IMPACT OF PHOSPHATE MINING ON STREAMFLOW

Prepared by
SCHREUDER, INC.

under a grant sponsored by

FIPR
Florida Institute of Phosphate Research

May 2006
The Florida Institute of Phosphate Research was created in 1978 by the Florida Legislature (Chapter 378.101, Florida Statutes) and empowered to conduct research supportive to the responsible development of the state's phosphate resources. The Institute has targeted areas of research responsibility. These are: reclamation alternatives in mining and processing, including wetlands reclamation, phosphogypsum storage areas and phosphatic clay containment areas; methods for more efficient, economical and environmentally balanced phosphate recovery and processing; disposal and utilization of phosphatic clay; and environmental effects involving the health and welfare of the people, including those effects related to radiation and water consumption.

FIPR is located in Polk County, in the heart of the central Florida phosphate district. The Institute seeks to serve as an information center on phosphate-related topics and welcomes information requests made in person, or by mail, email, or telephone.

Executive Director
Paul R. Clifford

Research Directors
G. Michael Lloyd, Jr.
J. Patrick Zhang
Steven G. Richardson
Brian K. Birky
- Chemical Processing
- Mining & Beneficiation
- Reclamation
- Public Health

Publications Editor
Karen J. Stewart

Florida Institute of Phosphate Research
1855 West Main Street
Bartow, Florida 33830
(863) 534-7160
Fax: (863) 534-7165
http://www.fipr.state.fl.us
IMPACT OF PHOSPHATE MINING ON STREAMFLOW

FINAL REPORT

Peter J. Schreuder, Principal Investigator

with

Julie K. Earls, Co-Investigator

and

John M. Dumeyer, Co-Investigator

SCHREUDER, INC.
Water Resources & Environmental Consultants
110 West Country Club Drive
Tampa, FL 33612

Prepared for

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH
1855 West Main Street
Bartow, Florida 33830 USA

Contract Manager: Dr. Steven G. Richardson
FIPR Project Number #01-03-145R

May 2006
DISCLAIMER

The contents of this report are reproduced herein as received from the contractor. The report may have been edited as to format in conformance with the FIPR Style Manual.

The opinions, findings and conclusions expressed herein are not necessarily those of the Florida Institute of Phosphate Research, nor does mention of company names or products constitute endorsement by the Florida Institute of Phosphate Research.

© 2006, Florida Institute of Phosphate Research.
PERSPECTIVE

It has been observed that flows in the Peace River have declined, particularly when flows for 1970-1999 are compared with flows for 1940-1969. The increase in phosphate mined acreage has led some to point to phosphate mining as the cause. This topic is of particular concern to water users in the lower Peace River Basin and also to phosphate mining companies who are seeking mining permits. Analyses performed in this study by Schreuder, Inc., and in studies by the Southwest Florida Water Management District (see Kelly 2004 in References section) show, however, that changes in rainfall patterns are the overriding causes for changes in streamflow. Consistent with this finding, both rainfall and streamflow have increased in the Peace River Basin from 2001-2005.

In this report, Schreuder and coworkers compared two tributaries of the Peace River with similar-sized watersheds but with different land use patterns. About 70% of the Payne Creek Basin has been mined, while none of the Joshua Creek Basin has been mined. Yet flows per square mile from Payne Creek were greater than from Joshua Creek even though rainfall was slightly higher and deep well pumpage for irrigated agriculture (see Kelly 2004) contributed to streamflow in the Joshua Creek Basin. In a separate but concurrent study, Kelly (2004) compared the flow rates per square mile in the North Prong and the South Prong of the Alafia River between 1972 and 1999. Although the South Prong had a much greater percentage (62%) of its land mined between 1972-1999 than the North Prong (19%), flows per square mile were virtually identical.

In addition to Payne and Joshua Creeks, Schreuder and coworkers compared cumulative yearly streamflow per square mile, and also cumulative streamflow versus cumulative rainfall, for several stream basins and sub-basins in central peninsular Florida for the period from 1980 through 2000. Comparisons were made between stream basins with extensive mining activity versus stream basins without mining. In addition, basins with extensive irrigated agriculture were also included. Their findings were that streamflows in basins with mining were equal to or greater than in basins without mining. They attributed this to more water being available because of reduced evapotranspiration on mined/reclaimed areas. In addition, the distribution of flows differed: flood flows were decreased, while base flows and median flows were increased in mining-affected basins compared to unmined basins in the Peace River and Alafia River watersheds.

Groundwater pumping has had effects on streamflow. Lowering of the water table due to groundwater pumping has had a negative effect on spring flow into the Peace River between Lake Hancock and Ft. Meade (Lewelling and others 1998). That stretch of the river has been observed to lose water to the underlying limestone aquifer and even to go dry in spots in the dry season. However, groundwater pumping for irrigated agriculture has resulted in increased streamflows in the Myakka River, the Manatee River, the Little Manatee River, and Joshua Creek (Kelly 2004).

Steven G. Richardson
Research Director - Reclamation
ABSTRACT

The impact of the phosphate mining industry on streamflow has long been in question in the State of Florida. The Florida Institute of Phosphate Research funded this study in an attempt to resolve this question. The proposal initially called for comparing land use changes to resulting streamflow changes in two basins of the Peace River watershed. These were the Payne Creek and Joshua Creek drainage basins. Close to seventy percent (70%) of the total surface area in the Payne Creek Basin has been affected by phosphate mining. No phosphate mining has taken place or is scheduled to occur in the Joshua Creek Basin, in which thirty percent (30%) of the land is used for irrigated agriculture. Initially, satellite imagery and aerial photographs were used to create a seasonal database of land use changes over the time period of 1985-2000 for use in a water budget spreadsheet model. The measured land-use elements were multiplied with several Evaporation/Evapotranspiration (ET/EV) loss factors. The range of land uses during the mining processes and subsequent reclamation yielded an element of uncertainty when trying to discern the actual runoff, ET/EV losses, drainage basin storage, and imports and exports. The modeling results of predicted seasonal and annual streamflow correlated reasonably well with the actual measured streamflow. The scatter diagram sum of least squares ($R^2$) of model-predicted and measured streamflow values ranged from 70% to 80%. This spreadsheet model approach confirmed the general trends but did not offer a clearly defined quantitative definition of the increased contribution of mined/reclaimed phosphate lands to streamflow.

To obtain a more definitive quantitative definition, the study was significantly expanded to include an exhaustive analysis of the correlation between measured rainfall and measured streamflow. This part of the study is based on the assumption that the record of streamflow measurements at the exit of a basin provides the best indicator of the overall hydrologic conditions in that basin. For this approach, the study looked at the relationships between streamflow and rain from measured stations in the entire Southern Water Use Caution Area, using double mass curves and regression analyses for the time period of 1980-2000. Data from 1932 through 2000 was used for the Peace River Basin.

The final results of the land-use model and detailed streamflow analyses indicate that the mined basins do, in fact, increase overall streamflow. The analyses also indicate that flood-flows from mined basins are reduced by mining operations while median and base-flows are significantly increased.
ACKNOWLEDGMENTS

Schreuder, Inc. would like to acknowledge the following individuals and/or agencies for their cooperation in accomplishing this research: Dr. Barnali Dixon and Gary Udouj of the University of South Florida; Greg Williams, Jeff Dodson, Joshua House and Dave Burke with IMC Phosphates Company; Gary Blitch with CF Industries; Tom Myers and Rosemarie Garcia with Cargill Fertilizer, Inc.; personnel with the SWFWMD (Lela Clark, Margit Crowell, David Sumner, Jim Whalen), USGS (Augustine Sepulveda, Cheryl O’Brien, Diane Burdick), FDEP (Monica Boland, Robert Vanderslice, Brian Irsch), Bureau of Mine Reclamation (Steve Partney, Jorge Lagos), FIPR, Florida Phosphate Council, and County Extension Services (Hardee, DeSoto, Hillsborough and Polk). The members of the staff of Schreuder, Inc. that contributed to this study were the Co-Investigators, Julie Earls and John Dumeyer, as well as Cliff Harrison, Holly Regar and Nicholas Schrier.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERSPECTIVE</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vi</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>Purpose and Objectives of the Study</td>
<td>5</td>
</tr>
<tr>
<td>Location of Study Area</td>
<td>5</td>
</tr>
<tr>
<td>Background</td>
<td>9</td>
</tr>
<tr>
<td>Satellite Analyses of Changes in Land Use Versus Changes in Streamflow</td>
<td>9</td>
</tr>
<tr>
<td>Multiple Streamflow Analyses</td>
<td>10</td>
</tr>
<tr>
<td>SATELLITE ANALYSIS OF LAND USE AND STREAMFLOW CHANGES</td>
<td>13</td>
</tr>
<tr>
<td>Methods</td>
<td>13</td>
</tr>
<tr>
<td>Satellite Imagery</td>
<td>13</td>
</tr>
<tr>
<td>Satellite Image Acquisition</td>
<td>15</td>
</tr>
<tr>
<td>Resolution Mixing</td>
<td>16</td>
</tr>
<tr>
<td>Land Use/Land Cover</td>
<td>16</td>
</tr>
<tr>
<td>Satellite Image Processing</td>
<td>17</td>
</tr>
<tr>
<td>Accuracy</td>
<td>20</td>
</tr>
<tr>
<td>Water Budget Spreadsheet Model</td>
<td>20</td>
</tr>
<tr>
<td>RESULTS</td>
<td>23</td>
</tr>
<tr>
<td>Satellite Image Analysis</td>
<td>23</td>
</tr>
<tr>
<td>Model Results and Verification</td>
<td>28</td>
</tr>
<tr>
<td>Joshua Creek Basin Modeling Results</td>
<td>28</td>
</tr>
<tr>
<td>Payne Creek Basin Modeling Results</td>
<td>30</td>
</tr>
<tr>
<td>Verification of Modeling Results</td>
<td>32</td>
</tr>
<tr>
<td>Comparisons Between Joshua Creek and Payne Creek Basins</td>
<td>33</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (CONT.)

Set-Up ........................................................................................................33
Comparative Analysis ................................................................................34

MULTIPLE STREAMFLOW ANALYSES ..........................................................37
Methodology ............................................................................................... 37
Hypotheses Underlying the Streamflow Analyses ....................................39
Results ...........................................................................................................40

Extent of Phosphate Mined/Reclaimed and Irrigated Agricultural Lands ................................................................................................................. 40
Integrated Rainfall/Streamflow Analyses ....................................................43

Three Major River Basins .........................................................................44
Rate of Change in the Three Major River Basins During the Last 21 Years ................................................................................................. 46
Long-Term Change in Rainfall/Streamflow Relation in the Peace River Basin .................................................................................. 48
Change in Long-Term Rainfall in the Peace River Basin ..................... 49
Change in Long-Term Streamflow in the Peace River Basin ............. 50
Changes in Peace River Flow from Decade to Decade ....................... 51
Analyses of Individual Streams in the SWUCA ...................................... 51

Characterization of Streamflow in Each Basin in the SWUCA ............ 53

Linear Streamflow Response Coefficients .............................................. 54
Polynomial Streamflow Response Coefficients ..................................... 56

Analyses of Streamflow Distribution .......................................................... 56

Flood (P-10) Flows ................................................................................. 57
Mean (P-50) Flows ............................................................................... 58
Base (P-90) Flows .............................................................................. 59
Comparative Analyses of Streamflow Distribution ................................ 61

Unit Streamflow in SWUCA Basins ......................................................... 64
Assessment of Land Use and Unit Streamflow ...................................... 65

Unit Streamflow of Percent Exceedance Trendlines ........................... 70

Comparisons Between Linear Trend and Unit Streamflow .................. 74
# TABLE OF CONTENTS (CONT.)

Impact of Slope on Unit Streamflow .................................................. 75

PRELIMINARY ANALYSES OF MINING EFFECTS ON DEEP RECHARGE ....... 77
CONCLUSIONS AND RECOMMENDATIONS ............................................. 83

Satellite Land Use Study Conclusions.................................................... 83
Streamflow Study Conclusions............................................................. 83

Conclusion 1 ........................................................................................ 83
Conclusion 2 ........................................................................................ 83
Conclusion 3 ........................................................................................ 84
Conclusion 4 ........................................................................................ 84
Conclusion 5 ........................................................................................ 84
Conclusion 6 ........................................................................................ 84
Conclusion 7 ........................................................................................ 84
Conclusion 8 ........................................................................................ 84

Recommendations .................................................................................. 85

REFERENCES ............................................................................................ 87

APPENDICES (on enclosed CD)

A. Joshua & Payne Creek Drainage Basins Accuracy Assessment,
   Associated Processed Satellite Images ............................................ A-1
B. Joshua and Payne Creek Drainage Basins Illustrative Maps ............ B-1
C. Cumulative Streamflow Versus Rain Double Mass (Polynomial and
   Linear) Analysis of Three Major River Basins............................... C-1
D. Historical SWUCA Streamflow and Rain Data and Supporting
   Information ..................................................................................... D-1
E. 1932-2000 Peace River at Arcadia Rain Versus Time Analyses
   (Polynomial) ............................................................................... E-1
F. 1932-2000 Peace River at Arcadia Streamflow Versus Time
   Analyses (Polynomial) .................................................................. F-1
G. 1932-2000 Peace River at Arcadia Streamflow Versus Rain
   Incremental Analyses (Polynomial) .............................................. G-1
H. 1980-2000 Major Basins and Sub-Basins Cumulative Streamflow
   Versus Rain Analyses (Polynomial and Linear) ............................ H-1
I. 1980-2000 Major Basins and Sub-Basins Cumulative Streamflow
   Percent Exceeds Versus Rain Analyses (Polynomial and Linear) .... I-1
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Major River Basins within the SWFWMD</td>
</tr>
<tr>
<td>2.</td>
<td>Joshua and Payne Creek Basin Locations with USGS Stream Gages</td>
</tr>
<tr>
<td>3.</td>
<td>Streamflow Basins Studied within the SWUCA</td>
</tr>
<tr>
<td>4.</td>
<td>Example of Polynomial Plot of Data</td>
</tr>
<tr>
<td>6.</td>
<td>Flow Diagram of Water Budget Spreadsheet Model</td>
</tr>
<tr>
<td>7.</td>
<td>Streamflow (BCF/Season) and Rain (BCF/Season) for Joshua Creek and Payne Creek Basins</td>
</tr>
<tr>
<td>8.</td>
<td>Joshua Modeled Versus Measured Streamflow with Rain (Wet Seasons)</td>
</tr>
<tr>
<td>9.</td>
<td>Joshua Modeled Versus Measured Streamflow with Rain (Dry Seasons)</td>
</tr>
<tr>
<td>10.</td>
<td>Joshua Modeled Versus Measured Streamflow with Rain (Water Years)</td>
</tr>
<tr>
<td>11.</td>
<td>Payne Modeled Versus Measured Streamflow with Rain (Wet Seasons)</td>
</tr>
<tr>
<td>12.</td>
<td>Payne Modeled Versus Measured Streamflow with Rain (Dry Seasons)</td>
</tr>
<tr>
<td>13.</td>
<td>Payne Modeled Versus Measured Streamflow with Rain (Water Years)</td>
</tr>
<tr>
<td>14.</td>
<td>Cumulative Double Mass of Rain for Joshua and Payne Creek Basins (Linear)</td>
</tr>
<tr>
<td>15.</td>
<td>Cumulative Double Mass of Rain for Joshua and Payne Creek Basins (Polynomial)</td>
</tr>
<tr>
<td>16.</td>
<td>Cumulative Double Mass of Streamflow for Joshua and Payne Creek Basins (Linear)</td>
</tr>
<tr>
<td>17.</td>
<td>Cumulative Double Mass of Streamflow for Joshua and Payne Creek Basins (Polynomial)</td>
</tr>
<tr>
<td>18.</td>
<td>Drainage Basins Used for Streamflow Study with Outline of Central Florida Counties and Major Rivers</td>
</tr>
<tr>
<td>19.</td>
<td>Major River Basin Land Use from SWFWMD GIS Data, 1999</td>
</tr>
<tr>
<td>20.</td>
<td>Cumulative 1980-2000 Rainfall and Streamflow (cfs/m) by Major Drainage Basin</td>
</tr>
<tr>
<td>21.</td>
<td>Cumulative Peace @ Arcadia Streamflow Versus Rain (cfs/m), 1980-2000 (Polynomial)</td>
</tr>
<tr>
<td>22.</td>
<td>Location of SWUCA Stream Drainage Basins and Peace River Gaging Stations</td>
</tr>
<tr>
<td>23.</td>
<td>Unit Streamflow 1980-2000 cfs/m for SWUCA Streams</td>
</tr>
<tr>
<td>24.</td>
<td>Potentiometric Surface Map of SWFWMD Showing Floridan Aquifer Elevations in Feet—May 2000 (red hatched is below MSL)</td>
</tr>
<tr>
<td>25.</td>
<td>Map of Mines Within the Payne Creek Drainage Basin with Area Estimates</td>
</tr>
<tr>
<td>26.</td>
<td>Unit Streamflow P-10 1980-2000 Average cfs/m for SWUCA Streams</td>
</tr>
<tr>
<td>27.</td>
<td>Unit Streamflow P-50 1980-2000 Average cfs/m for SWUCA Streams</td>
</tr>
<tr>
<td>28.</td>
<td>Unit Streamflow P-90 1980-2000 Average cfs/m for SWUCA Streams</td>
</tr>
<tr>
<td>29.</td>
<td>Correlation of Linear Trend “a” Coefficient to Unit Mean Streamflow</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>30.</td>
<td>Location of Drainage Basins and Regional Long-Term Monitor Well Clusters</td>
</tr>
<tr>
<td>31.</td>
<td>Cumulative Groundwater Level of Floridan Aquifer at Gardinier Monitor Well</td>
</tr>
<tr>
<td>32.</td>
<td>Cumulative Groundwater Level of Floridan Aquifer at ROMP 40 Monitor Well</td>
</tr>
<tr>
<td>33.</td>
<td>Cumulative Groundwater Level of Floridan Aquifer at ROMP 45 Monitor Well</td>
</tr>
<tr>
<td>34.</td>
<td>Cumulative Groundwater Level of Floridan Aquifer at ROMP 59 Monitor Well</td>
</tr>
<tr>
<td>35.</td>
<td>Cumulative Groundwater Level of Floridan Aquifer at ROMP 60 Monitor Well</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>SWFWMD Land Use for Alafia, Peace and Withlacoochee River Drainage Basins for Mined, Unmined and Other Lands</td>
<td>11</td>
</tr>
<tr>
<td>2.</td>
<td>Sub-Drainage Areas Within the Payne Creek and Joshua Creek Drainage Basins (determined by USGS)</td>
<td>13</td>
</tr>
<tr>
<td>3.</td>
<td>Landsat V Availability and Quality of Purchased Images</td>
<td>14</td>
</tr>
<tr>
<td>4.</td>
<td>List of Landsat V Satellite Band Uses, Range and Descriptions</td>
<td>15</td>
</tr>
<tr>
<td>5.</td>
<td>Land Use Classes Used for Determining ET, with Corresponding Classified Satellite Image Color</td>
<td>17</td>
</tr>
<tr>
<td>6.</td>
<td>Land Use Results in Square Mileage by Season for Joshua Creek Basin</td>
<td>23</td>
</tr>
<tr>
<td>7.</td>
<td>Land Use Results in Square Mileage by Season for Payne Creek Basin</td>
<td>24</td>
</tr>
<tr>
<td>8.</td>
<td>Daily Mean Streamflow per Basin Reported Seasonally</td>
<td>26</td>
</tr>
<tr>
<td>9.</td>
<td>Seasonal Rain per Basin Reported Seasonally</td>
<td>27</td>
</tr>
<tr>
<td>10.</td>
<td>Best Line Fit Coefficients of Scatter Diagrams Between Measured and Model-Predicted Streamflows</td>
<td>33</td>
</tr>
<tr>
<td>11.</td>
<td>Comparison of USGS Drainage Basin Areas Used for Study</td>
<td>40</td>
</tr>
<tr>
<td>12.</td>
<td>SWFWMD Land Use (1999) for Drainage Basins for Mined, Unmined and Other Lands</td>
<td>41</td>
</tr>
<tr>
<td>19.</td>
<td>Descriptive Statistics for Each Drainage Basin Determined Using USGS Average Annual Streamflow Measurements (cfs/m)</td>
<td>52</td>
</tr>
<tr>
<td>20.</td>
<td>Unit Rainfall and Streamflow in Basins in the SWUCA</td>
<td>53</td>
</tr>
<tr>
<td>21.</td>
<td>Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Streamflow for Streams in the SWUCA and Withlacoochee</td>
<td>54</td>
</tr>
<tr>
<td>22.</td>
<td>Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Ten Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins</td>
<td>57</td>
</tr>
<tr>
<td>23.</td>
<td>Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Fifty Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins</td>
<td>59</td>
</tr>
</tbody>
</table>
## LIST OF TABLES (CONT.)

