflow in the Peace River has decreased by one-third as compared to the prior 30 years. Both Mother Nature and man's activities factor into this observed decrease in streamflow. Between the 2 time periods, rainfall declined approximately 8 percent. During the latter 40-year period, land has been altered by agriculture, mining and urbanization, with each requiring more and more freshwater to be taken from the surface water and groundwater resources within the Peace River Basin.

1.1 STUDY OBJECTIVES

SDI Environmental Services, Inc., (SDI), as part of its services to Charlotte County, was asked to assess the potential magnitude and timing of the likely causes of streamflow reductions using the best available hydrologic data and mining information. In addition, SDI was asked to define and assess potential future decreases to streamflow that might be expected to result from increased mining and other anthropogenic activities.

2.0 TECHNICAL APPROACH AND EVALUATIONS

The following sections present the technical approach developed by SDI, including the major assumptions necessary to complete the analyses, and the results and conclusions developed from the technical evaluations.

2.1 THE EFFECT OF RAINFALL DECREASES ON STREAMFLOW

The decreases in rainfall and streamflow have been documented in a number of studies with some investigators attributing the decrease in rainfall to a climatic change. Over the Peace River Basin, this change was characterized by fewer large events, e.g., hurricanes, and lower average annual rainfall. Graphs of rainfall and streamflow at the Peace River near Arcadia gaging station versus time for a number of stations within and near the Peace River Basin indicate that the observed decline in rainfall, and usually a concurrent decrease in streamflow, for many of these stations began in 1963.

In order to determine what proportion of the observed streamflow decreases could be attributed to the observed decreases in rainfall after 1962, SDI developed a monthly rainfall/streamflow relationship regression model based on hydrologic conditions occurring prior to 1963. Once that relationship had been defined, the regression model was used to predict streamflows in the post-1962 time period that would be indicative of streamflow had no further ‘development’ occurred in the Peace River Basin after 1962. Any difference between measured and simulated streamflows was then assumed to be due to anthropogenic factors.

Three rainfall stations with long period of records were selected to represent average rainfall in the Peace River watershed. The stations were Bartow in the northern portion of the basin, Wauchula in the central portion of the basin, and Arcadia in the southern portion of the basin. The common period of records (1933 to present) were examined for missing data and any missing rainfall data were extrapolated from nearby stations. The average of the rainfall records for the three stations was then used to represent the average rainfall for the Peace River watershed above Arcadia. The average rainfall for the two periods is given in Table 1.

Table 1. Summary of Observed Hydrologic Changes in the Peace River Watershed above Arcadia

Period of Interest	Average Annual Rainfall (inches)	Average Annual Streamflow (inches)	Average Annual Streamflow (cfs)	Average Annual Streamflow (mgd)
1933 – 1962	55.48	13.25	1,334	862
1963 – 2002	51.02	8.78	884	571
Difference	4.46	4.47	450	291

Streamflow from the Peace River Basin was available for the period of interest. The records of the U.S. Geological Survey (USGS) stream gaging station on the Peace River near Arcadia indicated the average streamflow from the 1,367-square mile watershed declined approximately one-third from the 40-year period after 1962 as compared to the prior 30 years. To determine how much effect the decline in rainfall after 1962 had on streamflow, a rainfall/streamflow relationship was developed for the 1933-1962 period.

Graphs of monthly rainfall versus monthly streamflow were assessed for each month of the year separately. Visual examination identified two distinct groups, or relationships, of data points, which correlated to data representing the "typical" wet season months as opposed to the "typical" dry season months. The rainfall/streamflow data points seemed to be related to antecedent conditions. The "wet" antecedent condition was assumed when the sum of the two previous months' rainfall was greater than the 1933-1962 average of those two months. The "dry" antecedent condition was assumed when the sum of the two previous months' rainfall was less than the 1933-1962 average of those two months. The plots were visually examined and obvious outliers were moved to the other group prior to determining the exponential regression equations that are used to represent "wet" antecedent conditions and "dry" antecedent conditions for each month of the year.

An example of these plots is shown in Figure 1. To check the accuracy of the relationships in the regression model, the simulated streamflow for the 1933-1962 period was plotted against the observed streamflow as is shown in Figure 2. It was concluded that the rainfall/streamflow relationship accurately represents average hydrologic conditions in the Peace River watershed above Arcadia for the 1933-1962 period.

The observed average monthly rainfall over the Peace River watershed was input to the regression model to predict the quantity of monthly streamflow in the Peace River for the 1963-2002 period, absent any additional increases in the anthropogenic impacts. The simulated streamflow averaged 10.8 inches per year (in/yr) for the Peace River watershed above Arcadia for the 1963-2002 period, which is approximately 2.5 in/yr less than the 1933-1962 average annual rainfall. The difference between the simulated and observed streamflow for that period is approximately 2 in/yr, which represents the average annual total impacts to streamflow due to increased anthropogenic activities in the watershed. Figure 3 graphically shows the simulated versus observed streamflow for the entire 1933-2002 period. For the 1963-2002 period, the decreased rainfall accounts for 55 percent of the total observed decrease in streamflow.

2.2 HISTORY OF PHOSPHATE MINING

Phosphate in central and southern Florida, with much of the area being in the Peace River Basin, has occurred from the late 1800's to the present, with most of the growth in mining beginning in the early 1960's. Mining has generally progressed from the northern portions of the basin to the southern portions as areas have been mined out and improvements in equipment have allowed economic extraction of deeper ores.

To determine the acreages of the phosphate mined areas with time, several sources were used: Bureau of Mine Reclamation (BMR) data as digitized by Janicki Environmental, Inc.; 1970 and 1980 aerial photographs of Polk and Hillsborough Counties; 1987 USGS quadrangle maps (based on 1984 aerial photographs); and 1999 FDEP DOQQs. Figure 4 shows the distribution of phosphate mining estimated in 1930 by the BMR. Figures 5 and 6 show the distribution of phosphate mining in 1965 and 2003, respectively.

Figures 7 and 8 show the estimated annual growth rate of phosphate mining in the Peace River Basin since 1930 for the Peace River watershed and the Horse Creek watershed above the USGS streamflow gaging stations near Arcadia. BMR prepared maps for every decade beginning in 1930, and for every five years beginning in 1965. The estimated acreages of mined areas since 1975 agree favorably with other investigations.

2.3 PHOSPHATE MINED AREA IMPACTS

To test the hypothesis that phosphate mined areas reduce streamflows, available USGS streamflow data were reviewed for watersheds with and without mined areas, or watersheds that experienced large increases in mined areas while streamflows were gaged. Field observations and a review of streamflow data identified one watershed that appeared to be impacted primarily by mining and had measured streamflow data. This watershed is the South Prong of the Alafia River near Lithia (South Prong), which is heavily mined, but appears to have minimal other anthropogenic impacts within the watershed. Its streamflow period of record is from 1963 to present.

Comparable nearby watersheds were identified and are shown in Figure 9. None of the watersheds is believed to be impacted significantly by phosphate mining and other development prior to the 1990s. These comparable watersheds are Little Manatee River near Ft. Lonesome (gaged since 1963), Little Manatee River near Wimauma (gaged since 1939), Manatee River near Myakka Head (gaged since 1966), and the Horse Creek at Arcadia (gaged since 1950). Mining did begin to occur in some of these watersheds in the 1990's, but mined areas were believed to have undetectable streamflow impacts during the period of interest for this analysis.

Double-mass curve analyses were plotted to identify and evaluate potential streamflow changes both spatially and temporally for the selected watersheds to determine whether or not possible phosphate mining impacts were discernable. Excluding the South Prong watershed, the various combinations of double-mass curve analyses indicated no spatial or temporal anthropogenic changes in streamflow occurred at the four southern watersheds shown in Figure 9.