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.</td>
<td>Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Ninety Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins</td>
</tr>
<tr>
<td>25.</td>
<td>Summary of Linear Coefficients for Double-Mass Plots of Cumulative Rainfall Versus Cumulative Ten, Fifty and Ninety Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins</td>
</tr>
<tr>
<td>27.</td>
<td>Difference in Angles Between Percent Exceed Trendlines</td>
</tr>
<tr>
<td>28.</td>
<td>Total, Mined, Irrigated and Other Areas in Each Sub-Basin</td>
</tr>
<tr>
<td>29.</td>
<td>Comparison of Unit Streamflow to Percentage of Irrigated or Mined Areas</td>
</tr>
<tr>
<td>30.</td>
<td>Import to, and Export from, the Payne Creek Drainage Basin</td>
</tr>
<tr>
<td>31.</td>
<td>Linear Trendline Coefficients and Unit Mean Streamflow</td>
</tr>
<tr>
<td>32.</td>
<td>Table of Slope Calculations (ft./mi.) with 21-Yr. Unit Mean Streamflow (cfsm) for Comparison</td>
</tr>
</tbody>
</table>
### Conversion Factors and Abbreviations

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inch (in.)</td>
<td>2.54</td>
<td>centimeter (cm)</td>
</tr>
<tr>
<td>foot (ft)</td>
<td>0.3048</td>
<td>meter (m)</td>
</tr>
<tr>
<td>mile (mi)</td>
<td>1.609</td>
<td>kilometer (km)</td>
</tr>
<tr>
<td>square foot (ft²)</td>
<td>0.09290</td>
<td>square meter (m²)</td>
</tr>
<tr>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
</tr>
<tr>
<td>cubic foot per day (ft³/d)</td>
<td>0.02832</td>
<td>cubic meter per day (m³/d)</td>
</tr>
<tr>
<td>million gallons (Mgal)</td>
<td>3.785</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td>gram per cubic centimeter (g/cm³)</td>
<td>0.00112</td>
<td>pound mass per cubic inch (lb/in³)</td>
</tr>
<tr>
<td>inch (in.)</td>
<td>0.07367</td>
<td>cubic feet per second per mi² (cfs/m)</td>
</tr>
<tr>
<td>acre (ac.)</td>
<td>4,047</td>
<td>square meter (m²)</td>
</tr>
<tr>
<td>gallon (gal)</td>
<td>3.785</td>
<td>liter (L)</td>
</tr>
<tr>
<td>million gallons (Mgal)</td>
<td>3,785</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td>cubic feet per second (ft³/s or cfs)</td>
<td>0.02832</td>
<td>cubic meter per second (m³/s)</td>
</tr>
</tbody>
</table>

EV = evaporation  
ET = evapotranspiration  
FIPR = Florida Institute of Phosphate Research  
GIS = Geographic Information Systems (in this case ESRI ArcGIS 8x.)  
ISODATA = Iterative Self-Organizing Data Analysis Technique Algorithm  
(classification algorithm within ERDAS® Imagine satellite processing software)  
MGD = million gallons per day  
SWFWMD = Southwest Florida Water Management District  
LU/LC = land use/land cover  
SWUCA = Southern Water Use Caution Area  
BCF = billions of cubic feet  
BCFS = billions of cubic feet per season  
Wet season = June through September  
Dry season = October through May  
R = rain  
P = pumpage  
SFI = streamflow in  
ET = Evapotranspiration/Evaporation  
RC = recharge  
SFO = streamflow out  
ΔS = change in storage  
cfs/sq mi (or cfs/mi²) = cubic feet per second per square mile, also abbreviated cfsm* in this report

* Although csfm is not the normal convention, this was done for ease of graphical representation and always represents cubic feet per second per square mile in this report.
EXECUTIVE SUMMARY

In January 2002, Schreuder, Inc. (SI) submitted a proposal to the Florida Institute of Phosphate Research to evaluate the impacts of phosphate mining on streamflow. The reason for the study was a rather spirited debate among several stakeholders regarding whether or not phosphate-mining activity results in reduced flow of surface water. With the increased dependence of downstream users of the surface water flow in the Peace River as a source of drinking water for four coastal counties in Southwest Florida, this debate has intensified. The original intent of the study was to compare two basins of similar size in the Peace River watershed, one impacted by mining and one not. These were the Payne Creek and Joshua Creek basins. They were selected because approximately seventy percent (70%) of the Payne Creek Basin area has been mined or is being mined and reclaimed, while no mining has taken, or will take, place in the Joshua Creek Basin, where thirty percent (30%) of the surface area is being used for irrigated agriculture, predominantly to grow citrus crops.

The original study proposed to document the changes in land-use and land-cover over a period from 1985 through 2000 by analyzing satellite imagery. This period was chosen because it offered continuous satellite coverage by the same instrument (Landsat V). The proposed study envisioned a continuous documentation of land-uses and land-cover during this period. Each land area was to be classified by its use and a rate of evapotranspiration and evaporation (ET/EV) was assigned to each specific land use and land cover (LU/LC). The purpose of this work was to calculate the changes in ET/EV losses on an annual basis. This information was to then be combined with rainfall inputs, pumpage inputs, discharge from NPDES stations, recharge, and change in surficial aquifer storage data in a spreadsheet model. The purpose of the model was to predict the streamflow. The model-predicted streamflow was then compared to the actually measured streamflow. The hope was that the rather detailed documentation of the LU/LC changes could be clearly correlated with the observed streamflow record, thereby providing a clear and significant correlation based on the hypothesis that phosphate mining reduces ET/EV losses and thus would increase streamflow.

The success of this approach depended largely on the rate of ET/EV that could be assigned to each land cover. Unfortunately, the range in differing types of land cover was much greater than the available ET/EV multiplier coefficients. The results of the original study were therefore less conclusive than was anticipated.

The intent of the research was to clarify the role that the phosphate mining industry plays with regards to surface water flow in the Peace River Basin. Because the originally proposed study fell somewhat short of this goal, SI decided to expand the study by focusing entirely on relating measured rainfall inputs to measured streamflow outputs from each basin. This idea was based on the hypothesis that the best indicator of the overall hydrologic behavior in a watershed is the comparison between the rainfall inputs and the surface water outputs. SI also decided to expand the evaluation to the entire Peace River watershed above the Arcadia gaging station plus the Joshua Creek and Horse
Creek Basins that both discharge into the Peace River downstream of the Arcadia gaging station. In addition, SI added the Alafia River Basin and those of the coastal Little Manatee, Manatee and Myakka Rivers. To complete the comparisons among the major river basins, SI also included the Withlacoochee River Basin.

SI selected a time interval from 1980 through 2000. The reason for the selection of the 1980 starting date was three-fold: (1) there is a complete dataset of rainfall and streamflow for this time interval, (2) the imposition of the mandatory reclamation rule in 1975 would influence the hydrologic responses in mined and reclaimed basins, and (3) the lack of availability of continuous streamflow data prior to this time period.

SI performed extensive analyses using a combination of the double-mass analytical approach with computer-generated linear and polynomial best-fit trend lines. The cumulative annual rainfalls in these basins were plotted against the cumulative annual streamflows for the Peace River and its tributaries: Bowlegs, Charlie, Joshua, Payne and Horse Creeks, as well as the South Prong of the Alafia River and the Alafia at Lithia, the Little Manatee River at Wimauma, the Manatee River at Myakka Head, the Myakka River near Sarasota, and the Withlacoochee River at Holder.

In addition, SI determined the annual ten, fifty and ninety percent exceedance values for each system and prepared cumulative annual P-10, P-50 and P-90 double-mass plots against cumulative annual rainfall (i.e., plotting cumulative flow versus cumulative rain). A percent exceedance value is the percent of time the streamflow volume will equal or exceed that value (i.e., P-90 means 90% of the time the streamflow meets or exceeds the value and 10 percent of the time the streamflow volume will be less than this value). In general, the P-10 value is associated with the flow in surface water streams during flooding conditions. Similarly, the P-50 flows are associated with the average flow in a stream, while the P-90 generally represents baseflow conditions. Best-fit trend lines were also determined for these double-mass plots and the resulting coefficients were used in SI’s analyses.

Using similar techniques, a time series analysis was performed on the entire record of flow (beginning in 1932) in the Peace River at the Arcadia gaging station. The purpose was to investigate if and when a measurable and significant change occurred in the long-term relationship between rainfall and surface water flow in the Peace River. SI determined that that change occurred in 1973.

The results of all these analyses are that:

1. Although the size of the Payne Creek and Joshua Creek Basins are quite similar and the rainfall over the Payne Creek Basin was less during the period studied than over the Joshua Creek Basin, the total streamflow out of the Payne Creek Basin was higher than from the Joshua Creek basin. It should be noted that 70% of the Payne Creek Basin has been impacted by phosphate mining.
2. Unit mean streamflow is consistently higher from basins where phosphate mining dominates than in basins where irrigated agriculture dominates in both the Alafia and Peace River Basins.

3. In the Southern Water Use Caution Area (SWUCA) of the Southwest Florida Water Management District (SWFWMD), deep well pumpage from the Floridan aquifer, primarily in support of agriculture and irrigation has caused a significant decline in the potentiometric surface of the Floridan Aquifer. This decline has been extensively and continuously documented as representing the transfer of large volumes of groundwater from the deeper Floridan aquifer to the shallow surficial aquifer that is in direct contact with surface water streams. This is indirectly expressed by the fact that the unit mean streamflow is higher in the coastal river basins than either the Alafia or the Peace River basins.

4. The contribution of streamflows from Payne Creek, where seventy percent of the surface area is mined and/or reclaimed, significantly increased the unit mean streamflow in the Peace River from 0.40 cfs/m at the Ft Meade gaging station to 0.58 cfs/m at the next downstream gaging station at Zolfo Springs. This demonstrates clearly that additional surface water flow from tributary basins, where pumpage from the underlying confined aquifer system(s) or salvage of evapotranspiration losses is taking place, augments the surface water flow in the Peace River.

5. Polynomial trendline fits of the double-mass plots of unit mean streamflow versus unit rainfall for the 20 year period from 1980 through 2000 indicate increased streamflow in the studied streams, except for Upper Horse Creek, Bowlegs Creek and the Withlacoochee River. To assess the constancy between 2 phenomena, it is appropriate to use the single mass and double mass analytical approach. In the single mass method, the cumulative daily/monthly/annual values of rainfall (for example) are plotted against time. If the rainfall is constant, the plotted line will be very straight. Similarly, in a double-mass approach, the cumulative data of one parameter (e.g., streamflow) is plotted against the cumulative values from another parameter (e.g., rainfall). If no change in the relationship between those parameters occurs over time, this relationship will be shown as a straight line (using a polynomial fit to the trend of the data). If the trend between the 2 systems starts to deviate, it will be reflected in the deviation of the plotted line from a straight line.

6. Double-mass analyses confirm that streamflows from predominantly mined/reclaimed areas have not been declining, but in fact have been increasing at a greater rate than unmined areas with predominantly irrigated agriculture.
7. Analyses of the 10, 50 and 90 percent exceedances of the flow frequency curves of the streams in the SWUCA for the 1980 to 2000 period clearly indicate a distinctly different distribution of streamflow from the mined (reclaimed) basins versus the other basins. Mined areas tend to retain flood flows (P-10) for later release as median (P-50) and base flows (P-90).

8. The magnitude and seasonal distribution of streamflow are very similar among mined basins, but the magnitude and seasonal distribution of streamflow from predominantly mined basins are distinctly different from unmined, mostly agricultural basins. In the case of mining, gains in streamflow were related to reduced evapotranspiration (ET) losses associated with vegetation changes (less leaf area in young vegetation on reclaimed land compared to more mature pre-mining vegetation). In the case of irrigated agriculture, gains in streamflow were due to the importation of groundwater pumpage from the underlying confined aquifer.

This study clearly demonstrates that phosphate mining and subsequent reclamation have not reduced surface water flows from the basins in which mining is taking place. To the contrary, streamflows per unit of rainfall have actually increased in mining-affected basins. Salvage of the gain in water associated with reduced evapotranspiration in these mined areas could help reduce dependence on ground water by additional recharge using another FIPR-funded project on aquifer recharge and recovery (FIPR Pub. No. 03-113-186) and this could improve the water availability situation in the SWUCA. In some unmined basins, streamflows have increased also, but this has been due to importation of groundwater pumped from the underlying confined aquifers for irrigating agriculture fields.
INTRODUCTION

PURPOSE AND OBJECTIVES OF THE STUDY

In the state of Florida, there have long been debates regarding the impacts of phosphate mining on streamflow. It has been proposed that the impacts are negative, reducing streamflow by diverting more water from the river and not returning a sufficient amount to make up for these losses. Another theory argues that water losses to evapotranspiration (ET) are reduced through the process of phosphate mining that removes vegetation and subsequently contributes to increased streamflow through “water savings” from reduced rates of ET. The process of phosphate mining and reclamation is viewed as intrusive and unnatural, causing environmentalists and concerned citizens to oppose issuance of further mining permits in the Peace River and other river basins.

The purpose of this research was to determine if mining has negatively impacted the streamflow to the Peace River. To accomplish this, Schreuder, Inc. (SI) used a dual approach. The initial idea was to map the progression of land use changes over a 16-year period, assign ET rates to each land use category, calculate the overall change in ET for selected drainage basins, enter these values in a basin-wide water budget to calculate streamflow from the selected basins, and compare these calculated values to the measured streamflow leaving the basins. Initially, the two drainage basins that were chosen for the study were Payne Creek and Joshua Creek drainage basins. The Payne Creek drainage basin is located in central Florida, mostly contained within Polk and Hardee counties with a small portion in Hillsborough County. The exit of this drainage basin is to the Peace River near Bowling Green at the middle of the basin on the eastern boundary. The Joshua Creek drainage basin was chosen for its lack of mining, similar underlying potentiometric makeup and similarity in size to Payne Creek. Joshua Creek is located to the southeast of Payne Creek, almost entirely within DeSoto County. The exit of this drainage basin is in the southern portion on the west side of the basin near Nocatee. As the investigation progressed, other drainage basins within the Southwest Florida Water Management District (SWFWMD) were included for statistical and graphical analysis of the relationships between streamflow and rainfall that did not include the use of satellite imagery.

LOCATION OF STUDY AREA

The overall location of this project was the Southern Water Use Caution Area (SWUCA) in the SWFWMD of west-central Florida. The location of the entire SWFWMD and the SWUCA is presented in Figure 1. The land use part of the study focused primarily on the Payne Creek and Joshua Creek Basins shown in Figure 2. Some major river basins (namely the Withlacoochee) used in the statistical analysis extend beyond the region shown in Figure 1, but the majority of the drainage basins are within the SWUCA, as shown in Figure 3.
Figure 1. Major River Basins Within the SWFWMD.
Figure 2. Joshua and Payne Creek Basin Locations with USGS Stream Gages.
Figure 3. Streamflow Basins Studied Within the SWUCA.
BACKGROUND

The state of Florida is divided into five water management districts; the district in charge of west-central Florida’s water resources is the SWFWMD. This agency possesses a wealth of data that was tapped for this study (water use permits, wells, rain, GIS, etc). Within the SWFWMD, there is an area of concern known as the SWUCA, declared thus in 1992 by the District Governing Board due to the fact that its “water resources are or will become critical in the next twenty years” (SWUCA 1998). The extent of this designation is roughly 5,100 square miles, covering the majority of the southern portion of the SWFWMD. Within this region, it has been determined that 80-90% of the total water use is for citrus, row crops, mining and public supply. The distribution of groundwater use has changed within these categories over the past two decades; for example, in the early 1980s commercial use (primarily mining) accounted for 500-600 million gallons per day (MGD), but with technological advances and conservation efforts by the industry, the number for the late 1990s is roughly 200 MGD. While the public supply use of surface water has remained steady and is projected to continue (~50-75 MGD), the public supply use of groundwater has risen and is expected to continue that trend (in the late 1990s it was ~120MGD). Crop water use has declined as row crop acreage has been in a decline in recent years and is projected to remain basically stable, although there has been significant progress in conservation and irrigation technology in this industry as well. The citrus portion of the agricultural trade has grown rapidly, accounting for roughly 90% of the total planted acreage within the SWUCA. Efforts are being made by growers to constrain their water use and improve conservation (SWUCA 1998).

Satellite Analyses of Changes in Land Use Versus Changes in Streamflow

For the first part of this study, satellite images formed the basis of all the change in land use/land cover (LU/LC) analyses. Satellite images are invaluable assets for doing environmental work, as has been published in articles by Carlson and Arthur (2000), Ridd (1995), Moran (1994) and Gillies and others (1997). Landsat V scenes were available for several periods throughout the years and these were selected using the Department of the Interior, United States Geological Survey (USGS) website, EarthExplorer®. The major limitation was obtaining images with a minimal amount of clouds and radiometric disturbance, which was determined by the image preview available. A second complexity that arose was the diminished quality of the preview coupled with the study areas being only a small portion on the satellite scene, making it problematic to distinguish if small clouds were located with the desired area.

The data gathered was satellite imagery and aerial photography as well as in-depth land use, measured rain and streamflow records, pumping data, water use permit data, Geographic Information Systems (GIS) data, National Pollutant Discharge Elimination System (NPDES) data and Digital Orthophoto Quarter Quadrangles (DOQQs).