Double-mass curve analyses were then plotted to compare the unimpacted watersheds to the South Prong watershed. For each of the comparisons against streamflow in the South Prong watershed, two periods with distinctly different average streamflows were identified. For the South Prong watershed, the first period, 1963 to 1977, had an average streamflow of 14.8 inches and the second period, 1978 to 2000, had an average streamflow of 11.8 inches.

Review of aerial photographs indicated that the BMR mapping failed to identify much of the phosphate mined areas outside of the Peace River Basin. Using the same sources for historical phosphate mined areas as identified in Section 2.2, the distribution of mined areas for the South Prong watershed was estimated. In addition, historical USGS quad maps were reviewed in order to develop a 'pre-development' hydrography map of the South Prong watershed. Figure 10 shows a reconstruction of the major stream channel, tributaries, and wetlands in the watershed prior to mining. The upper third of the watershed is dominated by a large wetland system. By contrast, Figure 11 shows that the extent of the phosphate mined areas covered nearly 80 percent of the original watershed area by 2000. One should also note that the current watershed boundary is significantly different than the pre-development boundary. Today, the South Prong watershed is approximately 9 percent larger than its pre-development size. After updating the mining history maps, the estimated annual growth of phosphate mining was determined and is shown in Figure 12. The observed streamflow and average phosphate mined areas are shown in Table 2 for each of the two time periods of interest.

Table 2. Area and Streamflow Characteristics for the South Prong Watershed for Periods of Interest

Periods of Interest	Average Mined Area (acres)	Percent of Watershed Mined (%)	Average Observed Streamflow (in/yr)
1963 - 1977 (Period A)	23,000	32	14.8
1978 - 2000 (Period B)	46,000	64	11.8

Between the two periods of interest, the average mined area doubled from 32% to 64% of the entire South Prong watershed and the average observed streamflow decreased by 3 in/yr. The average mined area in Period A is equal to the increase from Period A to B; thus, the streamflow in Period A is assumed to be impacted 3 in/yr from the natural (non-impacted) streamflow. The unimpacted natural streamflow from the South Prong watershed is estimated to be 17.8 in/yr for the period of 1963 to 2000.

Using data from the two different periods for the South Prong watershed, a mathematical relationship between the fraction of mined areas and streamflow can be determined. For the South Prong watershed, the unimpacted natural unit rate of streamflow is estimated to be 17.8 in/yr and is denoted by the term R_N. The 3 in/yr impact on 32% of the entire watershed is equivalent to a 9.4 in/yr impact on the mined area (3.0/0.32). If the watershed was 100% mined, then the unit rate of streamflow from mined areas (R_D) is equal to 8.4 in/yr (17.8 - 9.4 = 8.4), which is 47 percent of R_N. Therefore, for the South Prong watershed, $R_N = 2.13\ R_D$. This relationship is assumed to be independent of the watershed and can be extrapolated regionally, assuming other anthropogenic impacts are negligible.

For any watershed, the fraction disturbed by mining (f_D) and the fraction undisturbed by mining (f_N) can be determined, leaving the general equation for the observed unit rate of streamflow (R_{OBS}) with two unknowns, R_D and R_N. However, for the South Prong watershed, both are known. Thus, the R_{OBS} equation can be re-arranged to solve for R_D.

$$R_{OBS} = f_N R_N + f_D R_D \qquad \text{(general equation)}$$

$$R_{OBS} = (1 - f_D)\ 2.13\ R_D + f_D R_D$$

$$R_{OBS} = 2.13\ R_D - 2.13\ f_D R_D + f_D R_D$$

$$R_{OBS} = R_D\,(2.13 - 2.13\ f_D + f_D) = R_D\,(2.13 - 1.13\ f_D)$$

Solving for R_D yields

$$R_D = R_{OBS} / (2.13 - 1.13\ f_D)$$

Using the R_{OBS} equation, R_N can be solved for and the impact due to mined areas estimated.

$$R_N = (R_{OBS} - f_D R_D) / f_N = (R_{OBS} - f_D R_D) / (1 - f_D)$$

$$R_N = R_{OBS} - f_D\,(R_{OBS} / (2.13 - 1.13\ f_D)) / (1 - f_D)$$

Because both R_{OBS} and f_D can be measured, the impact due to the mined area is equal to $R_N – R_{OBS}$. Therefore, the impact equation is:

$$\text{Impact} = 2.13\ (R_{OBS} / (2.13 – 1.13\ f_D)) - R_{OBS}$$

A check of this impact relationship was done by applying the impact equation to observed streamflow data for the South Prong watershed to obtain streamflows adjusted for mined area impacts. For the 1963-1977 period, the adjusted average annual streamflow was calculated to be 17.3 in/yr. For the 1978-2000 period, the adjusted average annual streamflow was 17.5 in/yr. Both of the adjusted average annual estimates agree favorably with the estimated R_N of 17.8 in/yr, indicating that the methodology can simulate adjusted impacts to streamflow as a function of mined area fractions with a watershed with gaged streamflows.

The impact relationship was further examined to determine whether streamflow impacts are different for reclaimed areas as compared to active (captured) mining areas; i.e., does the impact relationship change with the ratio of lands captured by mining to lands reclaimed. The first identified BMR mapping of reclaimed areas was 1975 when they indicated that 3,500 acres had been reclaimed in the South Prong. It is assumed that reclaimed areas report streamflow to the USGS gaging station. That acreage increased to 20,000 acres in 2000. Therefore, Period A has an average reclaimed area of less than 1% as compared to Period B, which has an average reclaimed area of 29% of the watershed. The observed streamflow impacts per unit mined area are of the same magnitude before and after 1978 in the South Prong watershed, regardless of the percentage of the watershed reclaimed. The conclusion is that the impacts from reclaimed areas must be similar to those from active mining areas.

2.4 CUMULATIVE REGIONAL STREAMFLOW IMPACTS

To extrapolate the impact relationship regionally, adjusted annual mined areas for major gaged watersheds in the Peace River Basin were developed as described in Section 2.2. As noted in Section 2.1, there has been a decline in average streamflow for the Peace River above Arcadia of 4.46 in/yr from the 1933-1962 period to the 1963-2002 period. However, the decline in rainfall only accounts for 55% of the total decline in streamflow between the two periods of interest. There are several possible anthropogenic causes for the remaining 45% in streamflow reduction. These include, but are not limited to, increases in mining; the increased effect of groundwater pumping for agriculture, industrial, municipal and mining on streamflow; and potential declines in groundwater discharges to streams due to changes in practices. Over the past decade or two, improved efficiencies in agriculture, industry, and mining have likely reduced impacts on streamflow. Municipal wastewater discharges are now being redirected to minimize new freshwater demands rather than being discharged to streams.

To estimate the effects of phosphate mined areas on the Peace River and Horse Creek streamflows, the mined area impact methodology was extended to these watersheds. It is assumed the methodology developed to estimate streamflow impacts from mined areas in the South Prong of the Alafia River watershed can be extended to any watershed where streamflows were gaged, and where the mining development history in the watershed can be quantified as a percentage of the total watershed area. The methodology also assumes that anthropogenic impacts other than mined area impacts are negligible. If this assumption is not true and the observed flows are known or believed to be decreased by other anthropogenic impacts, then the estimated mined area streamflow impacts will be underestimated. However, if, as is the case for the Peace River above Arcadia watershed, the ‘natural’ streamflow can be estimated or simulated, then the method can also be used to quantify the other anthropogenic impacts in addition to mined area streamflow impacts.

The methodology employed was to use the daily streamflow record from after the climatic break; i.e., from 01/01/1963 to 12/31/2002, as the base period. The mined areas for the Peace River and Horse Creek watersheds above Arcadia were then obtained, which allowed estimation of mined areas for the following years: 1930, 1940, 1950, 1960, 1965, 1970, 1975, 1980, 1984, 1985, 1990, 1995, 1999, and 2000. Linear growth was assumed between these years to estimate the mined areas for the intervening years. The average annual mined area was divided by the watershed areas to determine the average annual fraction disturbed (f_D) for the watersheds, which is provided in Table 3.