A key component in the first part of the study was the selection of evaporation and evapotranspiration rates for the different land use surfaces. According to the USGS
Water Supply Paper 2430, *Evapotranspiration from Areas of Native Vegetation in West Central Florida* (Bidlake and others 1996), the annual ET loss from dry prairie is 39.8 inches; from marsh vegetation 39.0 inches; from pine flatwoods 41.7 inches; and from a cypress swamp 38.2 inches. When mining begins and a pine flatwood is stripped from the area to be mined, ET losses will be reduced, assuming that ET from bare soil is less than that from a vegetated area. It is this reduction in ET losses that will be seen in the overall water budget for the site as a gain to be “neutralized” by an increase in the contribution to surface water flow. The land use prior to mining, progression of mining and the subsequent reclamation (during the 21-year study period) were mapped, and basin-wide capacity for ET losses was estimated. These findings were then correlated to the daily records at gaging stations operated by the USGS and others (when available). The aim of this study was to provide a quantitative assessment of the contributory relationship between phosphate mining and streamflow.

Creating a water budget spreadsheet model in which the streamflow was calculated after entering the ET and rainfall values performed the quantitative assessment. The calculated (residual) streamflow was then compared to the USGS measured streamflow for the basins.

In a study conducted by Geraghty & Miller, Inc. (1977) for the U.S. Army Corps of Engineers in 1975 through 1977, different rates of evapotranspiration were established for different times of the year. Others, notably John Garlanger with Ardaman & Associates (personal communication), have established specific ET and EV rates for different land uses. Work done by Bill Lewelling (1997) of the USGS on the comparisons between unmined and reclaimed basins appears to support the hypothesis that the contribution to surface water flow could be higher from reclaimed basins than from unmined basins. Studies on evaporation and evapotranspiration have varied in methodology; unfortunately, the results have been widely variable as well.

**Multiple Streamflow Analyses**

In the second phase of the study, the streamflow assessment, the focus was on determining if the surface water discharges from the basins had been diminishing, remaining the same, or increasing as compared to the rainfall inputs. The first decision to be made was the selection of the time interval for the analysis. The time period from 1980 through 2000 was selected. The land use change portion of this study starts in 1985 because the consistent satellite imagery starts at that date. The streamflow analysis was started five years earlier. The reasons for that are three-fold: (1) this is within a period where analyses by others have shown fairly constant weather conditions; (2) mandatory reclamation started in 1975 and it was assumed that, in general, land that was being prepared for mining in 1975 may have been under reclamation five years later at the earliest, but not yet released, and (3) the streamflow data available is sporadic or non-existent for many stations prior to this period. Thus looking at the impact of phosphate mining and reclamation on streamflow, the 21-year time interval is a reasonable period for potential impacts to fully develop and be observed as a possible trend in the streamflow discharges.
At the beginning of the streamflow analytical phase of the study, expanded work was done to determine a baseline by comparing long-term unit streamflow averages between the Peace, Alafia and Withlacoochee Rivers. Unit streamflow is defined as the annual mean streamflow over the period of the investigation divided by the total drainage area in that basin upstream of the surface water gaging station whose data is being used. This was important because the three river basins have different land usage coverages, but receive relatively similar rainfall inputs. The Peace and Alafia River Basins have been impacted primarily by phosphate mining operations and irrigated agriculture, while the Withlacoochee River Basin has not experienced widespread surface phosphate mining and much less agriculture. It should be noted that there are some rock mining operations in the Withlacoochee River Basin, but these have entirely different environmental and hydraulic dimensions than current phosphate mining practices. The major land use categories were phosphate mining, irrigated agriculture, and others (which includes all the other land uses). The actual surface areas for each one of the land uses and their percentage of the total basin area for the entire Alafia, Peace and Withlacoochee River drainage basins are shown in Table 1. The information in Table 1 was prepared using the SWFWMD 1999 land use database. It is important to note that the SWFWMD database is particularly robust in its classification of mined lands in that once lands are classified as mined, they tend to stay in that classification until long after reclamation. A further breakdown of the basins is provided later in the results section of this report.

Table 1. SWFWMD Land Use for Alafia, Peace and Withlacoochee River Drainage Basins for Mined, Unmined and Other Lands.

<table>
<thead>
<tr>
<th></th>
<th>Alafia Drainage Basin</th>
<th>Peace Drainage Basin</th>
<th>Withlacoochee Drainage Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dbasin Total Area mi²</td>
<td>422</td>
<td>2346</td>
<td>2058</td>
</tr>
<tr>
<td>Irrigated mi²</td>
<td>29</td>
<td>363</td>
<td>64</td>
</tr>
<tr>
<td>Mined mi²</td>
<td>151</td>
<td>229</td>
<td>23</td>
</tr>
<tr>
<td>Other mi²</td>
<td>242</td>
<td>1754</td>
<td>1971</td>
</tr>
<tr>
<td>Irrigated %</td>
<td>7</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Mined %</td>
<td>36</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Other %</td>
<td>57</td>
<td>75</td>
<td>96</td>
</tr>
</tbody>
</table>

In the actual streamflow analyses, SI relied to a large extent on the single- and double-mass plotting approach of comparing cumulative rainfall to cumulative streamflow. The basic concept underlying the double-mass analysis is that the relationship between the two variables can be described as linear. To assess the constancy between two phenomena, it is appropriate to use the single-mass and double-mass analytical approach. In the single-mass method, the cumulative daily/monthly/annual values of rainfall (for example) are plotted against time. If the rainfall is constant, the plotted line will be very straight. Similarly, in a double-mass approach, the cumulative data of one parameter (e.g., streamflow) is plotted against the cumulative values from another parameter (e.g., rainfall). If no change in the relationship between those parameters occurs over time, this relationship will be shown as a straight line (using a polynomial fit to the trend of the data). If the trend between the two systems starts to deviate, it will be reflected in the deviation of the plotted line from a straight line.
In the case where the surface hydrology in a basin is continuously changed as a result of the progression of the removal of vegetation preceding phosphate mining, it is reasonable to assume that the ongoing reduction in ET losses would be gradual and continuous. Due to this assumption, SI elected to use a quadratic polynomial curve-fitting technique to accommodate the continuously ongoing changes between rainfall and streamflow. Once the single- and double-mass plots were prepared, SI employed linear and polynomial curve fitting techniques and analyzed these results. In general, the linear and polynomial curve fitting provided a statistically acceptable result in that the $R^2$ value for all data plots was well above 0.98 (98%). The $R^2$ value is an indication of how well a given line passes through all the points plotted on a graph. The closer the $R^2$ value approaches the value of 1.0 (100%), the better the fit.

SI elected to use a polynomial curve-fitting relationship to define what the predicted responses and future impacts of the change in the hydrologic relationship in the basin would be. The polynomial curve fitting approach is particularly useful, because the value of the “a” coefficient associated with the quadratic function of cumulative rainfall will immediately indicate if, during the time period for which the data points were plotted, unit streamflow increased, remained the same, or decreased with respect to the unit rainfall input. For example a positive “a” value indicates that unit streamflow was increasing, while a negative value indicates that it was decreasing. A zero value of “a” indicates that streamflow remained unchanged. The “b” associated with the linear function of the cumulative rainfall value indicates the general slope of the line; the slope of the line indicates the general relationship between the unit rainfall and unit streamflow. The lower the value of “b”, the smaller the unit streamflow value will be as it relates to the unit rainfall. The “c” value represents where the trend line crosses the y-axis (not of strong significance in this analysis). In the simulated example of a polynomial fit below (Figure 4), the “a” coefficient would be +6.875 and the “b” coefficient would be -4.505 and the “c” coefficient would be +27.825. The dashed orange line is the data and the black line is the “fit” of the data.

![Graph showing polynomial fit](image)

Figure 4. Example of Polynomial Plot of Data.
METHODS

Satellite Imagery

The two drainage basins chosen for in-depth study were those of Payne Creek and Joshua Creek, for the reason that they are both located within the Peace River Basin and are similar in size, 122 mi\(^2\) and 120 mi\(^2\), respectively, and represent vastly different land use (mined versus agriculture). Within these two drainage basins are several tributaries, as listed in Table 2.

Table 2. Sub-Drainage Areas Within the Payne Creek and Joshua Creek Drainage Basins (Determined by USGS).

<table>
<thead>
<tr>
<th>Payne Creek Drainage Basin</th>
<th>Joshua Creek Drainage Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payne Creek</td>
<td>Joshua Creek</td>
</tr>
<tr>
<td>Bowling Green Run</td>
<td>Hawthorne Creek</td>
</tr>
<tr>
<td>Olive Branch</td>
<td>Unnamed Branch</td>
</tr>
<tr>
<td>Mined Area (x 5)</td>
<td>Lake Slough</td>
</tr>
<tr>
<td>Hickey Branch</td>
<td>Hog Bay</td>
</tr>
<tr>
<td>Gum Swamp Branch</td>
<td>Honey Run</td>
</tr>
<tr>
<td>Doe Branch</td>
<td></td>
</tr>
<tr>
<td>Unnamed Run (x 2)</td>
<td></td>
</tr>
<tr>
<td>Coons Bay Branch</td>
<td></td>
</tr>
<tr>
<td>Plunder Branch</td>
<td></td>
</tr>
<tr>
<td>Little Payne Creek</td>
<td></td>
</tr>
<tr>
<td>Shirrtail Branch</td>
<td></td>
</tr>
</tbody>
</table>

(Note: Multiplication factor is the indicated number of the specified type of drainage areas within the larger drainage basin boundary).

The basins combined within their respective larger drainage basins are shown in Appendix B, Figure B-2.

Bi-annual satellite images were purchased for the years of 1985-2000 to represent the wet (June-September) and dry (October-May) seasons for each year. These images were not always usable due to cloudiness in some of the wet seasons (shown in Table 3). Landsat 5 Thematic Mapper (TM) was launched in 1984 and was operational for the entire length of the study period. Once a sensor is chosen, it is best to stay with that sensor for the entire study even if a better sensor becomes available for part of the time period (such as Landsat 7, launched a few years later than this study began), so that all the data will be subject to the same variation. Landsat 5 operates from a Sun-synchronous orbit, imaging the same ground swaths 185 km (115 miles), every 16 days. The global coverage of this satellite is between roughly 81 degrees north latitude and 81
degrees south latitude. Landsat 5 TM’s scene has an instantaneous field of view (IFOV) of 30 meters by 30 meters (900 square meters) in Bands 1 through 5 and Band 7, and an IFOV of 120 meters by 120 meters (14,400 square meters) for Band 6 (thermal band). The specifics regarding each band’s wavelength and use are outlined in Table 4 below. For this study, Bands 1, 2 and 4 were used to perform the unsupervised classification and other bands were used in various combinations for reference when performing the final tidying. The 30 x 30m resolution of the satellite imagery was a reason to use as much ancillary imagery as possible when tidying (as aerials and DOQQs have better resolution).

Table 3. Landsat V Availability and Quality of Purchased Images.

<table>
<thead>
<tr>
<th>Joshua Creek</th>
<th>Image Date</th>
<th>Payne Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Clouds</td>
<td>Some Clouds</td>
<td>Unusable</td>
</tr>
<tr>
<td>x</td>
<td>1-9-1985w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>9-6-1985s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-28-1986w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>8-24-1986s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-15-1987w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>7-10-1987s</td>
<td>X</td>
</tr>
<tr>
<td>x</td>
<td>12-17-1987</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>7-12-1988s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-4-1989w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>4-13-1990w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>6-16-1990s</td>
<td>X</td>
</tr>
<tr>
<td>x</td>
<td>2-11-1991w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>5-2-1991s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>3-1-1992w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>5-4-1992s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-31-1993w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>7-26-1993s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>12-1-1993</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>2-22-1995w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>8-17-1995s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>12-7-95 (*96w)</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>7-2-1996s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-26-1997w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>6-19-1997s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>3-2-1998w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>6-22-1998s</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>1-16-1999w</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>7-25-2000w</td>
<td>x</td>
</tr>
</tbody>
</table>

Note: w after year represents Winter (dry) season and s represents Summer (wet).
Table 4. List of Landsat V Satellite Band Uses, Range and Descriptions.

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral Bands</th>
<th>Range (µm)</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blue-Green</td>
<td>0.4-0.5 µm</td>
<td>Useful for bathymetric mapping and distinguishing soil from vegetation and deciduous from coniferous vegetation.</td>
</tr>
<tr>
<td>2</td>
<td>Green</td>
<td>0.5-0.6 µm</td>
<td>Emphasizes peak vegetation, which is useful for assessing plant vigor.</td>
</tr>
<tr>
<td>3</td>
<td>Red</td>
<td>0.6-0.7 µm</td>
<td>Discriminates vegetation slopes.</td>
</tr>
<tr>
<td>4</td>
<td>Near-IR</td>
<td>0.7-1.3 µm</td>
<td>Emphasizes biomass content and shorelines.</td>
</tr>
<tr>
<td>5</td>
<td>Mid-IR</td>
<td>1.3-3.0 µm</td>
<td>Discriminates moisture content of soil and vegetation; penetrates thin clouds.</td>
</tr>
<tr>
<td>6</td>
<td>Thermal IR</td>
<td>3.0-10 µm</td>
<td>Useful for thermal mapping and estimated soil moisture.</td>
</tr>
<tr>
<td>7</td>
<td>Reflected IR</td>
<td>0.1 cm-1m</td>
<td>Useful for mapping hydrothermally altered rocks associated with mineral deposits.</td>
</tr>
</tbody>
</table>

ERDAS IMAGINE (now owned by Leica Geosystems) is remote sensing software that incorporates functions of both image processing and GIS. The program is capable of many types of interpretation of satellite and GIS data. For the purposes of this study, the program was used for (1) satellite band layerstacking, (2) image georectification, (3) image subsetting, (4) image classification, (5) image tidying, (6) accuracy assessment, and (7) generation of numbers in LU/LC categories for spreadsheet. The processes used in this study are further described below in the “Satellite Image Processing” section and the accompanying flowchart, Figure 4.

**Satellite Image Acquisition**

A satellite “scene” is defined as the image capture by a satellite (ERDAS 1999). The selection of scenes that were appropriate for the goals of this study (seasonally, summer and winter months) was determined early on in the project. Cloud cover is the most limiting factor (next to scene availability), so the selection of images that were cloud-free or where the study area is as cloud-free as possible is somewhat time-consuming but of critical importance. An online (using Earth Explorer) preview of all available satellite images preceded the final selection. As a result of the periodicity of the satellite passage, there were a limited number of dates from which to choose, and within those dates some images had sensor problems, clouds or other issues that prevented them from being usable scenes. Table 3 above lists the scenes that were purchased and their usefulness. It was easiest to find functional scenes in the winter (dry) season, whereas summer was much less accommodating. It was possible to use a scene that had a limited number of clouds, extremely small clouds or clouds over an area that had unchanging land use from year to year. There were five years that had no usable summer scene for Joshua Creek and six years that had no usable summer scene for Payne Creek.
Resolution Mixing

In the final classification process overseen by the remote sensing operator, it was determined helpful to compare as many different sources of ancillary data as possible. Therefore, the operator used aerials, DOQQs (a more recent means of storing aerials digitally to be used within GIS) and the GIS LU/LC dataset from SWFWMD whenever available to compare to the unsupervised classification produced by an ERDAS algorithm. It is recognized that these supplementary sources have varying degrees of accuracy and image resolution; therefore it is actually quite constructive to use them as a check against the accuracy of the classification and for interpreting the images themselves. Another approach that proved invaluable was to utilize unclassified images in differing band combinations in a second viewer, while classifying a processed image into the user-desired categories (this was particularly helpful for the Joshua Creek Basin as yearly aerials were not available). By looking at the image in raw form and numerous band combinations, certain land use types were more readily distinguishable than from the processed but untidied image.

Land Use/Land Cover

The land use classes that were important for the purposes of this study are detailed in Table 5 below. These classes were chosen either because of their abundance in the study area or their widely ranging ET rates in order to achieve the most representative water budget model. “Non-irrigated vegetation” represented in this study any vegetation that was not considered either wetland or a source of imported water into the watershed, for example, pasture, mixed rangeland, herbaceous lands, etc. “Citrus” was comprised of all tree crops, as most in these particular basins falls in the citrus tree category (FLUCCS Code # 2200). “Wetland” was a combination of all wetland classes of vegetation (basically, everything in the 6000 range in the FLUCCS Codes). “Timber” was considered to be pine flatwoods (FLUCCS Code # 4110). “Crop” was representative of row crops, nurseries, and vineyards (sod farms fall into this category - FLUCCS Codes # 2140, 2400 and 2440). “Water” was represented in the Joshua Creek Basin mainly by the reservoir and a few small ponds, whereas in the Payne Creek Basin there was some mixture between the water and clay settling area (CSA) classes (FLUCCS Codes # 5100, 5200, 5300 and 5400). The “CSA” category was water falling within the walls of a CSA (FLUCCS Codes listed previously). Reclaimed CSAs would be classed as their land use type in the image for the particular year of interest (for example, disturbed land, wetlands or non-irrigated (NI) vegetation). It should be noted that SWFWMD’s classification of mined/extractive land is not up-to-date; it is more of a general guideline of where the mine boundaries are, not particularly whether or not the land is actively being mined (i.e., if the land is now reclaimed as wetlands or pasture, that is not usually reflected in the LU/LC GIS database published on the website).
Table 5. Land Use Classes Used for Determining ET, with Corresponding Classified Satellite Image Color.

<table>
<thead>
<tr>
<th>Land Cover Classes</th>
<th>Classified Image Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Irrigated Vegetation</td>
<td>Bright Green</td>
</tr>
<tr>
<td>Citrus</td>
<td>Orange</td>
</tr>
<tr>
<td>Wetland</td>
<td>Aqua</td>
</tr>
<tr>
<td>Urban</td>
<td>Red</td>
</tr>
<tr>
<td>Timber</td>
<td>Dark Green</td>
</tr>
<tr>
<td>Water</td>
<td>Blue</td>
</tr>
<tr>
<td>Clay Settling Area</td>
<td>Maroon</td>
</tr>
<tr>
<td>Sand Tailing</td>
<td>White</td>
</tr>
<tr>
<td>Disturbed Land</td>
<td>Gray</td>
</tr>
<tr>
<td>Crop</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Satellite Image Processing

The procedure of satellite image processing is a repeatable procedure that is best described in Figure 5 below. Images came on a CD as seven separate bands. First they were layer-stacked (combined) into one file for manipulation as a single object for analysis. In this case, SI left out Band 6 (thermal) due to its resolution being different from the other bands (i.e., 120m versus 30m) and the fact that it was not of particular use in this study (it was decided that Bands 1, 2 and 4 were of maximum value).