In order to apply the impact equation methodology (see Section 2.3) directly, one must assume that the observed daily mean streamflow (R_{OBS}) for the period 1963-2002 does not include other anthropogenic impacts. For the Horse Creek watershed, this assumption is considered acceptable, and the estimated streamflow impacts due to mined areas is 2 cfs.

Table 3. 1963-2002 Average Mined Areas and Fraction Disturbed

RIVER BASIN	AVERAGE MINED AREA (ACRES)	AVERAGE FRACTION DISTURBED (F_D)
Peace River at Arcadia	118,200	0.135
Horse Creek at Arcadia	2,100	0.015

However, in the Peace River watershed, it is believed that anthropogenic impacts other than those due to mined areas are not negligible and must be considered. Because the regression model developed in Section 2.1 estimates the 'natural' streamflow in the 1963-2002 period, the impact equation methodology can be employed using a successive approximation approach to separate the total anthropogenic impacts into mined area impacts and other anthropogenic impacts. The average observed components of streamflow impacts for the Peace River watershed are given in Table 4.

Table 4. Components of Streamflow Impacts, Peace River at Arcadia Watershed

Parameter	Streamflow Impact (cfs)	Streamflow Impact (inches)	Percent of Total Impact (%)
Rainfall	249	2.47	55.3
Mined Area	78	0.78	17.5
Other Anthropogenic	123	1.22	27.2
Totals	450	4.47	100.0

2.5 FUTURE SCENARIOS

Quantifying the existing streamflow impacts provides a basis for estimating potential impacts to downstream users. Several phosphate companies have plans to further expand mining operations in the Peace River Basin and other waters had contributing flow to Charlotte Harbor. It is of interest to predict potential future mined area impacts as well as other anthropogenic impacts. Three future scenarios were selected for analysis: Existing Future, Identified Future, and Worst-Case Future.

- The Existing Future Scenario - assumes the existing, permitted mines will have mined out their permitted areas with no additional areas being permitted and mined.

- Identified Future Scenario - assumes the existing, permitted mines will have mined out their permitted areas, plus identified, but unpermitted, mines will obtain permits and will also have mined out their permitted areas.

- Worst-Case Scenario - assumes that the Identified Future Scenario and all remaining minable areas within selected watersheds contributing streamflow to Charlotte Harbor will have been mined out.

For the mined area impacts, the impact equation was used to determine the estimated impact for each scenario for both the Peace River and Horse Creek watersheds above Arcadia. For the other anthropogenic impacts, it was assumed that the observed historical impacts would increase at the same percentage rate as mined area impacts for each of the future scenarios for the Peace River at Arcadia. For Horse Creek at Arcadia, it was assumed that other anthropogenic impacts have historically been negligible. The Horse Creek watershed is not urbanized and agricultural uses are assumed to remain constant. It is, therefore, believed that any future changes in the other anthropogenic impacts will be minimal relative to the potential impacts in the watershed due to phosphate mining.

2.5.1 Description of Future Scenarios

The Existing Future scenario assumes that no new mines will be permitted and existing mines will have finished existing permitted areas. By the end of the buildout for existing permitted mines, the total estimated mined areas in the Peace River and Horse Creek watersheds above Arcadia would be approximately 203,100 acres and 19,200 acres, respectively.

There are a number of proposed phosphate mines that either have pending permit applications or have applications anticipated within a few years. These identified proposed mines include the following: Ona, Pine Level, Pioneer, Altman, Horse Creek Mine, Keys, South Fort Meade Extension and South Pasture Extension. For each of the proposed mines, it was assumed that 67% of the area within the mine boundary would be mined. At buildout for the Identified Future scenario, the total estimated mined areas in the Peace River and Horse Creek watershed above Arcadia would be approximately 232,100 acres and 62,100 acres, respectively.

To provide some estimate as to the total area that might be could under a "worst-case" scenario, 67% of the lands inside the area defined by the BMR as 'minable,' but not occupied by present-day urban areas, and included in USGS gaged watershed, was included. For the Worst-Case Scenario, the total estimated mined areas in the Peace River and Horse Creeks watersheds above Arcadia would be approximately 272,500 acres and 92,400 acres, respectively.

Table 5 summarizes the assumed acreages of phosphate mined areas for each scenario as compared to the average mined area for the 1963-2002 period. The 1963-2002 average area serves as the base for determining percentage growth rates that is used to increase the other anthropogenic impacts in the Peace River watershed above Arcadia.

Table 5. Mined Areas for Different Scenarios, Peace River and Horse Creek Watersheds

	Peace River		Horse Creek	
Scenario	Average Mined Area (ac)	Increase from Base (%)	Average Mined Area (ac)	Increase from Base (%)
1963 - 2002 (Base)	118,200	N/A	2,100	N/A
Existing Future	203,100	72	19,200	810
Identified Future	232,100	96	62,100	2,900
Worst-Case Future	272,500	131	92,400	4,300

2.5.2 Estimation of Future Streamflow Impacts

Once the area of potential phosphate mining has been defined, it is possible to estimate future streamflow impacts using the methodology and the assumptions discussed in previous sections. From the potential mined areas, the fraction of the watershed disturbed (f_D) can be determined. Because streamflow impacts from other anthropogenic activities (other than phosphate mined areas) have been estimated, the long-term observed streamflow record for Peace River at Arcadia can be adjusted to include all other anthropogenic impacts except for mined area impacts. This allows application of the impact equation methodology. Recall that the long-term observed Horse Creek streamflows do not need adjusted because other anthropogenic impacts are assumed to be negligible.

The streamflow adjustments were made for the 1963-2002 period of observed flows in the Peace River at Arcadia. The years of the adjusted daily streamflow data set were relabeled as years 1 to 40 for use in future scenarios. This assumes that the average rainfall for some 40-year period in the future is the same as the 1963-2002 average. There was no attempt made to estimate the growth rate of mining in each scenario. The total mined area at buildout was used to determine the disturbed fraction of the watershed, and that fraction was held constant through the entire 40-year period. The impact equation was then applied to estimate the average simulated streamflow impacts due to mined areas for each scenario.

Table 6 summarizes the total estimated simulated streamflow impacts due to mined areas and other anthropogenic activities for each of the 3 scenarios in the Peace River and Horse Creek watersheds above Arcadia. Relative to the average 1963-2002 mined area impact estimate (78 cfs), the impacts on the Peace River at Arcadia due to increased mined areas are simulated to increase to 133 cfs, 153 cfs, and 179 cfs for the Existing Future, Identified Future, and Worst-Case Future scenarios, respectively. Other anthropogenic impacts on the Peace River at Arcadia are simulated to increase from 123 cfs to 215 cfs, 241 cfs, and 283 cfs for the 3 scenarios, respectively. The long-term average simulated streamflow in the Peace River at Arcadia would decrease from an average of 884 cfs in the base period to 737 cfs, 691 cfs, and 623 cfs for each of the 3 scenarios, respectively. The percent reductions in simulated streamflows from the observed average base period stream flows are 17%, 22%, and 30% for Existing Future, Identified Future, and Worse-Case Future scenarios, respectively.

Table 6 also presents the simulated results for the Horse Creek watershed above Arcadia. Other anthropogenic impacts in this watershed were assumed to be negligible. Mined area impacts are 14 cfs, 54 cfs, and 96 cfs for the Existing Future, Identified Future, and Worse-Case Future scenarios, respectively. The long-term average simulated streamflow in the Horse Creek at Arcadia would decrease from an average of 174 cfs in the base period to 162 cfs, 122 cfs, and 80 cfs for each of the 3 scenarios, respectively. The percent reductions in simulated streamflows are 8%, 31%, and 55% for Existing Future, Identified Future, and Worse-Case Future scenarios, respectively. Figure 13 graphically presents the results in Table 6 for both the Peace River and Horse Creek watersheds above Arcadia.