The next step completed was georeferencing the images. Topologically Integrated Geographic Encoding and Referencing system (TIGER) files were used to rectify the images as they were obtained to ensure that all GIS files would overlay properly and the images would be usable. The TIGER road network files were used to establish known recognizable intersections as ground control points to be used for reference in creating a model using a low-order polynomial transform to reduce distortion in the final image. Once the ground control points were determined, the root mean square (RMS) error and total RMS in x and y were used to confirm error. A RMS of 0.5 pixels is +15m or ½ a pixel from the optimal location. A standard map area with boundaries set in UTM is established for each scene so that all images will occupy the same map area once rectified. UTM bounds are set according to file size, pixels and the minimum/maximum northing and easting required to contain the full scene. A new file of matching size is created for each image in the series, as well as a matching georeference segment.
The subsequent method of analysis was to perform principal components analysis on subсетted basins (not to the actual exact drainage basin, but to an area roughly twice the size). This was done before the unsupervised classification for the purpose of condensing redundant data into fewer bands. The PCA gives maximum variation (diversity) of data by band, then creates a composite band that the ERDAS user further classifies (ERDAS 1999). In this case, Bands 1, 2, and 4 were examined by the software and condensed into a composite band for detailed classification. These bands were chosen from those available (1-5 and 7) after investigating their ability to differentiate
between the land-use types decided to be important in this study, namely vegetation types and mining practices. The next procedure was to perform the classification step. This classification was performed on the image produced in the previous step. The classification “scheme” was developed by the researchers depending on the project; in this case, relating to the primary land-use types that would (1) cover the majority of the basin or (2) evapotranspire at significantly different rates from the rest of the classes. These classes are discussed below and displayed in Table 5 above. Through testing of methods, it was decided the most accurate means to determine land use/land cover was to have ERDAS perform an unsupervised classification (also called clustering) using the Iterative Self-Organizing Data Analysis Technique (ISODATA) method for pixel clustering. This method “uses the spectral distance…but iteratively classifies the pixels, redefines the criteria for each class and classifies again, so that the spectral distance patterns in the data gradually emerge” (ERDAS FG 1999). In short, the user set a convergence threshold at which the iterations stop (in this case, 95%) which means that better than 95% of the pixels are staying in the same clusters (“classes”) at that point. The user also set the number of output classes, which also established the corresponding signature classes to be developed. The number of classes selected through trial and error was 30. This means, in simple terms, the program generated 30 classes that the pixels fell into with the most consistency, using a 95% convergence threshold. It is highly recommended that the user choose several more classes than the final number desired in order to avoid mixing up classifications. In this case, the final number of classes desired for the Joshua Creek Basin was seven and for Payne Creek was nine, so 30 classes was well over three times the chosen numbers.

Using aerial photography, multi-year LU/LC maps and DOQQs for reference, these results were then renamed by the user into their respective classes (i.e., Citrus, NI Veg, CSA, etc). This file was then subsetted to the exact area of interest (the particular drainage basin) and was ready for the next step.

The next step was to “tidy” the images. This required more intensive analysis using the aforementioned supplementary reference materials. In this step, the user changes small “areas of interest” (AOI’s) within a class that were misclassified for any reason, whether it was a recurring problem or a one-time event. This was the most time-consuming and tedious step, as basically every part of the image was looked at and checked against any and all reference images available, section-by-section. The user then corrected misclassifications within small areas of interest to the correct classification. This was most easily accomplished where there was the most additional imagery to compare with, however the Joshua Creek Basin had many years for which there was nothing to compare but the SWFWMD LU/LC GIS files that are some years apart (i.e., 1980, 1988, 1995, 1999).

The last step was a final “recode” of the image, where the number of classes goes from thirty to the final seven or nine. Once accomplished, the result was used to arrive at the square mileage of land-use types for the ET measures in the water budget spreadsheet.
**Accuracy**

The process of checking accuracy is vital in every area of scientific research, particularly when there is user intervention or interpretation that creates potential for bias or altering of results. In the area of remote sensing, the best way to accomplish an accuracy assessment is by ground-truthing the data. Ground-truthing data consists of going into the field with randomly generated points and, in this instance, determining what type of land cover exists, then comparing that to the land cover type that has been determined by the program with the assistance of the expert. Aerial photographs, GIS maps, or LU/LC maps may also be provided by an outside agency to help with evaluating the accuracy of the analyses.

In this particular case, the study was somewhat handicapped by the fact that the most recent satellite images being studied were from 02-04-2000, while the year the ground truthing took place was 2003. Therefore, some minor interpretation must be done and reliance placed in the hands of the operator’s ability to accurately interpret changes. For some of the mines there were more recent satellite images that could be used as well as DOQQs. The results of the accuracy assessment are presented below. The accuracy assessment computed for this test used randomly generated reference points that were then ground-truthed in the field. The overall accuracy for the Joshua Creek drainage basin (unmined) classification was 76% and for the Payne Creek drainage basin (mined) was 78%. The accuracy reports are included in Appendix A.

**Water Budget Spreadsheet Model**

The square mileage from the land-use study of satellite images was then put into a water budget spreadsheet model. Recognizing that the general water budget is defined as in Equation 1, where \( R \) equals rain, \( P \) equals pumpage, \( SFI \) equals streamflow in, \( ET \) equals Evapotranspiration/Evaporation, \( RC \) equals recharge, \( SFO \) equals streamflow out, and \( \Delta S \) equals change in storage. The equation was then revised to Equation 2 and the water budget spreadsheet developed to operate by trying to predict the known measured data of \( SFO \) and assuming that \( \Delta S \) and \( RC \) are constant or unchanged over the time periods within their respective basins. Because the two factors that determine regional recharge, i.e., the average hydraulic gradient and the average vertical hydraulic conductivity of the confining layers between the surficial aquifer and the underlying intermediate and Floridan aquifers, do not change with time, the rate of recharge is not believed to change with time and is therefore presumed to be constant (see further discussion in section titled “Preliminary Analysis of Mining Effects on Deep Recharge”). Agricultural irrigation pumpage estimates from deep wells tapping the Upper Floridan Aquifer for the Joshua Creek Basin were estimated from the LU/LC area estimates. These estimates were multiplied by the irrigation requirements for a particular crop as used in the SWFWMD AGMOD model. This leaves the only undetermined variable to be \( ET \). It is recognized that this is a considerable portion of almost every water budget, especially in Florida, where \( ET \) can be as much as 85% of the water budget.
\[ R + P + SFI = ET + RC + SFO + \Delta S \] \hspace{1cm} \text{Equation 1.}

By rearranging terms, Equation 1 was revised to Equation 2 to calculate the resultant streamflow component SFO after the LU/LC have been mapped and multiplied by the appropriate ET factor.

\[ SFO = R + P + SFI - ET - RC \] \hspace{1cm} \text{Equation 2.}

An example of the water budget spreadsheet model is displayed in Figure B-4 in Appendix B. Figure 6 below illustrates the flow of the water budget spreadsheet analysis.

![Figure 6. Flow Diagram of Water Budget Spreadsheet Model.](image-url)
RESULTS

SATELLITE IMAGE ANALYSIS

The results of the land use mapping are presented in Tables 6 and 7 below and the final individual satellite maps with the square mileage of each land use category displayed are presented in Appendix A (following the accuracy assessment). Charts of the measured rain and streamflow inputs used for the water budget spreadsheet model are shown below in Figure 7. A map of the rain gauges used is shown as Appendix B (B-11). All available rain gauges with a reasonable amount of data were used (within and also outside the drainage basin when necessary). These rain data were summed seasonally and then averaged for each season. For the Payne Creek Basin, there were eight gauges used (six within the Basin, two from outside) and for the Joshua Creek Basin there were seven gauges used (six outside the Basin and one inside).

Table 6. Land Use Results in Square Mileage by Season for Joshua Creek Basin.

<table>
<thead>
<tr>
<th>LU</th>
<th>Pasture</th>
<th>Citrus</th>
<th>Wetland</th>
<th>Urban</th>
<th>Timber</th>
<th>Water</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>J'85w</td>
<td>67</td>
<td>26</td>
<td>18</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J'85s</td>
<td>66</td>
<td>26</td>
<td>18</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J'86w</td>
<td>69</td>
<td>26</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J'86s</td>
<td>69</td>
<td>25</td>
<td>17</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J'88w</td>
<td>70</td>
<td>23</td>
<td>17</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J'88s</td>
<td>66</td>
<td>26</td>
<td>17</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J'91w</td>
<td>58</td>
<td>34</td>
<td>18</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J'91s</td>
<td>60</td>
<td>35</td>
<td>13</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J'92w</td>
<td>58</td>
<td>34</td>
<td>15</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J'92s</td>
<td>59</td>
<td>33</td>
<td>16</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J'93w</td>
<td>57</td>
<td>35</td>
<td>16</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J'93s</td>
<td>58</td>
<td>34</td>
<td>16</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J'95w</td>
<td>53</td>
<td>34</td>
<td>20</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J'95s</td>
<td>56</td>
<td>34</td>
<td>16</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>J'96w</td>
<td>54</td>
<td>34</td>
<td>19</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>J'96s</td>
<td>53</td>
<td>34</td>
<td>20</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>J'98w</td>
<td>54</td>
<td>35</td>
<td>18</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>J'98s</td>
<td>55</td>
<td>35</td>
<td>17</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: Satellite images without eligible imagery for both basins were not included in this table.
Table 7. Land Use Results in Square Mileage by Season for Payne Creek Basin.

<table>
<thead>
<tr>
<th>LU</th>
<th>Pasture</th>
<th>Citrus</th>
<th>Wetland</th>
<th>Urban</th>
<th>Timber</th>
<th>Water</th>
<th>CSA</th>
<th>Dist. Tailings</th>
<th>Dist. Land</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>P'85w</td>
<td>42</td>
<td>14</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>P'85s</td>
<td>40</td>
<td>14</td>
<td>17</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>P'86w</td>
<td>43</td>
<td>14</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>P'86s</td>
<td>45</td>
<td>14</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>P'88w</td>
<td>39</td>
<td>14</td>
<td>26</td>
<td>2</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>P'88s</td>
<td>39</td>
<td>15</td>
<td>24</td>
<td>3</td>
<td>6</td>
<td>13</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>P'91w</td>
<td>34</td>
<td>15</td>
<td>21</td>
<td>3</td>
<td>7</td>
<td>11</td>
<td>6</td>
<td>4</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>P'91s</td>
<td>29</td>
<td>16</td>
<td>23</td>
<td>3</td>
<td>6</td>
<td>18</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>P'92w</td>
<td>33</td>
<td>17</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>16</td>
<td>8</td>
<td>3</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>P'92s</td>
<td>30</td>
<td>15</td>
<td>20</td>
<td>2</td>
<td>4</td>
<td>18</td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>P'93w</td>
<td>23</td>
<td>16</td>
<td>26</td>
<td>2</td>
<td>7</td>
<td>15</td>
<td>6</td>
<td>9</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>P'93s</td>
<td>27</td>
<td>14</td>
<td>25</td>
<td>3</td>
<td>4</td>
<td>15</td>
<td>7</td>
<td>7</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>P'95w</td>
<td>24</td>
<td>13</td>
<td>20</td>
<td>2</td>
<td>6</td>
<td>13</td>
<td>12</td>
<td>8</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>P'95s</td>
<td>30</td>
<td>14</td>
<td>21</td>
<td>3</td>
<td>7</td>
<td>10</td>
<td>13</td>
<td>8</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>P'96w</td>
<td>31</td>
<td>11</td>
<td>22</td>
<td>2</td>
<td>4</td>
<td>13</td>
<td>12</td>
<td>9</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>P'96s</td>
<td>27</td>
<td>11</td>
<td>17</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>15</td>
<td>13</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>P'98w</td>
<td>30</td>
<td>12</td>
<td>25</td>
<td>2</td>
<td>2</td>
<td>13</td>
<td>8</td>
<td>7</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>P'98s</td>
<td>22</td>
<td>10</td>
<td>26</td>
<td>20</td>
<td>2</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>30</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Satellite images without eligible imagery for both basins were not included in this table.
Figure 7. Streamflow (BCF/Season) and Rain (BCF/Season) for Joshua Creek and Payne Creek Basins.
Table 8. Daily Mean Streamflow per Basin Reported Seasonally.

<table>
<thead>
<tr>
<th>Payne Daily Mean Streamflow CF/Season</th>
<th>Payne BCF/Season</th>
<th>Season/Year</th>
<th>Payne Daily Mean Streamflow CF/Season</th>
<th>Payne BCF/Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,992</td>
<td>0.35</td>
<td>Dry 84-85</td>
<td>2,588</td>
<td>0.2</td>
</tr>
<tr>
<td>19,449</td>
<td>1.7</td>
<td>Wet 85</td>
<td>20,722</td>
<td>1.8</td>
</tr>
<tr>
<td>12,045</td>
<td>1.0</td>
<td>Dry 85-86</td>
<td>13,734</td>
<td>1.2</td>
</tr>
<tr>
<td>17,961</td>
<td>1.6</td>
<td>Wet 86</td>
<td>14,438</td>
<td>1.3</td>
</tr>
<tr>
<td>15,235</td>
<td>1.3</td>
<td>Dry 86-87</td>
<td>23,157</td>
<td>2.0</td>
</tr>
<tr>
<td>13,407</td>
<td>1.2</td>
<td>Wet 87</td>
<td>12,264</td>
<td>1.1</td>
</tr>
<tr>
<td>23,297</td>
<td>2.0</td>
<td>Dry 87-88</td>
<td>20,419</td>
<td>1.8</td>
</tr>
<tr>
<td>29,869</td>
<td>2.6</td>
<td>Wet 88</td>
<td>30,721</td>
<td>2.7</td>
</tr>
<tr>
<td>13,269</td>
<td>1.1</td>
<td>Dry 88-89</td>
<td>7,362</td>
<td>0.6</td>
</tr>
<tr>
<td>9,155</td>
<td>0.8</td>
<td>Wet 89</td>
<td>13,750</td>
<td>1.2</td>
</tr>
<tr>
<td>12,637</td>
<td>1.1</td>
<td>Dry 89-90</td>
<td>12,217</td>
<td>1.1</td>
</tr>
<tr>
<td>10,008</td>
<td>0.9</td>
<td>Wet 90</td>
<td>13,399</td>
<td>1.2</td>
</tr>
<tr>
<td>13,204</td>
<td>1.1</td>
<td>Dry 90-91</td>
<td>11,956</td>
<td>1.0</td>
</tr>
<tr>
<td>25,877</td>
<td>2.2</td>
<td>Wet 91</td>
<td>26,392</td>
<td>2.3</td>
</tr>
<tr>
<td>12,052</td>
<td>1.0</td>
<td>Dry 91-92</td>
<td>7,139</td>
<td>0.6</td>
</tr>
<tr>
<td>26,604</td>
<td>2.3</td>
<td>Wet 92</td>
<td>42,140</td>
<td>3.6</td>
</tr>
<tr>
<td>23,914</td>
<td>2.1</td>
<td>Dry 92-93</td>
<td>20,915</td>
<td>1.8</td>
</tr>
<tr>
<td>12,611</td>
<td>1.1</td>
<td>Wet 93</td>
<td>7,281</td>
<td>0.6</td>
</tr>
<tr>
<td>15,674</td>
<td>1.4</td>
<td>Dry 93-94</td>
<td>8,399</td>
<td>0.7</td>
</tr>
<tr>
<td>42,956</td>
<td>3.7</td>
<td>Wet 94</td>
<td>37,944</td>
<td>3.3</td>
</tr>
<tr>
<td>38,138</td>
<td>3.3</td>
<td>Dry 94-95</td>
<td>20,972</td>
<td>1.8</td>
</tr>
<tr>
<td>38,749</td>
<td>3.3</td>
<td>Wet 95</td>
<td>55,122</td>
<td>4.8</td>
</tr>
<tr>
<td>31,895</td>
<td>2.8</td>
<td>Dry 95-96</td>
<td>21,068</td>
<td>1.8</td>
</tr>
<tr>
<td>10,172</td>
<td>0.9</td>
<td>Wet 95-96</td>
<td>10,853</td>
<td>0.9</td>
</tr>
<tr>
<td>9,745</td>
<td>0.8</td>
<td>Dry 96-97</td>
<td>12,830</td>
<td>1.1</td>
</tr>
<tr>
<td>14,731</td>
<td>1.3</td>
<td>Wet 97</td>
<td>18,283</td>
<td>1.6</td>
</tr>
<tr>
<td>72,348</td>
<td>6.3</td>
<td>Dry 97-98</td>
<td>58,228</td>
<td>5.03</td>
</tr>
<tr>
<td>25,870</td>
<td>2.2</td>
<td>Wet 98</td>
<td>19,607</td>
<td>1.7</td>
</tr>
<tr>
<td>21,357</td>
<td>1.8</td>
<td>Dry 98-99</td>
<td>12,053</td>
<td>1.0</td>
</tr>
<tr>
<td>10,639</td>
<td>0.9</td>
<td>Wet 99</td>
<td>27,111</td>
<td>2.3</td>
</tr>
<tr>
<td>9,370</td>
<td>0.8</td>
<td>Dry 99-00</td>
<td>6,981</td>
<td>0.6</td>
</tr>
<tr>
<td>3,937</td>
<td>0.3</td>
<td>Wet 00</td>
<td>10,511</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Note: Dry season is Oct-May, wet season is June-Sept.
<table>
<thead>
<tr>
<th></th>
<th>Payne Rain by Season</th>
<th>Joshua Rain by Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum Avg. /Season</td>
<td>BCF/Season</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.17</td>
<td>2.86</td>
<td>Dry 84-85</td>
</tr>
<tr>
<td>29.73</td>
<td>8.36</td>
<td>Wet 85</td>
</tr>
<tr>
<td>16.75</td>
<td>4.71</td>
<td>Dry 85-86</td>
</tr>
<tr>
<td>29.766</td>
<td>8.37</td>
<td>Wet 86</td>
</tr>
<tr>
<td>22.69</td>
<td>6.38</td>
<td>Dry 86-87</td>
</tr>
<tr>
<td>27.03</td>
<td>7.60</td>
<td>Wet 87</td>
</tr>
<tr>
<td>14.98</td>
<td>4.21</td>
<td>Dry '87-'88</td>
</tr>
<tr>
<td>35.28</td>
<td>9.92</td>
<td>Wet '88</td>
</tr>
<tr>
<td>15.85</td>
<td>4.46</td>
<td>Dry '88-'89</td>
</tr>
<tr>
<td>26.11</td>
<td>7.34</td>
<td>Wet '89</td>
</tr>
<tr>
<td>15.97</td>
<td>4.49</td>
<td>Dry '89-'90</td>
</tr>
<tr>
<td>28.35</td>
<td>7.97</td>
<td>Wet '90</td>
</tr>
<tr>
<td>25.52</td>
<td>7.17</td>
<td>Dry '90-'91</td>
</tr>
<tr>
<td>29.74</td>
<td>8.36</td>
<td>Wet '91</td>
</tr>
<tr>
<td>16.44</td>
<td>4.62</td>
<td>Dry '91-'92</td>
</tr>
<tr>
<td>31.41</td>
<td>8.83</td>
<td>Wet '92</td>
</tr>
<tr>
<td>24.56</td>
<td>6.90</td>
<td>Dry '92-'93</td>
</tr>
<tr>
<td>23.10</td>
<td>6.50</td>
<td>Wet '93</td>
</tr>
<tr>
<td>20.37</td>
<td>5.73</td>
<td>Dry '93-'94</td>
</tr>
<tr>
<td>43.30</td>
<td>12.17</td>
<td>Wet '94</td>
</tr>
<tr>
<td>19.50</td>
<td>5.48</td>
<td>Dry '94-'95</td>
</tr>
<tr>
<td>33.98</td>
<td>9.55</td>
<td>Wet '95</td>
</tr>
<tr>
<td>26.08</td>
<td>7.33</td>
<td>Dry '95-'96</td>
</tr>
<tr>
<td>19.51</td>
<td>5.49</td>
<td>Wet '96</td>
</tr>
<tr>
<td>19.97</td>
<td>5.62</td>
<td>Dry '96-'97</td>
</tr>
<tr>
<td>20.40</td>
<td>5.74</td>
<td>Wet '97</td>
</tr>
<tr>
<td>31.94</td>
<td>8.98</td>
<td>Dry '97-'98</td>
</tr>
<tr>
<td>29.64</td>
<td>8.33</td>
<td>Wet '98</td>
</tr>
<tr>
<td>14.98</td>
<td>4.21</td>
<td>Dry '98-'99</td>
</tr>
<tr>
<td>26.78</td>
<td>7.53</td>
<td>Wet '99</td>
</tr>
<tr>
<td>9.72</td>
<td>2.73</td>
<td>Dry '99-'00</td>
</tr>
<tr>
<td>22.96</td>
<td>6.45</td>
<td>Wet '00</td>
</tr>
</tbody>
</table>

Note: Dry season is Oct-May, wet season is June-Sept.
MODEL RESULTS AND VERIFICATION

In the water budget model the outputs were the predicted surface water outflows from the Joshua and Payne Creek Basins. SI attempted to quantify all the model input parameters, but was not able to obtain these inputs for all the years that were to be modeled. The ET/EV parameters are derived from the size and the land-use, multiplied by the ET/EV rate for that particular land-use category. There were nine years (as shown in Tables 6 and 7) in which satellite coverage was sufficiently clear simultaneously in both basins and both seasons to determine the individual land-use sizes. Very little or no information was reliably available for pumpage or recharge for the time period. It was therefore decided to calculate streamflow as a function of rainfall and ET/EV. To accommodate the differences between the dry season and wet season analyses, the observed rain and streamflow as well as the modeled results were listed as dry season, wet season and water year. The water-year results are the addition of the dry-season and wet-season results. The results are listed in billion cubic feet per season and water year.

Joshua Creek Basin Modeling Results

The modeling results of the Joshua Creek Basin are shown in Figures 8 through 10, which represent the wet season, dry season and water year information and include the rainfall, the observed (measured) stream flow, and the modeled stream flow. In general the modeled results follow the trends shown by the observed data. This is not surprising because the rainfall input is a dominant factor. It is interesting to note that the model underestimated the ET/EV losses during the wet season as shown in Figure 8, in which the modeled data points are above the measured data points except in 1988. In Figure 9, the results of the dry season modeling runs are showing that the model predicted streamflow is consistently lower that the measured streamflow values. In Figure 10, the information shows that on an annual basis, the model still underestimates the streamflow in seven of the nine years. In 1995 the model-predicted streamflow matched the measured streamflow and in 1986 the model-predicted streamflow was higher than the measured streamflow. The negative values shown for predicted streamflow mean that in the real world, the stream would be dry and no surface flow would be measured. If actual flow is still occurring at these times, it might be a contribution of unmeasured importation or model under-predicting.
Figure 8. Joshua Modeled Versus Measured Streamflow with Rain (Wet Seasons).

Figure 9. Joshua Modeled Versus Measured Streamflow with Rain (Dry Seasons).
Payne Creek Basin Modeling Results

The modeling results of the Payne Creek Basin are shown in Figures 11 through 13, which represent the wet season, dry season and water year information and include the rainfall, the observed (measured) streamflow, and the modeled streamflow. In general, the modeled results follow the trends shown by the observed data. This is not surprising because the rainfall input is a dominant factor. As shown in the Joshua Creek results, the model underestimated the ET/EV losses during the wet season as shown in Figure 11, in which the modeled data points are above the measured data points except in 1995. In Figure 121, the results of the dry season modeling runs are showing that the model-predicted streamflow is consistently lower that the measured streamflow values. In Figure 13, the information shows that on an annual basis, the model still underestimates the streamflow in eight of the nine years.
Figure 11. Payne Modeled Versus Measured Streamflow with Rain (Wet Seasons).

Figure 12. Payne Modeled Versus Measured Streamflow with Rain (Dry Seasons).
Verification of Modeling Results

There are many factors that influence the modeling results. One of those is the importation of water into the basin from sources other than rainfall, such as pumpage from the underlying Floridan Aquifer by irrigation of agricultural crops. In the Joshua Creek Basin there are approximately 37 square miles of orange grove that are irrigated. Assuming that an average of 18 inches of irrigation per year for orange groves will be permitted the total importation of irrigation water amounts to 35,520 acre-feet or 1.55 BCF. Further, assuming 85% irrigation efficiency implies that a maximum of 15% could be supplemental streamflow, or 0.232 BCF. On an average annual basis, the difference between the model-predicted streamflow and the measured streamflow is 1.29. It is anticipated that the average annual importation of ground water is 0.23 BCF, reducing the difference between the measured and predicted streamflow to 1.06 BCF/year, resulting in an overestimation of 3.8 inches of ET/EV per year. This is less than 10% of the average annual totals.

To further evaluate the differences between the measured and modeled streamflows, scatter diagrams were prepared as shown in Figures B-5 through B-10 in Appendix B. Best-fit linear trend lines were drawn through the six graphs and the linear equations (y = bx + c) were listed in the graphs along with the sum of the least squares values ($R^2$). The results are summarized in the following Table 10.
Table 10. Best Line Fit Coefficients of Scatter Diagrams Between Measured and Model-Predicted Streamflows.

<table>
<thead>
<tr>
<th></th>
<th>Joshua Creek</th>
<th>Payne Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>“b”</td>
<td>1.2828</td>
<td>1.2230</td>
</tr>
<tr>
<td>R²</td>
<td>0.5813</td>
<td>0.8458</td>
</tr>
</tbody>
</table>

In an ideal case, the values of the model streamflows would equal those of the measured streamflows. In such a case, the “b” coefficient would be 1.000. Thus the closer the “b” values are to 1.000 the better the relationship between the modeled and measured streamflow value. Based on this criterion, the best correlation is for the annual flow in the Joshua Creek Basin. The second best correlation is for the dry-season flow in the Payne Creek Basin.

There is quite a “scatter” in the data. However, the R² values provide an indication of how well the entire data sets correlate. The weakest correlation was for the wet season in the Joshua Creek Basin, the strongest for the dry season in the Joshua Creek Basin.

While a very large effort was undertaken to properly identify the land-uses and land classifications and combine these with the best available ET/EV rates, the modeling results were less than decisive in answering the question of the impacts of LU/LC changes caused by phosphate mining on streamflow.

COMPARISONS BETWEEN JOSHUA CREEK AND PAYNE CREEK BASINS

Set-Up

Because the modeling results were somewhat inconclusive about the impact of phosphate mining on streamflow, SI considered another approach by comparing the measured rainfall inputs into each basin and comparing the resultant measured streamflow outputs from each basin for the 16-year period. In Figure 13, a double-mass plot is presented of the annual rainfall in the Joshua and Payne Creek Basins. In Figure 13, a best-fit linear trend line was added as well as the equation governing that trend line and the R² value. In Figure 14, a best-fit polynomial trend line was added to the double mass curve of the annual rainfall in both basins.

In Figure 15, the double mass plot of the annual measured streamflow in the Joshua and Payne Creek Basins is presented. A best-fit linear trend line is added to the double mass plot in Figure 15, along with the equations governing that trend line. In Figure 16, a best fit polynomial trend line is added to the double mass plot along with its governing equation and sum of least square numbers.
Comparative Analysis

The data plotted in Figure 14 indicates an $R^2$ of 0.9982, which indicates a very good fit. If the rainfall in the Joshua Creek and Payne Creek Basins were identical in value over this period, the straight line in Figure 14 would be represented with an “a” coefficient of 1.0000. The fact that the “a” coefficient in Figure 14 shows as 1.0286 indicates that it had an upward slope, implying more rain fell in the Joshua Creek Basin than the Payne Creek Basin. Therefore, the information in Figure 14 indicates that over the 16-year period slightly more rain (2.86%) fell on the Joshua Creek Basin than on the Payne Creek Basin. Similarly, as shown in Figure 16, the straight-line double-mass analysis indicates that the streamflow from the Payne Creek Basin is $[(1.0000 - 0.9497) \times 100\%]$, or 5% greater than from the Joshua Creek Basin. These trends are further confirmed by the fact that the “a” coefficient in Figure 15 indicating that the rate of change towards more rainfall on the Joshua Creek Basin is slightly positive, while the “a” coefficient in Figure 17, indicating increasing streamflow in the Payne Creek Basin, is slightly negative.

Based on these comparisons, it can be concluded that while the rainfall on the Payne Creek Basin was less during the 16-year period, the streamflow was more than in the Joshua Creek Basin with a comparable basin size, but no phosphate mining. It can therefore be reasonably argued that phosphate-mining operations do not diminish streamflow. To better define this conclusion, SI performed many and much more detailed analyses of the rainfall/streamflow relationships in several of the river basins and basins to the Peace River watershed. These analyses are presented in the next section.

**Figure 14. Cumulative Double Mass of Rain for Joshua and Payne Creek Basins (Linear).**
Figure 15. Cumulative Double Mass of Rain for Joshua and Payne Creek Basins (Polynomial).

Figure 16. Cumulative Double Mass of Streamflow for Joshua and Payne Creek Basins (Linear).
Figure 17. Cumulative Double Mass of Streamflow for Joshua and Payne Creek Basins (Polynomial).

\[ y = -0.0018x^2 + 1.0529x - 0.0578 \]

\[ R^2 = 0.9993 \]
MULTIPLE STREAMFLOW ANALYSES

METHODOLOGY

The LU/LC and ET approach was a deterministic method used in the water budget spreadsheet model. Because there is no comprehensive agreement among the many environmental scientists, engineers and biologists regarding the ET rates from different LU/LC, the results of the spreadsheet model varied accordingly. While this is of great interest to present general trends, it is not a very sensitive tool to accurately determine if and to what extent land use changes might have affected streamflow. A more detailed approach is to analyze the direct relationship between the rainfall input into a basin and the resultant streamflow leaving that basin. If the rainfall inputs vary, the resultant streamflow outflows should vary accordingly. If any changes in the long-term hydrologic behavior of the watershed occur, the overall long-term relationship between rainfall inputs and streamflow output is expected to change accordingly. Therefore, relating the long-term rainfall inputs directly to the long-term streamflow outputs provides a tool to evaluate the long-term hydrologic changes in the watershed.

The approach selected for relating the long-term rainfall to long-term streamflow is the double-mass plotting method. To evaluate the changes in the rainfall or streamflow with time, the single-mass plotting method was used. While visual inspections of the plotted line could indicate a change in the relationship between the rainfall and streamflow at the point where the line deviated markedly from its linearity, for this study SI employed curve-fitting techniques. These techniques produce general equations to describe the best-fit line. These equations can be both linear and polynomial. The linear equations reveal a fixed relationship between the two variables of the double-mass plotting method. The polynomial (quadratic) curve-fitting of the double-mass data indicates the degree of change in the relationship between rainfall and streamflow.

The general equation relating streamflow to rainfall can be rewritten as:

\[ SFO = R + [P + SFI - (ET + RC)] \]  

Equation 3.

In these equations, \( R \) = rain, \( P \) = pumpage, \( SFI \) = streamflow in, \( ET \) = Evapotranspiration/Evaporation, \( RC \) = recharge, \( SFO \) = streamflow out and \( \Delta S \) = change in storage. This study opted to relate SFO and R to each other as the dependent and independent variables. The relationship is, however, influenced by the term:

\[ [P + SFI - (ET + RC)] \]  

Equation 4.

This term was chosen to define the overall basin characteristics. From a practical point of view, the ET term is by far the largest variable. For example, the general regional water budget for the SWUCA lists the long-term average annual rainfall (R) as 53.0 inches per year, the ET as 42.0 inches per year, pumpage (P) from the Floridan Aquifer as 2.5 inches per year, recharge (RC) to the Floridan Aquifer as 2.0 inches per
year, streamflow into the SWUCA at 0.0 inches per year, and streamflow from the SWUCA as 11.5 inches per year. It is clear from the numbers quoted in the example that the ET value is the second largest value (after rainfall) in the general water budget.

In the actual streamflow analyses, SI relied to a large extent on the single- and double-mass plotting approach. An example of a single-mass plot is relating the cumulative sum of rainfall at a given location to the time since the data was collected. A double-mass is a plot of the cumulative sum of rainfall, for example, versus the sum of the cumulative streamflow for equivalent time periods or similar occurrences.

Once the single- and double-mass plots were prepared, SI employed linear and polynomial curve fitting techniques and analyzed these results. It is important to mention that in general the linear and polynomial curve fitting technique provided results that were statistically satisfactory in that the $R^2$ value for all data plots was well above 0.98 (98%) value. The $R^2$ value is an indication how well a given line goes through all the points plotted on a graph. The closer the $R^2$ value approaches the value of 1.0 (100%), the better the fit and the more “believable” the predictions are that are based on these analyses.

The mathematical expression of the polynomial and linear data point fit lines are presented as:

\[ y = ax^2 + bx + c \]  \hspace{1cm} \text{(Polynomial) Equation 5.} \]

and

\[ y = bx + c \]  \hspace{1cm} \text{(Linear) Equation 6.} \]

in which:

- $y =$ the cumulative value of the unit streamflow in cfsm
- $x =$ the cumulative value of the unit rainfall in cfsm
- $a =$ coefficient describing the rate of change of the slope
- $b =$ coefficient describing the slope of the data point fitting line
- $c =$ the value on the y axis where the fitted line will intercept the y-axis

The polynomial curve-fitting approach is particularly useful, because the value of the “$a$” coefficient indicates whether, during the time period for which the data points were plotted, unit streamflow increased, remained the same or decreased with respect to the unit rainfall input. For example a positive “$a$” value indicates that unit streamflow is increasing, while a negative value indicates that it was decreasing. A zero value of “$a$” indicates streamflow remained unchanged. The “$b$” value indicates the general slope of the line; the slope of the line indicates the general relationship between the unit rainfall and unit streamflow. The lower the value of “$b$,” the smaller the unit streamflow value will be as it relates to the unit rainfall.
In the multiple streamflow analysis approach, it was decided to look at the time period of 1980 to 2000 and to utilize the measured streamflow and rain data of SWFWMD. In addition, the long-term rainfall and streamflow records were analyzed for selected streams to establish when the relationship between rainfall and streamflow changed. Further, a detailed analysis of selected time intervals was done and the results compared. The purpose of these analyses was to establish degrees to which changes in the watershed might have influenced the rainfall/streamflow relationship.

The annual totals were used for rainfall and converted to cubic feet per second per square mile (cfsm) to be in comparable units to streamflow. This cumulative data was then plotted as double-mass charts with $R^2$ and trendline equations for both polynomial and linear fits. For reference, one inch of rain on one square mile is equal to 53.3 acre-feet, or 0.074 cfsm.

To quantify the "importation" of water into a stream basin, "importation" is defined as any water that is pumped from a confined aquifer underlying the basin or any water that is imported as surficial water from an area outside the watershed boundaries of the stream drainage basin. A serious effort was made to quantify the importation of water by deep groundwater pumpage. As shown previously, the quantity of the deep groundwater pumpage ($P$) is rather small in comparison to the rainfall ($R$) and evapotranspiration ($ET$). Because few metering records exist of agricultural pumpage, SI estimated the agricultural pumpage based on the observed and recorded acreages and crop use, as illustrated in the following paragraphs.

**Hypotheses Underlying the Streamflow Analyses**

SI asserts that importation of water for irrigation acts as an additional source of water into the surface systems of a watershed. This importation may in turn show up as an additional streamflow component. Similarly, phosphate mining and subsequent reclamation reduces the water losses from evapotranspiration ($ET$), thereby allowing the salvaged water to be recorded as additional streamflow. In addition to the salvage of reduced ET losses, active mining operations import water from the underlying confined aquifers as production and sealing water well pumpage. Both activities will allow more water to be present in a watershed and thus be measured as additional streamflow.

In the single- and double-mass analyses, the location of the stream gaging station was related to a rain gaging station(s) in the same basin or basin in which streamflow was being recorded, or SWFWMD totals for that basin were used when available and appropriate.
RESULTS

Extent of Phosphate Mined/Reclaimed and Irrigated Agricultural Lands

SI used GIS information provided by SWFWMD and other sources to determine the extent of lands that were mined/reclaimed or are still being mined for phosphate ore extraction and lands that are being irrigated with water assumed to be pumped from the Floridan Aquifer. This effort extended to all of the three major river basins as well as all the basins in the SWUCA.

A working hypothesis was that land use could be used as a possible identifier of importation to the drainage basin from outside sources or the underlying Floridan Aquifer system. The land use types were determined from the 1999 land use GIS coverages from SWFWMD. The three types of land use focused on for this part of the study were irrigated agriculture, mining and other. Irrigated agriculture was determined to be any FLUCCS code of 2140 (row crops), 2200 (tree crops), 2400 (nurseries and vineyards) and 2440 (vineyards). The mining class was determined to be the FLUCCS code of 1600 (extractive). All remaining categories were considered not a source of importation so they were combined into a class called “other.”

When clipping all the land use data to the individual basin boundaries, it was discovered that there was a discrepancy between the total basin areas listed in the USGS Water Resources Data Books versus the areas calculated by the GIS software. The shapefiles for the drainage basins were obtained from the USGS as well, and after many contacts with the USGS, it was determined that the published area had not been updated in many years; therefore, the GIS data areas were used in this study. Table 11 provides a summary of the differences between the two reported areas.

Table 11. Comparison of USGS Drainage Basin Areas Used for Study.

<table>
<thead>
<tr>
<th>Drainage Basin Name</th>
<th>USGS Published Area in mi²</th>
<th>USGS Shapefile Area mi²</th>
<th>Difference in mi² (Book - Shapefile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alafia @ Lithia</td>
<td>335</td>
<td>336</td>
<td>-1</td>
</tr>
<tr>
<td>S Prong Alafia nr Lithia</td>
<td>107</td>
<td>102</td>
<td>5</td>
</tr>
<tr>
<td>Bowlegs nr Ft Meade</td>
<td>47</td>
<td>47</td>
<td>0</td>
</tr>
<tr>
<td>Charlie nr Gardner</td>
<td>330</td>
<td>330</td>
<td>0</td>
</tr>
<tr>
<td>Horse nr Arcadia</td>
<td>218</td>
<td>220</td>
<td>-2</td>
</tr>
<tr>
<td>Horse nr Myakka Head</td>
<td>42</td>
<td>41</td>
<td>1</td>
</tr>
<tr>
<td>Joshua @ Nocatee</td>
<td>132</td>
<td>120</td>
<td>12</td>
</tr>
<tr>
<td>Little Manatee nr Wimauma</td>
<td>149</td>
<td>148</td>
<td>1</td>
</tr>
<tr>
<td>Manatee nr Myakka Hd</td>
<td>65</td>
<td>68</td>
<td>-2</td>
</tr>
<tr>
<td>Myakka nr Sarasota</td>
<td>229</td>
<td>232</td>
<td>-3</td>
</tr>
<tr>
<td>Payne nr Bowling Green</td>
<td>121</td>
<td>122</td>
<td>-1</td>
</tr>
<tr>
<td>Peace @ Arcadia</td>
<td>1367</td>
<td>1362</td>
<td>5</td>
</tr>
<tr>
<td>Peace @ Bartow</td>
<td>390</td>
<td>390</td>
<td>0</td>
</tr>
<tr>
<td>Peace @ Ft Meade</td>
<td>480</td>
<td>466</td>
<td>14</td>
</tr>
<tr>
<td>Peace @ Zolfo Springs</td>
<td>826</td>
<td>825</td>
<td>1</td>
</tr>
<tr>
<td>Withlacoochee @ Trilby</td>
<td>570</td>
<td>572</td>
<td>-2</td>
</tr>
<tr>
<td>Withlacoochee nr Holder</td>
<td>1820</td>
<td>1831</td>
<td>-11</td>
</tr>
</tbody>
</table>
The locations of the major river basins and the basins are presented in Figure 18. It should be noted that for the Withlacoochee and Alafia River Basins, SI only shows that area extent of the basin upstream from the gaging station for which data were used in the analyses. Also presented in Figure 18 are the basins in the SWUCA. After SI established the total drainage areas in the major river and basins, the next step was recording the irrigated acreages and mined acreages in each basin. The remaining acreages were classified as “other.” The results of these analyses for the basins in the SWUCA are presented in Table 12. The results of these analyses for the three major river basins are presented in Figure 19. Embedded in Figure 19 is a table summarizing the information.