Table 6. Potential Simulated Impacts to Streamflow

RIVER BASIN	SCENARIO	AVERAGE OBSERVED STREAMFLOW PLUS ESTIMATED MINED AREA & OTHER ANTHROPOGENIC IMPACTS (CFS)	MINED AREA IMPACT (CFS)	OTHER ANTHROPOGENIC IMPACT (CFS)	OBSERVED [OBS] OR SIMULATED [SIM] STREAMFLOW (CFS)	REDUCTION IN STREAMFLOW FROM BASE PERIOD (%)
Peace River At Arcadia	Base Period 1963-2002	1,085	78	123	884 [obs]	-
	Existing Future	1,085	133	215	737 [sim]	17
	Identified Future	1,085	153	241	691 [sim]	22
	Worst-Case Future	1,085	179	283	623 [sim]	30
Horse Creek At Arcadia	Base Period 1963-2002	176	2	0	174 [obs]	-
	Existing Future	176	14	0	162 [sim]	8
	Identified Future	176	54	0	122 [sim]	31
	Worst-Case Future	176	96	0	80 [sim]	55

3.0 SUMMARY AND CONCLUSIONS

Charlotte County is concerned about further reductions of flow into Charlotte Harbor. Both Mother Nature and man's activities have combined to lower post-1962 average Peace River streamflows at Arcadia by one-third. The objectives of this study were to:

1. determine what proportion of the flow reductions in the Peace River Basin were due to reduced rainfall versus anthropogenic activities;
2. identify the historical expansion of phosphate mining activities in the Peace River Basin;
3. develop a methodology to allow quantification of streamflow impacts due to mining;
4. estimate the regional streamflow impacts due to mining; and
5. assess the future streamflow impacts with increased phosphate mine development and other increased anthropogenic activities.

Common periods of rainfall and streamflow records generally exist for the Peace River beginning in 1933. Numerous investigators have identified 2 periods of rainfall with distinctly different rainfall averages: a 30-year period beginning in 1933 and a 40-year period beginning in 1963. The average rainfall in the latter period is 8 percent less than the 1933-1962 period. A monthly rainfall/streamflow relationship was developed for the early 30-year period (for the Peace River at Arcadia streamflow gaging station) when major anthropogenic impacts to streamflow were believed to be minimal. Using monthly rainfall data, the relationship predicted that 55% of the decline in the 1963-2002 average Peace River streamflow could be attributed to the reduction in rainfall. The remaining 45% streamflow reduction is the result of anthropogenic activities above the gaging station.

The Bureau of Mine Reclamation developed maps showing the historical distribution of phosphate mining in the Peace River Basin. Using that information plus additional aerial photographs and USGS quad sheets, annual estimates of mined areas were developed for the Peace River and Horse Creek watersheds beginning in 1930. Annual estimates of mined areas were also estimated for the South Prong of the Alafia River watershed, which was used in the development of methodology to estimate streamflow impacts when a portion of a watershed has been disturbed by mining.

Extensive phosphate mining has occurred in the South Prong watershed, with nearly 80% of the area being mined. A hydrologic analysis of USGS gaged streamflow records for the South Prong and selected nearby watersheds indicated that significant streamflow impacts had occurred in the South Prong watershed. Assuming that mining was the only major anthropogenic activity in the watershed, a mathematical relationship was defined using the fraction of the watershed mined and the observed streamflow from the watershed to estimate the magnitude of streamflow impacts. Because the relationship is based upon the ratio of streamflow between natural areas and mined areas, the impact equation can be extrapolated regionally to other watersheds satisfying the constraints of the methodology.

The impact equation was applied directly to the Horse Creek watershed where other anthropogenic impacts were assumed to be negligible. Because phosphate mining only began in the Horse Creek watershed in the late 1980s, the average 1963-2002 streamflow impact due to mined areas was approximately 2 cfs, which is approximately 1 % of the 1963-2002 average streamflow in the Horse Creek above Arcadia watershed.

Previous analyses conducted during this study determined that approximately 45% of the recent streamflow reductions in the Peace River above Arcadia watershed were due to other anthropogenic activities, which is exclusive of streamflow reductions due to mined areas. Using the rainfall/streamflow relationship developed previously for the Peace River watershed allowed the quantification of the other anthropogenic impacts. This then allowed the application of the developed impact equation to estimate streamflow reductions due to mined areas. The average 1963-2002 streamflow impact due to mined areas was estimated to be 78 cfs, which is approximately 9% of the observed average streamflow. The other anthropogenic impacts were estimated to be 123 cfs, which is approximately 14% of the observed average streamflow. Of the total anthropogenic impacts determined for the Peace River watershed, approximately 39% is attributed to mined areas and the remaining 61% is attributed to other anthropogenic activities.

The last objective of the study assessed the future streamflow impacts with increased phosphate mining and other anthropogenic activities in those gaged watersheds with mining that contribute flow to Charlotte Harbor. Three future phosphate mining scenarios were defined.

1. The Existing Future Scenario - assumes the existing, permitted mines will have mined out their permitted areas with no additional areas being permitted and mined.

2. Identified Future Scenario - assumes the existing, permitted mines will have mined out their permitted areas, plus identified, but unpermitted, mines will obtain permits and will also have mined out their permitted areas.

3. Worst-Case Scenario - assumes that the Identified Future Scenario and all remaining minable areas within selected watersheds contributing streamflow to Charlotte Harbor will have been mined out.

With increase phosphate mining and other anthropogenic activities, simulated streamflow entering Charlotte Harbor from the Peace River would further decrease. For the base period (1963-2002), the average annual combined streamflow (Peace River at Arcadia plus Horse Creek at Arcadia) is 1,058 cfs. Under the 3 future scenarios, the combined streamflow reductions would be 15%, 23%, and 34%, respectively. The combined simulated streamflow would be 899 cfs, 813 cfs, and 703 cfs for the Existing Future, Identified Future, and Worst-Case Future scenarios, respectively.

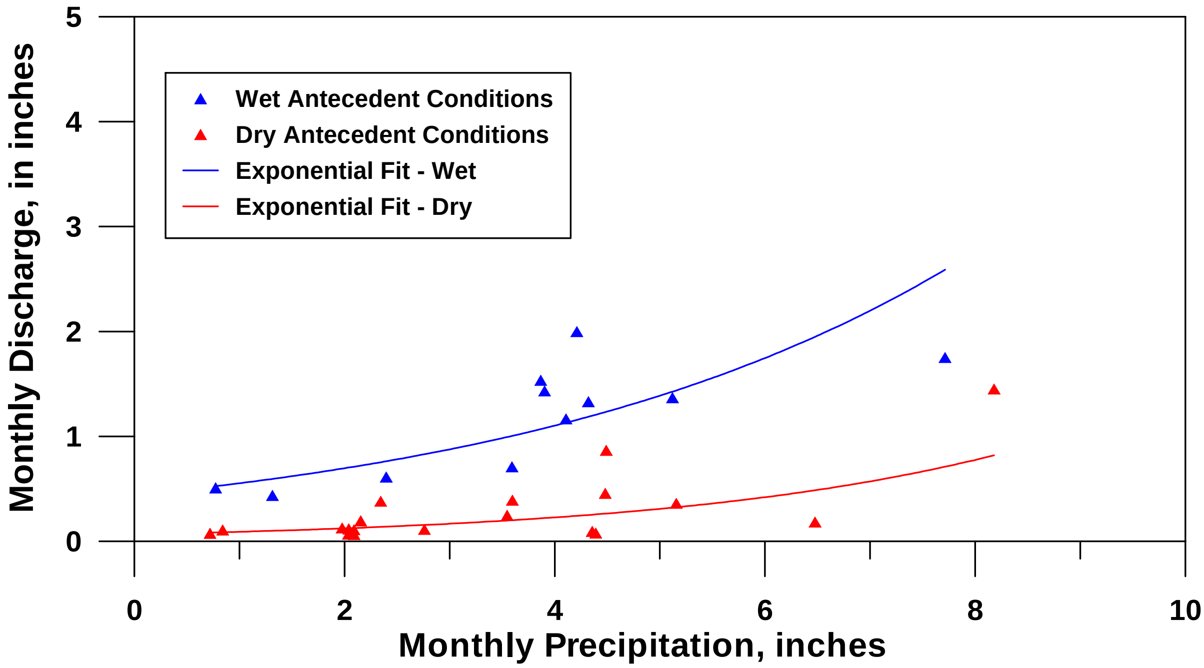


Figure 1. **April Rainfall/Streamflow Relationship for the Peace River Watershed above Arcadia**

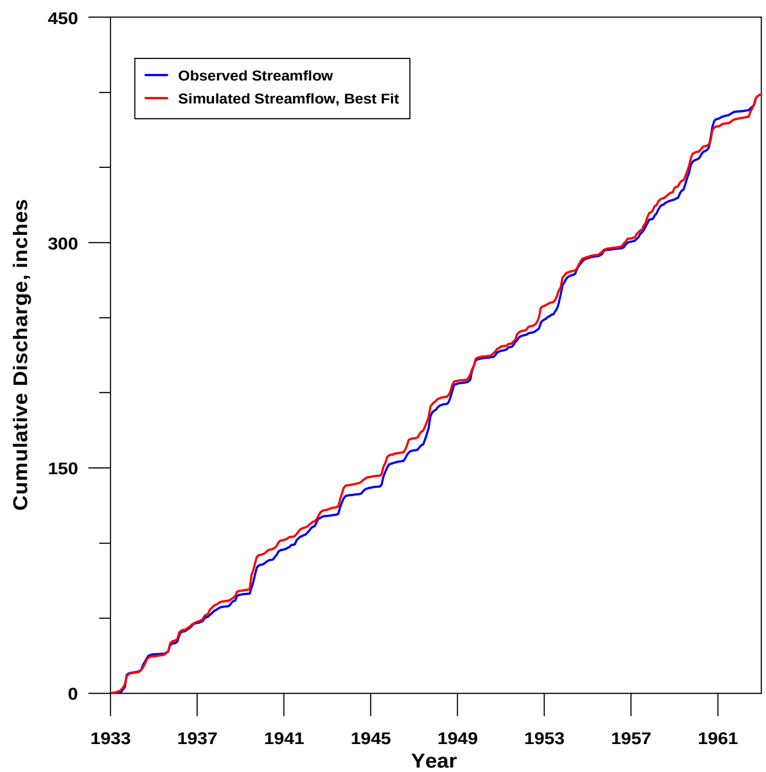


Figure 2. **Observed vs. Simulated Streamflow, 1933 - 1962 for Peace River Watershed above Arcadia**

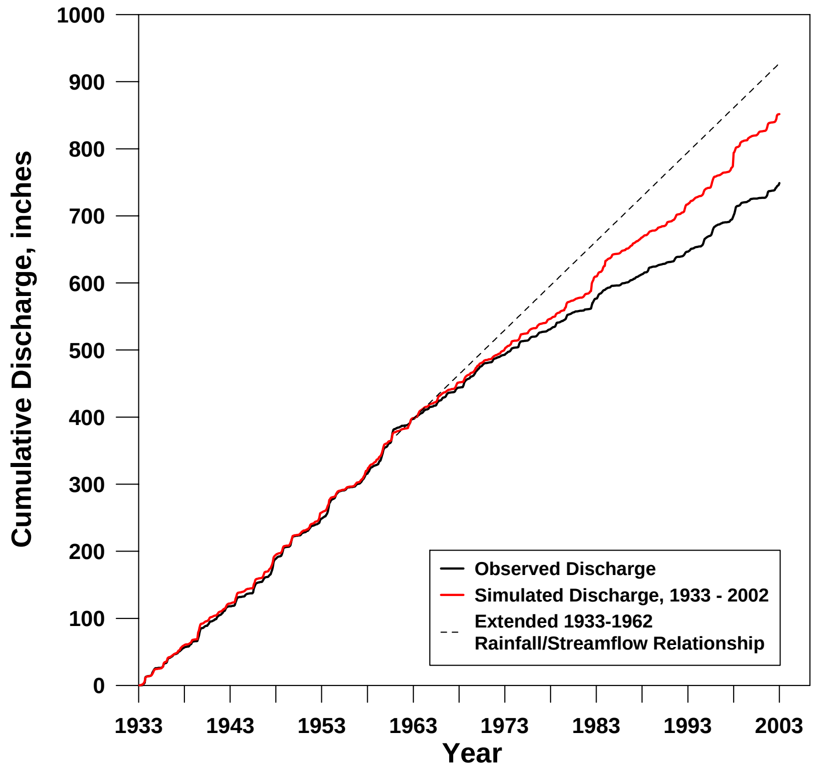


Figure 3. Observed, Simulated, and Extended Streamflow, 1933 - 2002 for Peace River Watershed above Arcadia