It is interesting to note that in 1999 approximately 229 square miles had been, or were being, mined/reclaimed to extract phosphate ore in the Peace River Basin. This is a little less than ten percent (10%) of the overall drainage area of 2,346 square miles.

In the Alafia River Basin, 151 square miles had been, or were being, mined and reclaimed for the extraction of phosphate ore. This represents less than thirty six percent (36%) of the 422 square mile drainage basin.

In the Withlacoochee River Basin, 23 square miles had been, or were being, mined and reclaimed primarily for limestone aggregate (no phosphate). This represents slightly more than one percent (1%) of the 2,058 square mile drainage basin.

Table 12. SWFWMD Land Use (1999) for Drainage Basins for Mined, Unmined and Other Lands.

<table>
<thead>
<tr>
<th>Basin</th>
<th>Dbasin mi²</th>
<th>Irrigated mi²</th>
<th>Mined mi²</th>
<th>Other mi²</th>
<th>Irrigated %</th>
<th>Mined %</th>
<th>Other %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S Prong Alafia</td>
<td>102</td>
<td>3</td>
<td>72</td>
<td>27</td>
<td>3</td>
<td>70</td>
<td>27</td>
</tr>
<tr>
<td>Alafia</td>
<td>336</td>
<td>26</td>
<td>147</td>
<td>163</td>
<td>7</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>Little Manatee</td>
<td>148</td>
<td>11</td>
<td>32</td>
<td>105</td>
<td>7</td>
<td>22</td>
<td>71</td>
</tr>
<tr>
<td>Manatee</td>
<td>68</td>
<td>5</td>
<td>8</td>
<td>55</td>
<td>8</td>
<td>11</td>
<td>81</td>
</tr>
<tr>
<td>Horse</td>
<td>220</td>
<td>22</td>
<td>15</td>
<td>183</td>
<td>10</td>
<td>7</td>
<td>83</td>
</tr>
<tr>
<td>Payne</td>
<td>122</td>
<td>10</td>
<td>78</td>
<td>34</td>
<td>8</td>
<td>64</td>
<td>28</td>
</tr>
<tr>
<td>Joshua</td>
<td>120</td>
<td>37</td>
<td>0</td>
<td>83</td>
<td>31</td>
<td>0</td>
<td>69</td>
</tr>
<tr>
<td>Charlie</td>
<td>330</td>
<td>49</td>
<td>0</td>
<td>281</td>
<td>15</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>Bowlegs</td>
<td>47</td>
<td>8</td>
<td>0</td>
<td>39</td>
<td>17</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>Myakka</td>
<td>232</td>
<td>26</td>
<td>2</td>
<td>204</td>
<td>11</td>
<td>1</td>
<td>88</td>
</tr>
<tr>
<td>Upper Horse</td>
<td>41</td>
<td>2</td>
<td>13</td>
<td>26</td>
<td>5</td>
<td>31</td>
<td>64</td>
</tr>
</tbody>
</table>
Figure 18. Drainage Basins Used for Streamflow Study with Outline of Central Florida Counties and Major Rivers.
Integrated Rainfall/Streamflow Analyses

This chapter analyzes and compares the rainfall/streamflow relationships in the three major river basins followed by analyses of the streams in the basins in the SWUCA.
The purpose of this analysis was to determine if there are meaningful differences in patterns between predominantly mined basins and unmined basins.

Three Major River Basins

The Alafia, Withlacoochee and Peace River Basins were studied intensively, comparing rainfall to annual mean streamflow from the respective rivers. The Alafia and Peace River Basins are the major hydrologic units located within the Southern Water Use Caution Area (SWUCA) and have differing land uses. The Withlacoochee has differing land uses as well as geological and hydrological configuration. It is expected that these contributing factors have varying degrees of impact on the streamflow within their basins, such as inputs of excess runoff from irrigation practices for agriculture or increased drawdown from withdrawals of groundwater for pumping. The Withlacoochee surficial system is in more direct hydraulic contact with underlying aquifers than the other basins studied. The Peace and Alafia systems have confining layers that do not allow for the recharge/recycling capacity of the Withlacoochee. The Withlacoochee also receives significantly more input from natural springs than the Peace and Alafia Rivers do. The Withlacoochee River does not have the importation from the agricultural community that the Peace or Alafia Rivers have (nor the importation from mining activities). This outside input would account for the majority of differences (anthropogenic inputs) in the trends seen between the basins.

SWFWMD has been an advocate of comparing the hydrology of the three major river basins in an attempt to address an assertion that certain land uses such as phosphate mining have been the main cause of the decline in surface water flow in the Peace and Alafia Rivers. At the 18th Annual Regional Phosphate Conference (late 2003), Dr. Marty Kelly of SWFWMD showed a slide that presented the comparison of flows for the three major river drainages (Kelly 2004). He presented the Five Year Running Average for the Peace River at Arcadia, the Withlacoochee at Holder, and the Alafia River at Lithia. While this graphical illustration showed similar patterns and was therefore used to emphasize that there is essentially no difference and therefore the assertion does not have a foundation in fact, SI decided to prepare a more mathematically based analysis. Figure 20 presents the single-mass correlation between time and cumulative rainfall in the three river basins (upper part of the graph) for the 1980 to 2000 period. The closeness of the lines illustrates that the cumulative rainfall in the Peace and Withlacoochee River drainage basins was quite similar. Cumulative rainfall in the Alafia River drainage basin was slightly less during this time period.

On the bottom of Figure 20 are the cumulative single-mass curves of the streamflow versus time for the 1980 to 2000 period. These curves show that the largest streamflow occurred in the Alafia River, followed by a lesser flow in the Peace River. The flow in the Withlacoochee River was less than those in the Peace and Alafia Rivers.
Comparing these two graphs leads to the observation that, while the unit cumulative rainfall is the least in the Alafia River, the unit cumulative streamflow is the highest. Or, while the unit cumulative rainfall in the Alafia is less than in the Peace River Basin, the streamflow in the Alafia River is markedly higher than in the Peace River.

To further explore the potential impact of groundwater importation on streamflow, SI determined the total acreages of the three land uses, as previously discussed. In the table in Figure 19 the land use in the three major river basins is listed as recorded by SWFWMD in 1999. In Figure 19, the total acreage of phosphate-mined and reclaimed lands are shown (in gray tones) and the total of irrigated agriculture is shown in green tones. The data in the table in Figure 19 were used to prepare the following summary:

<table>
<thead>
<tr>
<th>Basin</th>
<th>% Mined</th>
<th>% Irrigated Ag.</th>
<th>% of Total Mined + Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withlacochee River</td>
<td>1.1</td>
<td>3.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Alafia River</td>
<td>35.9</td>
<td>6.9</td>
<td>42.8</td>
</tr>
<tr>
<td>Peace River</td>
<td>9.8</td>
<td>15.5</td>
<td>25.3</td>
</tr>
</tbody>
</table>

Combining the total areas of irrigated agriculture with mining is an indication of the potential of the capture and salvage of ET losses and importation of deeper groundwater. These percentages of the combined irrigated agriculture and mining areas are shown in the last column in the previous table. It is interesting to note that 42.8% of
the Alafia River Basin upstream of the Lithia gaging station consists of mined and irrigated agricultural areas. This also coincides with a higher average unit streamflow in the Alafia (0.80 cfs/m) as compared to the Peace (second highest with 0.62 cfs/m) and the lowest in the Withlacoochee (0.43 cfs/m).

**Rate of Change in the Three Major River Basins During the Last 21 Years**

As discussed, the polynomial equation representing the best fit of the double-mass curve of rainfall versus streamflow for the time period from 1980 through 2000 provides further information about the hydrologic dynamics in these three major river basins. The graphical plots of these double-mass lines with their polynomial fits are presented in Appendix C as Figure C-1 (Withlacoochee), Figure C-2 (Alafia), and Figure C-3 (Peace). As an example, Figure 21 below shows the Peace River at Arcadia polynomial fit.

![Figure 21. Cumulative Peace @ Arcadia Streamflow Versus Rain (cfs/m), 1980-2000 (Polynomial). Also presented as Appendix C-3.](image)

The information presented in Appendix C is summarized as follows:

<table>
<thead>
<tr>
<th>Basin</th>
<th>“a” Coefficient</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withlacoochee</td>
<td>-0.0003</td>
<td>0.9887</td>
</tr>
<tr>
<td>Alafia</td>
<td>0.0004</td>
<td>0.9969</td>
</tr>
<tr>
<td>Peace</td>
<td>0.0006</td>
<td>0.9943</td>
</tr>
</tbody>
</table>

The first observation is that the fit of the double-mass lines as shown in the $R^2$ values is very good. The “a” values indicate that during the time period from 1980 through 2000, less streamflow would occur for the same increase in rainfall in the Withlacoochee River, but more in the Alafia and Peace Rivers. The greatest (positive) change occurred in the Peace River. Its rate of change value is 50% higher than for the Alafia River. This might be caused by the fact that the cumulative rainfall for the Alafia River Basin was slightly less than for the Peace River Basin.

Also presented in Appendix C are the graphs for the linear fits to the double-mass plots for the Withlacoochee (C-4), the Alafia (C-5), and the Peace River (C-6). As an example, Figure 22 below shows the Peace River at Arcadia linear fit.

Figure 22. Cumulative Peace @ Arcadia Streamflow Versus Rain (cfsm), 1980-2000 (Linear). Also presented as Appendix C-6.

The data are summarized in Table 14.

<table>
<thead>
<tr>
<th>Basin</th>
<th>“b” Coefficient</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withlacoochee</td>
<td>0.1107</td>
<td>0.9858</td>
</tr>
<tr>
<td>Alafia</td>
<td>0.2154</td>
<td>0.9957</td>
</tr>
<tr>
<td>Peace</td>
<td>0.1611</td>
<td>0.9891</td>
</tr>
</tbody>
</table>

The values in the “b” column indicate the amount of unit streamflow that can be expected to occur in response to the unit rainfall input. The “b” coefficient is the highest in the Alafia River Basin and the least in the Withlacoochee River Basin. This is not unexpected in that the City of Lakeland has been discharging treated wastewater from the treatment wetlands on the Bonnie Lake Mine to the North Prong of the Alafia River, thereby importing water to the Alafia River Basin. Because the Alafia is the smallest of the three river basins, the importation of treated wastewater in quantities that vary between 5 to 10 MGD would have a measurable impact.

Long-Term Change in Rainfall/Streamflow Relation in the Peace River Basin

As mentioned previously, the time interval selected for the analysis of the relationship between rainfall and streamflow was based on two factors. The first of these was the availability of the satellite information from the same instrument. That time interval was from 1985 through 2000. The second factor was that in 1975, reclamation of mined phosphate lands was made mandatory. Also, water use permitting by SWFWMD began in earnest in 1977. Based on the belief that it likely took a few years to get the regulatory programs in place and to be effective in enforcing the new rules, SI opted to begin the research period in 1980.

During an administrative hearing, it was stated that a significant change in the rainfall/streamflow pattern occurred in the Peace River Basin in the early 1960s. To ascertain why this change occurred, SI prepared a time-sequential double-mass analysis of the oldest flow data for the Peace River at the Arcadia gaging station. The sequential double-mass analysis involved preparing double-mass plots of the data for the time periods shown in the following Table 15.

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Figure #</th>
<th>“a” coefficient</th>
<th>“b” coefficient</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932-1940</td>
<td>D-1</td>
<td>0.0763</td>
<td>78.825</td>
<td>0.9939</td>
</tr>
<tr>
<td>1932-1950</td>
<td>D-2</td>
<td>0.1543</td>
<td>74.389</td>
<td>0.9978</td>
</tr>
<tr>
<td>1932-1960</td>
<td>D-3</td>
<td>0.0892</td>
<td>77.468</td>
<td>0.9985</td>
</tr>
<tr>
<td>1932-1970</td>
<td>D-4</td>
<td>0.0193</td>
<td>83.437</td>
<td>0.9979</td>
</tr>
<tr>
<td>1932-1980</td>
<td>D-5</td>
<td>-0.0376</td>
<td>89.358</td>
<td>0.9974</td>
</tr>
<tr>
<td>1932-1990</td>
<td>D-6</td>
<td>-0.0743</td>
<td>94.028</td>
<td>0.9974</td>
</tr>
<tr>
<td>1932-2000</td>
<td>D-7</td>
<td>-0.0708</td>
<td>93.437</td>
<td>0.9977</td>
</tr>
<tr>
<td>1932-2002</td>
<td>D-8</td>
<td>-0.0689</td>
<td>93.143</td>
<td>0.9978</td>
</tr>
</tbody>
</table>

The data were extracted from the graphs presented in Appendix D. The number in the “Figure #” column after the year interval designates the corresponding graph in Appendix D. The most important feature in the analysis is the fact that the “a” coefficient, which indicates the rate of change, had a positive but declining value until the 1932-1970 interval. For the 1932-1980 time interval, the value had become negative. This remained so until 2002, but it appears to be trending back to zero.

More detailed analyses for the time interval between 1970 and 1980 indicate that the “a” coefficient changed from a positive to a negative value in 1973. In 1980, Geraghty & Miller Inc. completed a hydrologic study for the Highland Ridge area in which they documented a definitive change in the relationship between rainfall and the water levels in the surficial aquifer and certain lakes in the Highlands Area. These changes are graphically presented in Figures D-9 through D-12. They clearly indicate that a change in the hydrologic system occurred in the 1970 to 1980 time period.

Change in Long-Term Rainfall in the Peace River Basin

Appendix E contains the single-mass plots of the long-term annual rainfall data for the Peace River Basin. The plots are sequential and are presented with a polynomial best-fit line. The purpose of the exercise is to see if and when the long-term rainfall pattern changed and to what degree. This is numerically expressed by the “a” coefficient in the polynomial equation. The results of these analyses are summarized in Table 16, as presented below.

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Figure #</th>
<th>“a” Coefficient</th>
<th>“b” Coefficient</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932-1940</td>
<td>E-1</td>
<td>0.0577</td>
<td>-219.61</td>
<td>0.9992</td>
</tr>
<tr>
<td>1932-1950</td>
<td>E-2</td>
<td>0.0146</td>
<td>-52.68</td>
<td>0.9995</td>
</tr>
<tr>
<td>1932-1960</td>
<td>E-3</td>
<td>0.0060</td>
<td>-19.401</td>
<td>0.9994</td>
</tr>
<tr>
<td>1932-1970</td>
<td>E-4</td>
<td>0.0011</td>
<td>-0.0726</td>
<td>0.9997</td>
</tr>
<tr>
<td>1932-1980</td>
<td>E-5</td>
<td>-0.0056</td>
<td>25.849</td>
<td>0.9996</td>
</tr>
<tr>
<td>1932-1990</td>
<td>E-6</td>
<td>-0.0049</td>
<td>22.968</td>
<td>0.9997</td>
</tr>
<tr>
<td>1932-2000</td>
<td>E-7</td>
<td>-0.0067</td>
<td>30.186</td>
<td>0.9997</td>
</tr>
</tbody>
</table>

The pattern in the rainfall record appears to be the same as in the double-mass analyses of rainfall versus streamflow. Given the nature of the double-mass analysis, this is to be expected. The rate of change in the long-term single-mass rainfall curves goes from positive to negative in the same 1970 to 1980 interval, reinforcing that a system change occurred at this time.

Change in Long-Term Streamflow in the Peace River Basin

Appendix F contains the single-mass plots of the long-term annual streamflow data for the Peace River Basin at Arcadia. The plots are sequential and are presented with a polynomial best-fit line. The purpose of the exercise is to see if and when the long-term streamflow pattern changed and to what degree. This is numerically expressed by the “a” coefficient in the polynomial equation. The results of these analyses are summarized in Table 17, as presented below.


<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Figure #</th>
<th>“a” Coefficient</th>
<th>“b” Coefficient</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932-1940</td>
<td>F-1</td>
<td>4.8906</td>
<td>-18621</td>
<td>0.9947</td>
</tr>
<tr>
<td>1932-1950</td>
<td>F-2</td>
<td>4.2512</td>
<td>-16162</td>
<td>0.9963</td>
</tr>
<tr>
<td>1932-1960</td>
<td>F-3</td>
<td>1.9818</td>
<td>-7356.9</td>
<td>0.9970</td>
</tr>
<tr>
<td>1932-1970</td>
<td>F-4</td>
<td>0.0044</td>
<td>336.62</td>
<td>0.9972</td>
</tr>
<tr>
<td>1932-1980</td>
<td>F-5</td>
<td>-1.5927</td>
<td>6561.8</td>
<td>0.9966</td>
</tr>
<tr>
<td>1932-1990</td>
<td>F-6</td>
<td>-2.0343</td>
<td>8286.4</td>
<td>0.9974</td>
</tr>
<tr>
<td>1932-2000</td>
<td>F-7</td>
<td>-1.8168</td>
<td>7434.1</td>
<td>0.9976</td>
</tr>
</tbody>
</table>

Again, the pattern in the streamflow record is similar to that of the rainfall. This should not be a surprise because streamflow is dependent on rainfall, so it is natural that it exhibits the same pattern. The rate of change in the long-term single-mass rainfall
curves goes from positive to negative in the same 1970 to 1980 interval, again supporting a hydrologic change somewhere in this interval. There are, however, a few very interesting surprises. For example, after the value of the “a” coefficient changed from positive to negative in the 1932-1980 time period for both the rainfall and the streamflow, the trend in the magnitude was opposite. For the rainfall, the “a” values for the three time periods 1932-1980, 1932-1990, and 1932-2000 were -0.0056, -0.0049, and -0.0067, respectively. For the same time periods, the “a” values for the streamflow were -1.5927, -2.0343, and -1.8168, respectively. These trends were opposites of each other. The rate of change in rainfall was high - low - higher. For the streamflow it was lowest - highest - lower. This leads to the conclusion that from 1980 to 1990, streamflow declined more than can be accounted for by the rainfall pattern. The opposite seems to be true for the next time interval from 1990 to 2000, when the rate of change in the rainfall became more negative, while the rate of change in streamflow was more positive than for the previous time interval.