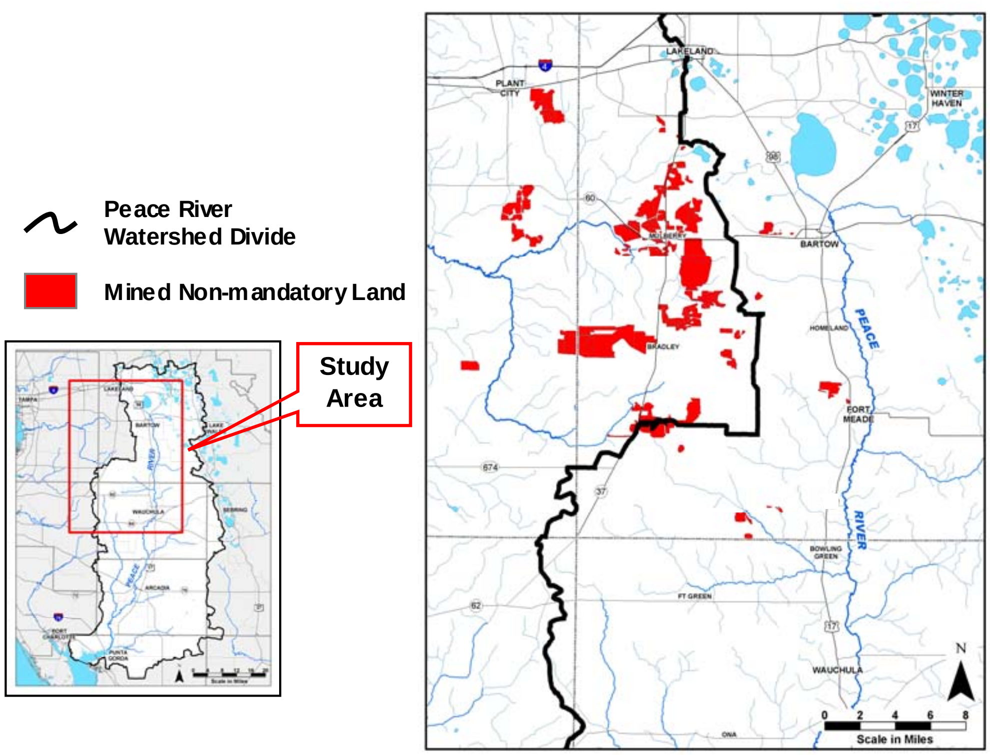


Figure 4. 1930 Distribution of Mined Lands

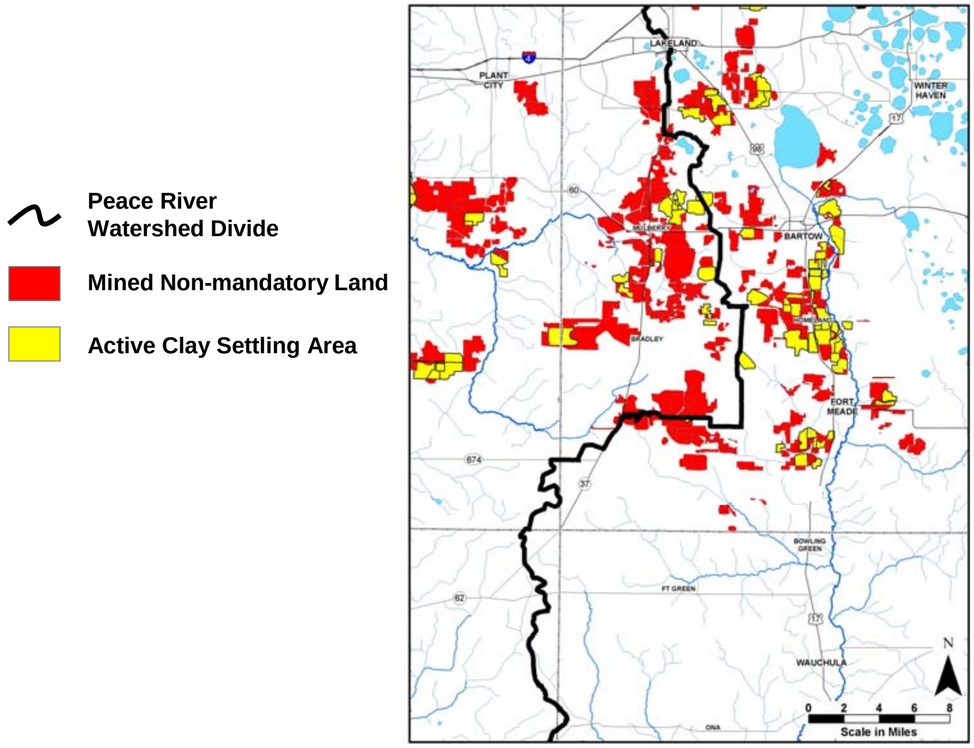


Figure 5. **1965 Distribution of Mined Lands**

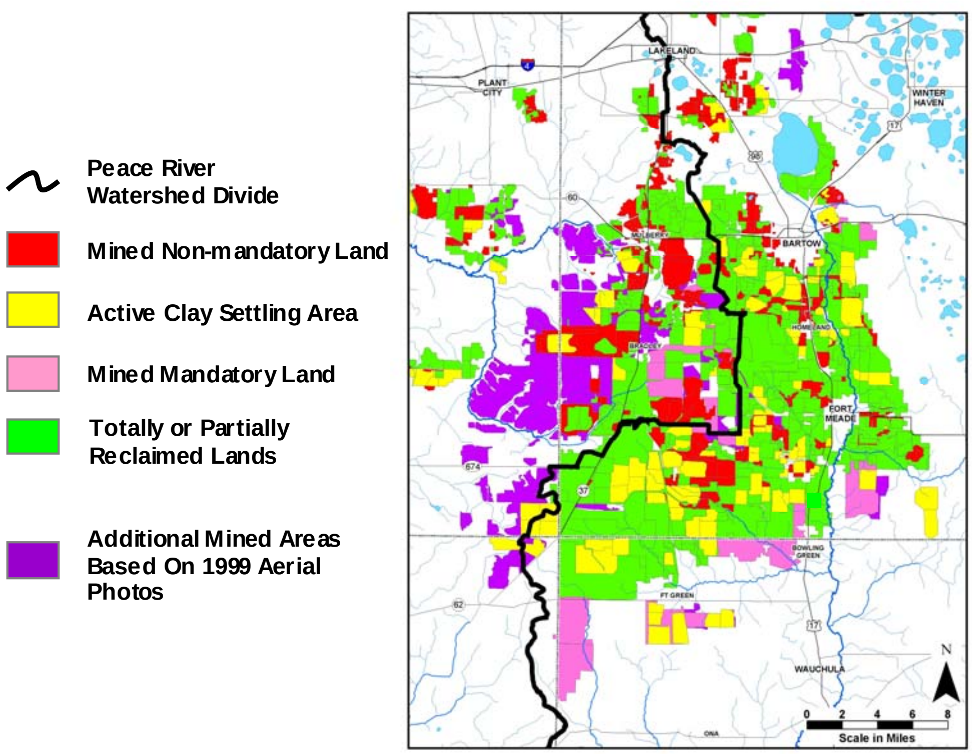


Figure 6. **2003 Distribution of Mined Lands**

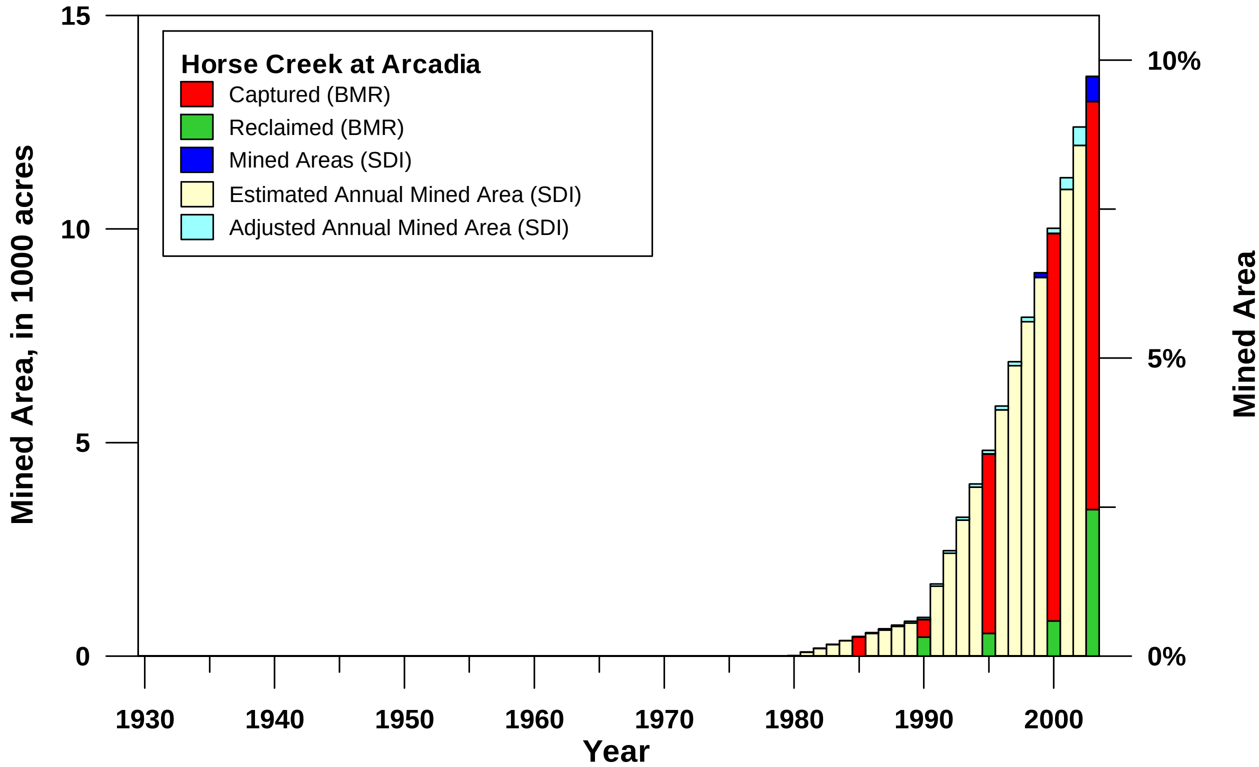


Figure 7. **Estimates of Historical Phosphate Mined Areas, Horse Creek Watershed above Arcadia**