**Changes in Peace River Flow from Decade to Decade**

In Appendix G, the double-mass plots of the rain versus streamflow for the time periods shown in Table 17 are presented. The data are summarized in the following Table 18.

The information presented in this table indicates that during the decades from 1970 to 1980 and from 1980 to 1990, the rate of change in rainfall/streamflow relationship was negative, implying less streamflow for the same rainfall increment. During the last decade from 1990 to 2000, the rate of change became positive again, implying that more streamflow could be expected for the same rainfall increment.

**Table 18. Summary of Polynomial Analyses of Double-Mass Data Plots for Single Decades of the Flow in the Peace River at Arcadia Since 1932.**

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Figure #</th>
<th>“a” Coefficient</th>
<th>“b” Coefficient</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932-1940</td>
<td>G-1</td>
<td>0.0763</td>
<td>78.825</td>
<td>0.9939</td>
</tr>
<tr>
<td>1941-1950</td>
<td>G-2</td>
<td>0.05484</td>
<td>69.767</td>
<td>0.9955</td>
</tr>
<tr>
<td>1951-1960</td>
<td>G-3</td>
<td>0.4656</td>
<td>74.565</td>
<td>0.9878</td>
</tr>
<tr>
<td>1961-1970</td>
<td>G-4</td>
<td>0.2570</td>
<td>57.887</td>
<td>0.9989</td>
</tr>
<tr>
<td>1971-1980</td>
<td>G-5</td>
<td>-0.0164</td>
<td>61.662</td>
<td>0.9984</td>
</tr>
<tr>
<td>1981-1990</td>
<td>G-6</td>
<td>-0.1964</td>
<td>59.266</td>
<td>0.9836</td>
</tr>
<tr>
<td>1991-2000</td>
<td>G-7</td>
<td>0.0264</td>
<td>78.072</td>
<td>0.9843</td>
</tr>
</tbody>
</table>

**Analyses of Individual Streams in the SWUCA**

To evaluate the difference in the hydrologic behavior of the watersheds with a significant phosphate mining/reclamation area from those without any phosphate
mining/reclamation areas, SI decided to compare the behavior and patterns of streamflow in the watersheds in the SWUCA. This evaluation consisted of determining the average long-term (twenty-one year) unit streamflow and comparing these values to the twenty-one year rainfall data. In addition, double-mass analyses were performed using linear and polynomial best-fit curve matching on the streamflow and rainfall data for each basin. This information was used to determine the possible degree of the rate of change in the rainfall/streamflow relationship.

Other double-mass and curve-fitting techniques were employed to determine the long-term behavior and trends in the 10%, 50%, and 90% exceedance categories. The purpose of these analyses was to distinguish the overall hydrologic behavior in each basin and correlate that to the land use.

In the watersheds in the SWUCA there are several basins where long-term streamflow records exist. As stated before, the hypothesis of this study is that the streamflow measured at the "exit" of a basin is the best and most reliable indicator of the overall hydrologic conditions of that basin. Several basins in the Peace River watershed have a significant area as mined and/or reclaimed phosphate land, while in others irrigated agriculture is the predominant factor. The Payne Creek Basin is an example of the former (mining), while the Joshua Creek Basin is an example of the latter (agriculture).

In Table 19 below is listed the streamflow descriptive statistics for all of the drainage basins studied. These numbers are based on the 21-year (1980-2000) average annual cfsm (except in the case of Bowlegs, where the period of record begins later).

Table 19. Descriptive Statistics for Each Drainage Basin Determined Using USGS Average Annual Streamflow Measurements (cfsm).

<table>
<thead>
<tr>
<th>Drainage Basin</th>
<th>Mean</th>
<th>Median</th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
<th>Sum</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace R. at Bartow</td>
<td>0.42</td>
<td>0.37</td>
<td>1.15</td>
<td>0.07</td>
<td>1.22</td>
<td>8.92</td>
<td>21</td>
</tr>
<tr>
<td>Peace R. at Ft Meade</td>
<td>0.58</td>
<td>0.51</td>
<td>1.29</td>
<td>0.10</td>
<td>1.39</td>
<td>12.23</td>
<td>21</td>
</tr>
<tr>
<td>Peace R. at Zolfo Springs</td>
<td>0.58</td>
<td>0.51</td>
<td>1.29</td>
<td>0.10</td>
<td>1.39</td>
<td>12.23</td>
<td>21</td>
</tr>
<tr>
<td>Peace R. at Arcadia</td>
<td>0.62</td>
<td>0.53</td>
<td>1.45</td>
<td>0.22</td>
<td>1.67</td>
<td>13.00</td>
<td>21</td>
</tr>
<tr>
<td>Bowlegs Creek</td>
<td>0.59</td>
<td>0.49</td>
<td>1.01</td>
<td>0.17</td>
<td>1.17</td>
<td>5.32</td>
<td>9</td>
</tr>
<tr>
<td>Charlie Creek near Gardner</td>
<td>0.66</td>
<td>0.52</td>
<td>1.90</td>
<td>0.20</td>
<td>2.10</td>
<td>13.96</td>
<td>21</td>
</tr>
<tr>
<td>Joshua Creek at Nocatee</td>
<td>0.78</td>
<td>0.76</td>
<td>1.44</td>
<td>0.19</td>
<td>1.63</td>
<td>16.45</td>
<td>21</td>
</tr>
<tr>
<td>Payne Creek at Bowling Green</td>
<td>0.88</td>
<td>0.78</td>
<td>1.90</td>
<td>0.16</td>
<td>2.07</td>
<td>18.50</td>
<td>21</td>
</tr>
<tr>
<td>Up. Horse Creek near Myakka Hd.</td>
<td>0.65</td>
<td>0.57</td>
<td>1.16</td>
<td>0.05</td>
<td>1.21</td>
<td>13.71</td>
<td>21</td>
</tr>
<tr>
<td>Horse Creek near Arcadia</td>
<td>0.79</td>
<td>0.75</td>
<td>1.50</td>
<td>0.18</td>
<td>1.67</td>
<td>16.66</td>
<td>21</td>
</tr>
<tr>
<td>Myakka R. near Sarasota</td>
<td>1.08</td>
<td>0.97</td>
<td>1.69</td>
<td>0.40</td>
<td>2.10</td>
<td>22.76</td>
<td>21</td>
</tr>
<tr>
<td>Upper Manatee R. near Myakka Hd.</td>
<td>1.12</td>
<td>1.18</td>
<td>1.80</td>
<td>0.30</td>
<td>2.10</td>
<td>23.46</td>
<td>21</td>
</tr>
<tr>
<td>Upper L. Manatee R. near Wim.</td>
<td>1.12</td>
<td>1.05</td>
<td>1.73</td>
<td>0.44</td>
<td>2.17</td>
<td>23.51</td>
<td>21</td>
</tr>
<tr>
<td>S. Prong Alafia R. near Lithia</td>
<td>0.83</td>
<td>0.76</td>
<td>1.66</td>
<td>0.10</td>
<td>1.76</td>
<td>17.33</td>
<td>21</td>
</tr>
<tr>
<td>Alafia R. at Lithia</td>
<td>0.80</td>
<td>0.75</td>
<td>1.43</td>
<td>0.33</td>
<td>1.76</td>
<td>16.82</td>
<td>21</td>
</tr>
<tr>
<td>Withlacoochee R. at Trilby</td>
<td>0.41</td>
<td>0.44</td>
<td>1.07</td>
<td>0.01</td>
<td>1.09</td>
<td>8.71</td>
<td>21</td>
</tr>
<tr>
<td>Withlacoochee R. at Holder</td>
<td>0.42</td>
<td>0.39</td>
<td>1.00</td>
<td>0.06</td>
<td>1.06</td>
<td>8.90</td>
<td>21</td>
</tr>
</tbody>
</table>
The streamflow and rainfall information for the period from 1980 through 2000 was analyzed and the mean cfs/m determined. The results are presented in Table 20.

### Table 20. Unit Rainfall and Streamflow in Basins in the SWUCA.

<table>
<thead>
<tr>
<th>Gaging Station</th>
<th>Long-Term (21-Yr) Unit Flow (cfs/m)</th>
<th>Rainfall (cfs/m)</th>
<th>Flow as % of Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace R. at Bartow</td>
<td>0.42</td>
<td>3.73</td>
<td>11.3</td>
</tr>
<tr>
<td>Peace R. at Ft Meade</td>
<td>0.40</td>
<td>3.64</td>
<td>11.0</td>
</tr>
<tr>
<td>Peace R. at Zolfo Springs</td>
<td>0.58</td>
<td>3.64</td>
<td>15.9</td>
</tr>
<tr>
<td>Peace R. at Arcadia</td>
<td>0.62</td>
<td>3.77</td>
<td>16.4</td>
</tr>
<tr>
<td>Bowlegs Creek</td>
<td>0.58</td>
<td>3.64</td>
<td>15.9</td>
</tr>
<tr>
<td>Charlie Creek near Gardner</td>
<td>0.66</td>
<td>3.62</td>
<td>18.2</td>
</tr>
<tr>
<td>Joshua Creek at Nocatee</td>
<td>0.78</td>
<td>3.76</td>
<td>20.7</td>
</tr>
<tr>
<td>Payne Creek at Bowling Green</td>
<td>0.88</td>
<td>3.38</td>
<td>26.0</td>
</tr>
<tr>
<td>Upper Horse Creek near Myakka Hd.</td>
<td>0.65</td>
<td>3.64</td>
<td>17.9</td>
</tr>
<tr>
<td>Horse Creek near Arcadia</td>
<td>0.79</td>
<td>3.53</td>
<td>22.4</td>
</tr>
<tr>
<td>Myakka R. near Sarasota</td>
<td>1.08</td>
<td>4.04</td>
<td>26.7</td>
</tr>
<tr>
<td>Upper Manatee R. near Myakka Hd.</td>
<td>1.12</td>
<td>3.87</td>
<td>28.9</td>
</tr>
<tr>
<td>Upper L. Manatee R. near Wim.</td>
<td>1.12</td>
<td>3.78</td>
<td>29.6</td>
</tr>
<tr>
<td>S. Prong Alafia R. near Lithia</td>
<td>0.82</td>
<td>3.68</td>
<td>22.3</td>
</tr>
<tr>
<td>Alafia R. at Lithia</td>
<td>0.80</td>
<td>3.68</td>
<td>21.7</td>
</tr>
<tr>
<td>Withlacoochee R. at Trilby</td>
<td>0.41</td>
<td>3.71</td>
<td>11.0</td>
</tr>
<tr>
<td>Withlacoochee R. at Holder</td>
<td>0.42</td>
<td>3.71</td>
<td>11.3</td>
</tr>
</tbody>
</table>

### Characterization of Streamflow in Each Basin in the SWUCA

To further investigate the behavior of surface waters in the majority of the streams in the SWUCA during the period from 1980 through 2000, SI used single-mass and double-mass plotting combined with computerized straight-line and polynomial curve-fitting procedures. The purpose of this analysis was to describe the general relationship between the rainfall and the streamflow in each basin for the 1980 to 2000 period.

The relationship between the variables of streamflow and rainfall is depicted in the double-mass graphs shown in Appendix H. Polynomial and linear trendlines were added and a correlation coefficient generated to explain the relationship between the variables. Easily observed is the fact that these variables are highly correlated, as shown by the high $R^2$ values (closest to 1 is the best correlation). The results of the correlations graphically shown in Appendix H are summarized in Table 21.
Table 21. Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Streamflow/Rainfall for Streams in the SWUCA and Withlacoochee.

<table>
<thead>
<tr>
<th>Stream Gaging Station</th>
<th>Figure #</th>
<th>Coefficients</th>
<th>Polynomial</th>
<th>Linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace R.-Bartow</td>
<td>H-1, H-2</td>
<td>6</td>
<td>6.02</td>
<td>98.34</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>H-3, H-4</td>
<td>9</td>
<td>4.35</td>
<td>98.33</td>
</tr>
<tr>
<td>Peace R. – Zolfo Springs</td>
<td>H-5, H-6</td>
<td>8</td>
<td>9.66</td>
<td>99.16</td>
</tr>
<tr>
<td>Peace R.-Arcadia</td>
<td>H-7, H-8</td>
<td>6</td>
<td>11.45</td>
<td>99.43</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>H-9, H-10</td>
<td>-14</td>
<td>22.34</td>
<td>99.23</td>
</tr>
<tr>
<td>Charlie Creek - Gardner</td>
<td>H-11, H-12</td>
<td>8</td>
<td>11.67</td>
<td>99.06</td>
</tr>
<tr>
<td>Joshua Creek-Nocatee</td>
<td>H-13, H-14</td>
<td>6</td>
<td>18.86</td>
<td>99.87</td>
</tr>
<tr>
<td>Upper Horse Creek - M. Head</td>
<td>H-17, H-18</td>
<td>-4</td>
<td>22.04</td>
<td>99.71</td>
</tr>
<tr>
<td>Horse Creek - Arcadia</td>
<td>H-19, H-20</td>
<td>10</td>
<td>15.62</td>
<td>99.48</td>
</tr>
<tr>
<td>Alafia R. - Lithia</td>
<td>H-23, H-24</td>
<td>4</td>
<td>18.56</td>
<td>99.69</td>
</tr>
<tr>
<td>Little Manatee R. - Wimauma</td>
<td>H-25, H-26</td>
<td>7</td>
<td>23.82</td>
<td>99.74</td>
</tr>
<tr>
<td>Manatee R. - M. Head</td>
<td>H-27, H-28</td>
<td>7</td>
<td>22.26</td>
<td>99.84</td>
</tr>
<tr>
<td>Myakka R. - Sarasota</td>
<td>H-29, H-30</td>
<td>9</td>
<td>22.83</td>
<td>99.82</td>
</tr>
<tr>
<td>Withlacoochee - Holder</td>
<td>H-31, H-32</td>
<td>-3</td>
<td>11.44</td>
<td>98.87</td>
</tr>
</tbody>
</table>

The information in Table 21 is arranged such that the flow in the Peace River measured at the four gaging stations is in one group, with the most upstream station at the top. The next group in the table is all the basins on the east side of the Peace River, followed by a group of all the basins on the west side of the Peace River. After this are listed the basins in the Alafia River watershed, which borders the Peace River watershed to the northwest. In the next-to-last group are the basins in the coastal watersheds to the west of the Peace River watershed. These are mostly upstream basins in these watersheds.

The information presented in Table 21 was compiled to facilitate the comparative analysis between the basins and to enable a clear distinction in the hydrologic behavior of these basins.

**Linear Streamflow Response Coefficients**

The information in the Linear “b” column in Table 20 indicates how much streamflow can be expected to occur in response to rainfall. The higher the number, the more streamflow can be expected to occur. The information in the column Linear “b” indicates, for example, that the flow in the Peace River at the Bartow and Ft. Meade gaging stations is rather similar. The streamflow response to rainfall at the next downstream gaging station on the Peace River at Zolfo Springs has increased markedly from 0.1130 to 0.1618, an average increase of nearly 43%. This is caused by the inflow of surface water from the Payne Creek Basin. At that station, the streamflow response to rainfall is 0.2613, an increase of 131% compared to the response at the Ft. Meade gaging
station. The response at the Arcadia gaging station on the Peace River (0.1611) is essentially similar to that at the Zolfo Springs gaging station.

For the basins on the east side of the Peace River (Bowlegs, Charlie and Joshua Creek), the responses of streamflow to rainfall are 0.1713, 0.1784, and 0.2391, respectively. From our previous work on defining land use in each basin, it is clear that the distinction between the Bowlegs Creek and Charlie Creek Basins and the Joshua Creek Basin is the fact that the latter has much more irrigated agriculture than the two previous ones, with irrigation importing water from the Floridan Aquifer. A part of the water will become tail water that will augment base flow. More importantly, the agricultural irrigation will keep water tables in the surficial aquifer elevated, thereby reducing flood storage during high rainfall events. This reduced storage increases the surface water runoff potential during storm events, increasing the overall streamflow discharge.

The basins on the west side of the Peace River include Payne Creek, Upper Horse Creek and the entire Horse Creek. The linear “b” coefficients respectively are 0.2613, 0.1909, and 0.2343. Again it should be noted that the streamflow response to rainfall in the Payne Creek Basin is the highest of all basins in the Peace River watershed, in spite of the fact that approximately 8,000 acres (12.5 mi²) of the Ft. Meade mine drain through Whidden Creek and Bryant’s Branch directly to the Peace River without being recorded by the USGS gaging station on Payne Creek. These flows through Whidden Creek and Bryant’s Branch reach the Peace River upstream from the USGS gaging station near Zolfo Springs. There is a significant phosphate mining/reclamation area in the Upper Horse Creek Basin. Over the twenty-one year period, an average of approximately 8.45 cfs is estimated to have been pumped from the 13 square mile mining area in the Upper Horse Creek Basin to the Payne Creek Basin. In spite of that diversion, the streamflow response coefficient for the entire Horse Creek Basin is quite similar to that of the Joshua Creek Basin.

In the Alafia River Basin the streamflow response coefficient is 0.2390, while the value for the entire basin upstream from the Lithia gaging station is 0.2154. The total drainage basin area at the Lithia gaging station is 336 mi², while the drainage area of the South Prong of the Alafia River is 102 mi². The streamflow response coefficient for the remainder of the Alafia River Basin not including the area for the South Prong of the Alafia Basin must be much lower, because the flow from the South Prong is providing support to arrive at the 0.2154 value.

The streamflow response values for the coastal basins are all significantly higher than in the Peace River watershed. Another interesting fact is that the values are “clustered” in a rather narrow range from a low of 0.2834 at the Manatee River station near Myakka Head to a high of 0.3002 in the Little Manatee River at Wimauma, with the value for the Myakka River near Sarasota in between at 0.2983.
It is noteworthy that the streamflow response coefficient in the Withlacoochee River Basin is slightly lower than the one for the upper reaches of the Peace River at Bartow and Ft. Meade.

**Polynomial Streamflow Response Coefficients**

In the results of the polynomial analyses, the values presented in the polynomial column “a” in Table 20, indicate the potential during the last twenty-one years for the rate of change in streamflow in response to rainfall to be positive or negative. In other words, a change in the polynomial “a” coefficients indicates a change in the overall hydrologic conditions in the basins. For example, they indicate whether streamflow will increase, decrease or remain the same in response to rainfall. All the polynomial “a” values were positive except for those in the Bowlegs Creek and Upper Horse Creek Basins and in the Withlacoochee River at Holder. These positive “a” values for Bowlegs Creek and the Withlacoochee River indicate that a decrease in streamflow can be expected in response to rainfall. The positive “a” value for the Upper Horse Creek Basin has been, in part, influenced by the diversion of surface water from the mined portion in the Upper Horse Creek watershed to the Payne Creek Basin. All values were relatively low ranging in the positive range from a low of 0.0004 (in the Alafia River Basin) to a high of 0.0012 (in the Payne Creek Basin). This implies that the rate of change in the relationship between streamflow and rainfall in the Payne Creek Basin during the last twenty-one (21) years have been higher than in any other basin. The smallest changes were observed in the Alafia River Basin.