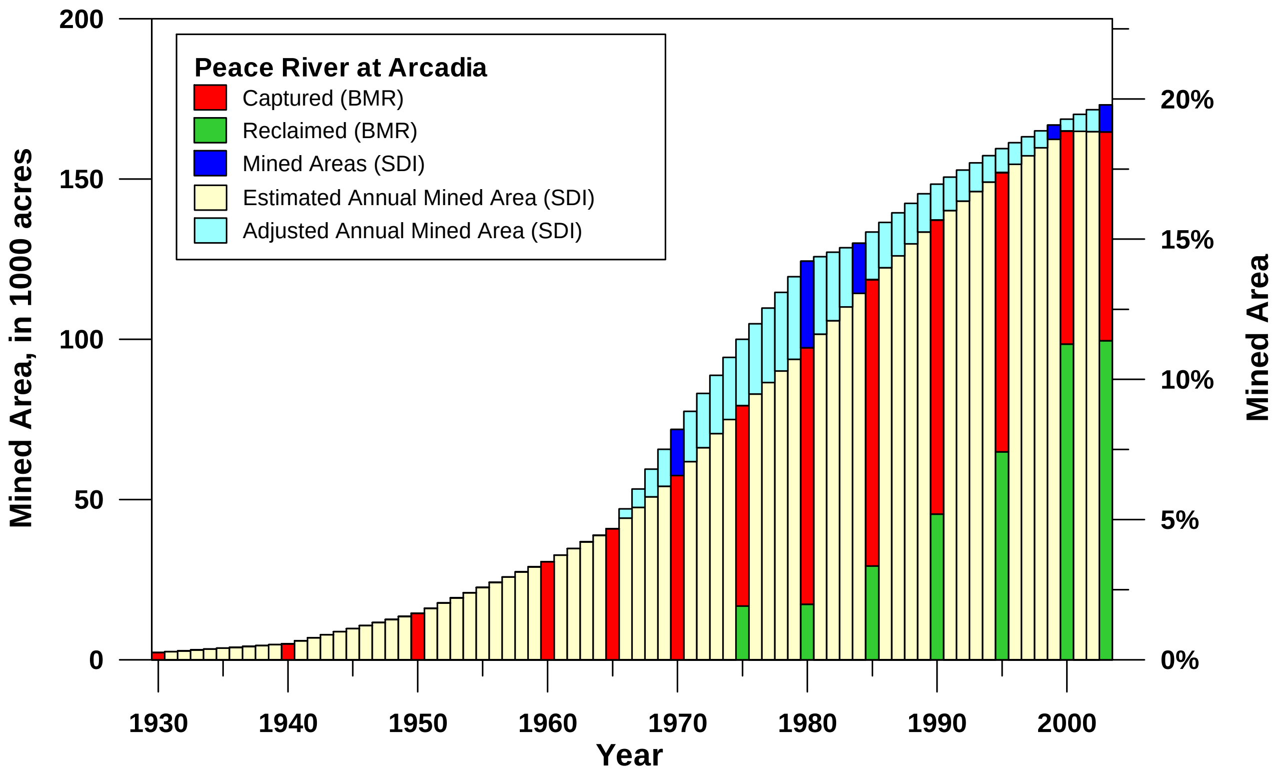


Figure 8. **Estimates of Historical Phosphate Mined Areas, Peace River Watershed above Arcadia**

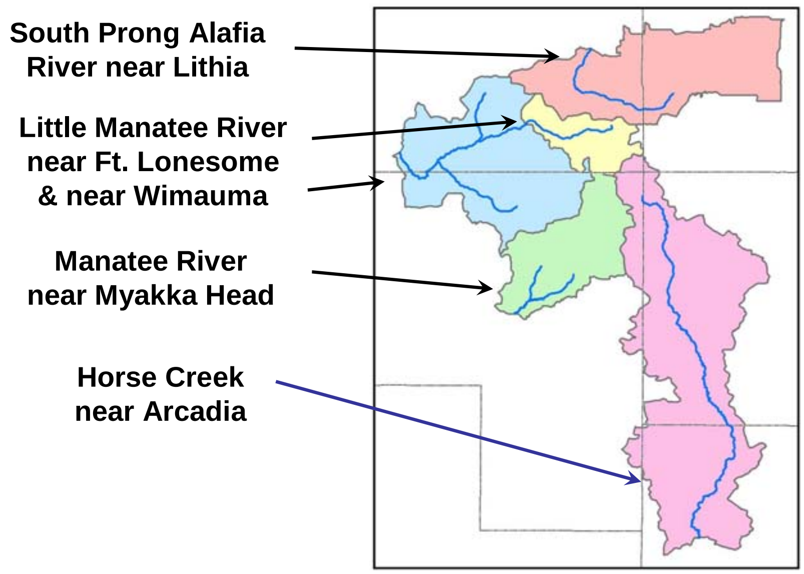
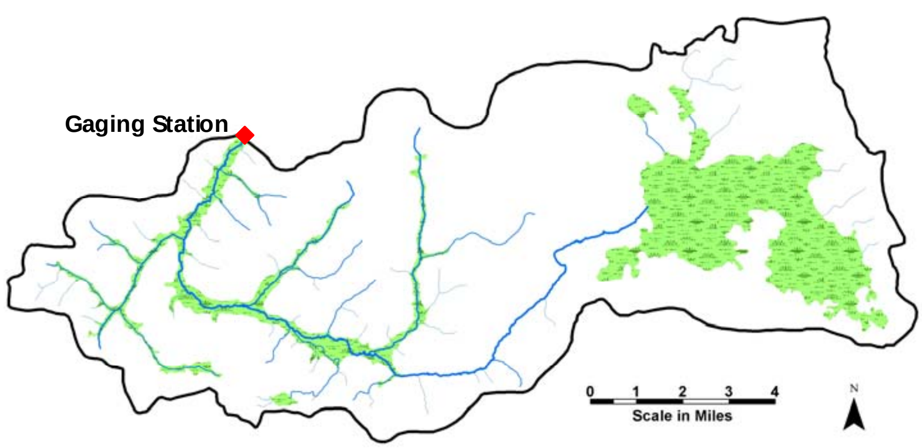


Figure 9. Locations of Gaged Watersheds of Interest



Watershed Area: 104.4 sq. mi.; 66,796 acres

Source: SDI, Digitized from 1949, 1955 & 1956 USGS Quadrangle maps in DRG format

Figure 10. Historic Pre-Mining Hydrography, South Prong of the Alafia River Watershed

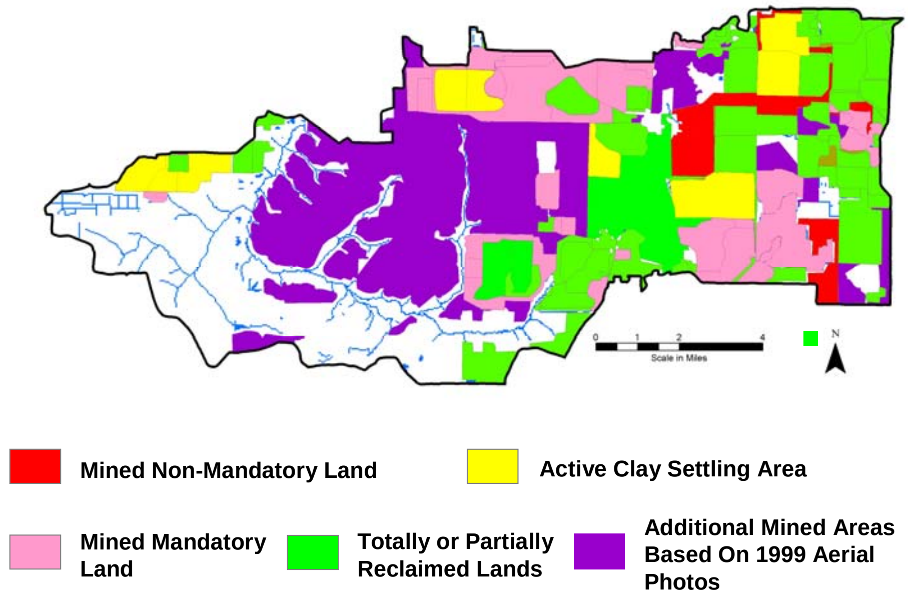


Figure 11. 2000 Extent of Mining, South Prong of the Alafia River Watershed

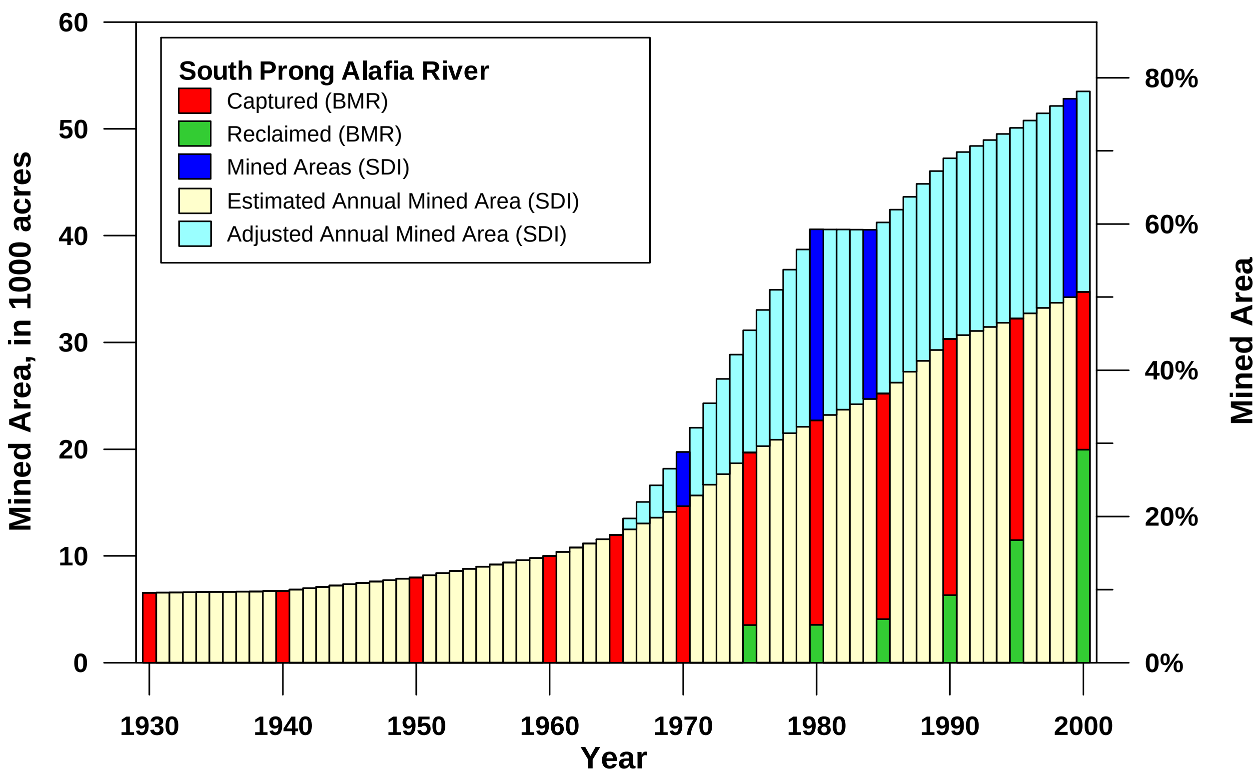


Figure 12. Estimates of Historical Phosphate Mined Areas in the South Prong Alafia River Watershed

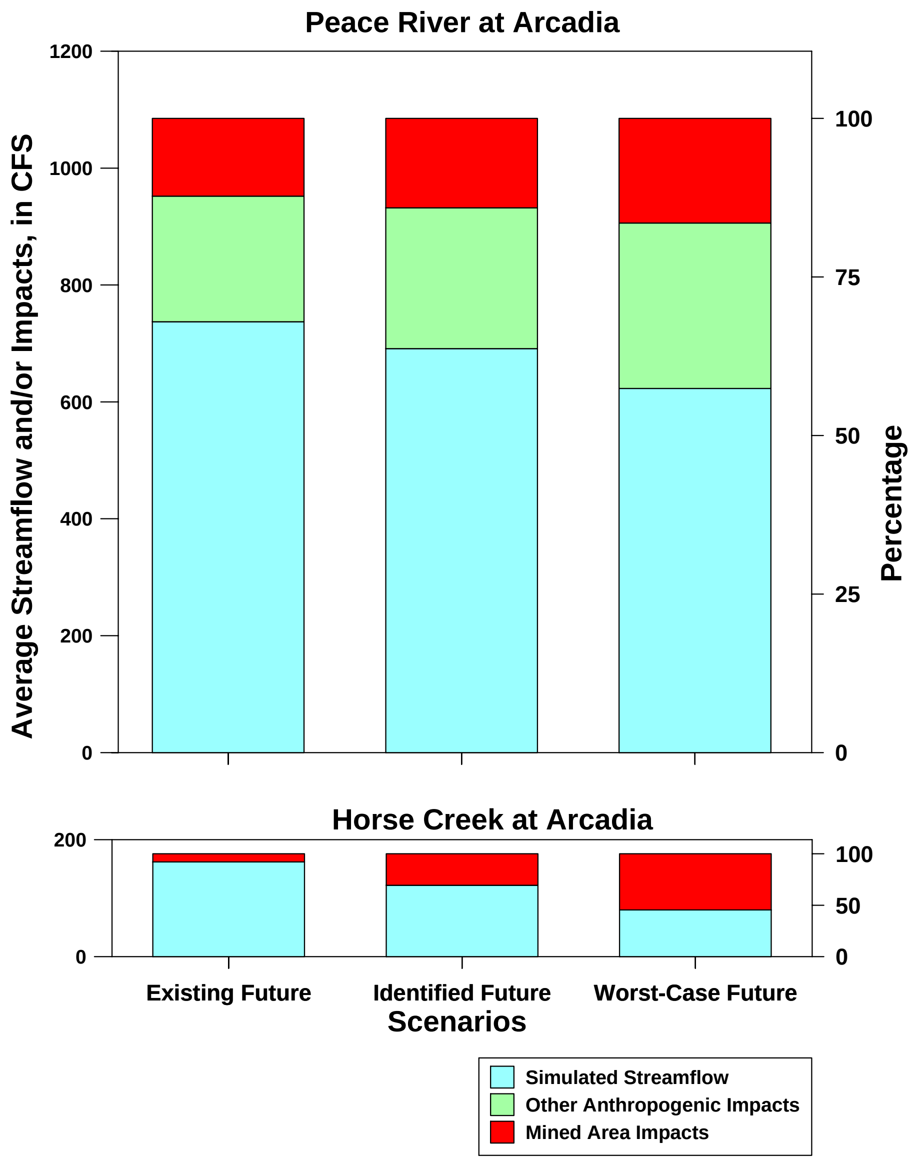


Figure 13. **Long-Term Average Simulated Streamflows and Impacts in the Peace River and Horse Creek Watersheds above Arcadia for the Three Future Scenarios**