**Analyses of Streamflow Distribution**

To further explore the relationship between mining, agriculture, and streamflow, the annual percent exceedances were calculated from the daily mean streamflow at the ten percent exceedance (P10), at the fifty percent exceedance (P50) and at the ninety percent exceedance (P90). These cumulative streamflow values in cfs/m were plotted against cumulative rain in cfs/m in a linear and double-mass analysis. The individual graphs are displayed in Appendix I. The data from the linear and double-mass fit trendlines and the associated line equations and R² value for each are summarized in the following Tables 22 through 24.

The purpose of these analyses is to distinguish the hydrologic responses of each basin to rainfall by looking at the streamflow under flood conditions, as represented by the P-10 values, under normal or mean flow conditions (P-50), and under baseflow conditions (P-90). For example, it is hypothesized that in a basin where significant mining and reclamation has occurred, due to the changes in the topography, the reduction of ET losses and the creation of mine cuts filled with permeable tailing sand, the hydrologic response in that basin might differ from a basin where such changes did not occur or from a basin that contains a high percentage of irrigated agriculture. The distribution of the linear and polynomial trendlines for one basin will be different from
those for another basin. To compare the trendlines’ “signatures” for each basin, all the graphs have been prepared with standard “x” and “y” axes that have the same size from graph to graph.

As previously discussed, the polynomial and linear trendlines are described by the “a” and “b” coefficients in each equation for each trendline. To facilitate the comparison among the hydrologic responses from each basin, the polynomial “a” and “b” and the linear “b” coefficients have been summarized in the following Tables 22 through 24.

**Table 22. Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Ten Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins.**

<table>
<thead>
<tr>
<th>Stream</th>
<th>Figure #</th>
<th>Coefficients</th>
<th>Coefficients</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Polynomial</td>
<td>Linear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>“a”*10^-4</td>
<td>“b”*10^-2</td>
<td>R2 %</td>
</tr>
<tr>
<td>Peace R. - Bartow</td>
<td>I-1, I-2</td>
<td>20</td>
<td>14.11</td>
<td>98.67</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>I-3, I-4</td>
<td>24</td>
<td>9.41</td>
<td>98.45</td>
</tr>
<tr>
<td>Peace R. – Zolfo Springs</td>
<td>I-5, I-6</td>
<td>23</td>
<td>19.90</td>
<td>99.06</td>
</tr>
<tr>
<td>Peace R. - Arcadia</td>
<td>I-7, I-8</td>
<td>17</td>
<td>27.48</td>
<td>99.30</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>I-9, I-10</td>
<td>-21</td>
<td>52.09</td>
<td>97.97</td>
</tr>
<tr>
<td>Charlie Creek – Gardner</td>
<td>I-11, I-12</td>
<td>19</td>
<td>34.30</td>
<td>98.69</td>
</tr>
<tr>
<td>Joshua Creek – Nocatee</td>
<td>I-13, I-14</td>
<td>17</td>
<td>44.18</td>
<td>99.86</td>
</tr>
<tr>
<td>Payne Creek – Bowling Green</td>
<td>I-15, I-16</td>
<td>32</td>
<td>33.84</td>
<td>99.70</td>
</tr>
<tr>
<td>Upper Horse Creek – M. Head</td>
<td>I-17, I-18</td>
<td>-8</td>
<td>52.92</td>
<td>99.69</td>
</tr>
<tr>
<td>Horse Creek – Arcadia</td>
<td>I-19, I-20</td>
<td>27</td>
<td>40.21</td>
<td>99.50</td>
</tr>
<tr>
<td>South Prong A.R. – Lithia</td>
<td>I-21, I-22</td>
<td>15</td>
<td>39.87</td>
<td>99.54</td>
</tr>
<tr>
<td>Alafia R. – Lithia</td>
<td>I-23, I-24</td>
<td>13</td>
<td>33.71</td>
<td>99.46</td>
</tr>
<tr>
<td>Little Manatee R. – Wimauma</td>
<td>I-25, I-26</td>
<td>29</td>
<td>43.36</td>
<td>99.40</td>
</tr>
<tr>
<td>Manatee R. – M. Head</td>
<td>I-27, I-28</td>
<td>22</td>
<td>50.72</td>
<td>99.69</td>
</tr>
<tr>
<td>Withlacoochee R. - Holder</td>
<td>I-31, I-32</td>
<td>-0.1</td>
<td>21.35</td>
<td>98.50</td>
</tr>
</tbody>
</table>

**Flood (P-10) Flows**

To evaluate the flood flow (P-10) responses to rainfall, it is useful to look at the linear “b” values in Table 22. The highest responses are in the coastal basins, where the values are rather close together, ranging from 67.93*10^-2 to 73.61*10^-2, averaging 70.37*10^-2. The lowest responses are in the Peace River.
The flood flow response at the Bartow and Ft Meade gaging stations range from 30.34*10^{-2} to 28.70*10^{-2}, respectively. In contrast, the gaging stations downstream from the confluence of the Peace River and Payne Creek show a significantly higher flood flow response ranging from 38.75*10^{-2} at Zolfo Springs to 41.69*10^{-2} at Arcadia. The flood flows from the predominantly agricultural basins of Bowlegs and Charlie Creeks range from 44.53*10^{-2} to 49.60*10^{-2}. These values are measurably higher than for the Peace River as a whole. The flood flow response from the Joshua Creek Basin, with a significant irrigated agricultural acreage, is 58.15*10^{-2}, which is markedly higher than for the Peace River and the other agricultural basins (Bowlegs and Charlie Creeks). These flood flows from Joshua Creek are nearly forty percent (40%) higher than the flood flows in the Peace River at the Arcadia gaging station. The highest flood flows of 61.02*10^{-2} in the entire Peace River Basin are in the Horse Creek near Arcadia. The flood flows from the Payne Creek Basin are 57.80*10^{-2}, which is 39% higher than the flood flows in the Peace River at Arcadia.

The flood flows from the Alafia River Basin at Lithia are 44.28*10^{-2}, which includes, but is lower than, the flood flows from the South Prong at 51.98*10^{-2}. The flood flows in the Withlacoochee River at Holder have the lowest value in flood flow of all measured stations with 21.23*10^{-2}.

The polynomial “a” coefficient indicates the rate of change in the relationship between cumulative unit rainfall and cumulative unit streamflow. A positive value indicates that more streamflow can be expected to occur for the same increment of a change in rainfall. In other words, the closer the value of “a” approaches zero, the lesser the rate of change. A negative value indicates that less streamflow can be expected to occur for the same increment of change in rainfall. For the flood flow (P-10) relationship, of all the streams investigated, the highest rate of positive change (32*10^{-2}) was for the Payne Creek Basin; this means that there was a continuous increase in the surface water runoff under flood flow conditions in this basin. The lowest rate of positive change (13*10^{-2}) was for the Alafia River Basin. The most negative rate of change in the runoff under flood flow conditions (-21*10^{-2}) occurred in the Bowlegs Creek Basin. The least negative rate of change (- 0.1*10^{-2}) occurred in the Withlacoochee River Basin at Holder. Both values mean that over time a lesser amount of runoff can be expected to occur from these basins under flood flow conditions.

**Mean (P-50) Flows**

The linear “b” values of the mean flows are presented in Table 23. The comparisons of the values shown in Table 23 present a different picture from that of the P-10 flood flows. Using the linear “b” coefficients shown in Table 23, it shows that in general, values are much lower. This is to be expected in that the magnitude of the mean flows are substantially less, but occur 50% of the time. For example, the mean P-50 flow in the Peace River at Arcadia is 8.23*10^{-2}. The “b” coefficient for the flood P-10 flow at the same gaging station is 41.69*10^{-2}, thus the mean P-50 flow is only 19.74% of the flood flow.
The highest mean flow “b” coefficient \((15.99 \times 10^{-2})\) was in the Payne Creek Basin, followed closely \((14.99 \times 10^{-2})\) by the South Prong of the Alafia River. The lowest values were in the Upper Horse Creek Basin \((4.99 \times 10^{-2})\), followed by the Peace River at Ft. Meade \((5.79 \times 10^{-2})\).

The highest positive rate of change, as expressed in the values of the polynomial “a” coefficient in Table 23, was in the Payne Creek Basin \((8 \times 10^{-4})\), followed by Joshua Creek \((5 \times 10^{-4})\) and the Peace River at Bartow \((5 \times 10^{-4})\). The smallest positive value \((1 \times 10^{-4})\) was in the Little Manatee River. The greatest negative change was in Bowlegs Creek \((-7 \times 10^{-4})\), followed by the Withlacoochee River \((-4 \times 10^{-2})\).

Table 23. Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Fifty Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Figure #</th>
<th>Coefficients</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Polynomial</td>
<td></td>
<td>Linear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“a”*10^{-4}</td>
<td>“b”*10^{-2}</td>
<td>R² %</td>
</tr>
<tr>
<td>Peace R. - Bartow</td>
<td>I-1, I-2</td>
<td>5</td>
<td>4.99</td>
<td>99.74</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>I-3, I-4</td>
<td>4</td>
<td>2.34</td>
<td>97.26</td>
</tr>
<tr>
<td>Peace R. – Zolfo Springs</td>
<td>I-5, I-6</td>
<td>3</td>
<td>6.38</td>
<td>99.08</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>I-9, I-10</td>
<td>-7</td>
<td>8.72</td>
<td>98.86</td>
</tr>
<tr>
<td>Charlie Creek – Gardner</td>
<td>I-11, I-12</td>
<td>2</td>
<td>3.86</td>
<td>98.82</td>
</tr>
<tr>
<td>Joshua Creek – Nocatee</td>
<td>I-13, I-14</td>
<td>5</td>
<td>4.59</td>
<td>99.86</td>
</tr>
<tr>
<td>Payne Creek – Bowling Green</td>
<td>I-15, I-16</td>
<td>8</td>
<td>10.17</td>
<td>99.70</td>
</tr>
<tr>
<td>Upper Horse Creek – M. Head</td>
<td>I-17, I-18</td>
<td>2</td>
<td>4.87</td>
<td>99.04</td>
</tr>
<tr>
<td>Horse Creek – Arcadia</td>
<td>I-19, I-20</td>
<td>2</td>
<td>5.65</td>
<td>99.50</td>
</tr>
<tr>
<td>Alafia R. – Lithia</td>
<td>I-23, I-24</td>
<td>0.8</td>
<td>11.85</td>
<td>99.46</td>
</tr>
<tr>
<td>Manatee R. – M. Head</td>
<td>I-27, I-28</td>
<td>3</td>
<td>5.54</td>
<td>99.56</td>
</tr>
<tr>
<td>Withlacoochee R. - Holder</td>
<td>I-31, I-32</td>
<td>-4</td>
<td>11.69</td>
<td>98.74</td>
</tr>
</tbody>
</table>

Base (P-90) Flows

The linear and polynomial coefficients associated with the double-mass analyses of unit cumulative rainfall versus unit cumulative streamflow at the P-90 frequency exceedance (base-flow conditions) are presented in Table 24. Looking at the linear “b” coefficients, the highest values were in the Alafia River \((7.70 \times 10^{-2})\) followed by the
second highest in the Little Manatee River \((6.19 \times 10^{-2})\). The lowest values were for Charlie Creek \((0.69 \times 10^{-2})\) and for the Peace River at Ft. Meade \((1.02 \times 10^{-2})\).

The polynomial “a” coefficients in Table 24 indicate the rate of change in the P-90 base-flows during the 1980 to 2000 period. The greatest positive rate of change \((4 \times 10^{-4})\) was in the Alafia River Basin. The smallest positive rate of change \((0.3 \times 10^{-4})\) occurred in the Peace River at Arcadia. Negative changes occurred at the Peace River at Bartow \((-0.5 \times 10^{-4})\) and Ft. Meade \((-0.6 \times 10^{-4})\), at Bowlegs Creek \((-2 \times 10^{-4})\), the South Prong of the Alafia River \((-1 \times 10^{-4})\), the Little Manatee River \((-0.5 \times 10^{-4})\), the Myakka River \((-2 \times 10^{-4})\), and the Withlacoochee River \((-3 \times 10^{-4})\).

The numbers indicate that those with the least negative values experienced a decline in the baseflow component with regards to the rainfall inputs. In the case of the South Prong of the Alafia River this could occur because mining activity has declined and therefore the additional support of deep well pumpage, which will be most critical during the drier period, has also declined. In the case of the Withlacoochee River, it is entirely possible that the pumpage of groundwater, in particular during the dry season, has diminished spring flow, which is most critical during the base flow conditions in a river.

### Table 24. Summary of Linear and Polynomial Coefficients for Double-Mass Plots of Rainfall/Ninety Percent Exceedance in Streamflow for Streams in the SWUCA and Withlacoochee River Basins.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Figure #</th>
<th>Coefficients</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Polynomial</td>
<td>Linear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“a”(\times 10^{-4})</td>
<td>“b”(\times 10^{-2})</td>
</tr>
<tr>
<td>Peace R. - Bartow</td>
<td>I-1,I-2</td>
<td>-0.5</td>
<td>1.46</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>I-3, I-4</td>
<td>-0.6</td>
<td>1.47</td>
</tr>
<tr>
<td>Peace R. – Zolfo Springs</td>
<td>I-5, I-6</td>
<td>2</td>
<td>4.04</td>
</tr>
<tr>
<td>Peace R. – Arcadia</td>
<td>I-7, I-8</td>
<td>0.3</td>
<td>2.48</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>I-9,I-10</td>
<td>-2</td>
<td>2.22</td>
</tr>
<tr>
<td>Charlie Creek – Gardner</td>
<td>I-11, I-12</td>
<td>0.4</td>
<td>0.38</td>
</tr>
<tr>
<td>Joshua Creek – Nocatee</td>
<td>I-13, I-14</td>
<td>2</td>
<td>1.50</td>
</tr>
<tr>
<td>Payne Creek – Bowling Green</td>
<td>I-15,I-16</td>
<td>2</td>
<td>4.42</td>
</tr>
<tr>
<td>Upper Horse Creek – M. Head</td>
<td>I-17,I-18</td>
<td>0.4</td>
<td>0.30</td>
</tr>
<tr>
<td>Horse Creek – Arcadia</td>
<td>I-19,I-20</td>
<td>0.5</td>
<td>0.66</td>
</tr>
<tr>
<td>South Prong A.R. – Lithia</td>
<td>I-21,I-22</td>
<td>-1</td>
<td>5.49</td>
</tr>
<tr>
<td>Alafia R. – Lithia</td>
<td>I-23, I-24</td>
<td>4</td>
<td>4.45</td>
</tr>
<tr>
<td>Manatee R. – M. Head</td>
<td>I-27,I-28</td>
<td>0.4</td>
<td>1.71</td>
</tr>
<tr>
<td>Myakka R. – Sarasota</td>
<td>I-29,I-30</td>
<td>-2</td>
<td>4.85</td>
</tr>
<tr>
<td>Withlacoochee R. - Holder</td>
<td>I-31,I-32</td>
<td>-3</td>
<td>7.32</td>
</tr>
</tbody>
</table>
Comparative Analyses of Streamflow Distribution

The data presented in Tables 22 through 24 have been rearranged to facilitate the comparisons of the distribution of streamflow among the basins in the SWUCA. The linear trendline coefficients are presented in Table 25, while the polynomial trendline coefficients are presented in Table 26. In this comparative analysis, the linear trendline coefficients will be used to compare the relationship between the P-10, P-50 and P-90 in each stream and to compare these results from stream to stream. The results of the polynomial trendlines’ coefficients will be used to assess the trends during the 1980 to 2000 period if streamflow increased, remained the same, or decreased in each one of the P-10, P-50, and P-90 trends for each stream.

The linear trendline coefficients shown in Table 25 were used to compare the P-50 values to the P-10 values and similarly compared the P-90 values to the P-10 values. The purpose of this comparison is to look for distinct differences in the various basins. Although not shown the values were related to each other by calculating them as percentages. The highest percentages of the P-50 compared to P-10 were for the Peace River at Bartow (29%), Payne Creek (28%), South Prong (29%), Alafia River (28%), and the Withlacoochee River (40%). The base flow (P-90) percentage compared to the flood flow (P-10) was also computed. The highest percentages were for the Peace River at Zolfo Springs (14%), Payne Creek (10%), South Prong (9%), Alafia River (17%), Little Manatee River (9%), and the Withlacoochee River (24%).

<table>
<thead>
<tr>
<th>Stream</th>
<th>Linear Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>“b”*10^-2</td>
</tr>
<tr>
<td>Peace R. - Bartow</td>
<td>30.34</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>28.70</td>
</tr>
<tr>
<td>Peace R. – Zolfo Springs</td>
<td>38.75</td>
</tr>
<tr>
<td>Peace R. - Arcadia</td>
<td>41.69</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>44.53</td>
</tr>
<tr>
<td>Charlie Creek - Gardner</td>
<td>49.60</td>
</tr>
<tr>
<td>Joshua Creek - Nocatee</td>
<td>58.15</td>
</tr>
<tr>
<td>Payne Creek – Bowling Green</td>
<td>57.80</td>
</tr>
<tr>
<td>Upper Horse Creek – Myk Head</td>
<td>46.55</td>
</tr>
<tr>
<td>Horse Creek - Arcadia</td>
<td>61.02</td>
</tr>
<tr>
<td>South Prong A.R. - Lithia</td>
<td>51.98</td>
</tr>
<tr>
<td>Alafia R. - Lithia</td>
<td>44.28</td>
</tr>
<tr>
<td>Little Manatee R. - Wimauma</td>
<td>67.93</td>
</tr>
<tr>
<td>Manatee R. – Myakka Head</td>
<td>69.56</td>
</tr>
<tr>
<td>Myakka R. – Sarasota</td>
<td>73.61</td>
</tr>
<tr>
<td>Withlacoochee R. – Holder</td>
<td>21.23</td>
</tr>
</tbody>
</table>

It is important to note that both basins with the highest mining percentages (Payne Creek and the South Prong of the Alafia River), have consistently higher P-50 and P-90
percentages of 28%-10% and 29%-9% respectively. These relationships for the Alafia and Withlacoochee River are 28%-17% and 40%-24%, respectively. Both the P-50 and P-90 are very high. This is attributed to the fact that the Alafia River receives discharges of treated wastewater from a City of Lakeland WWTP and the Withlacoochee River is supported to a much larger degree by groundwater inflows than are the rivers in the SWUCA. The relatively large percentage of the P-50 flow at the Bartow gaging station in the Peace River is influenced by flows from Lake Hancock and the Peace Creek canal which drains several other large lakes in the area.

It is also important to note that the P-50 and P-90 percentages for the agricultural areas in the coastal basins (20%-9%, 12%-3%, and 19%-4%) are distinct in their P-50 and P-90 “signatures” and differ markedly from the phosphate mining basins. This is also true for the agricultural basins (Bowlegs 14%-4%, Charlie 12%-1%, Joshua 15%-5% and Horse 12%-2%).


<table>
<thead>
<tr>
<th>Polynomial Coefficients</th>
<th>Stream</th>
<th>10%</th>
<th>50%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)*10^{-4}</td>
<td>(b)*10^{-2}</td>
<td>(a)*10^{-4}</td>
<td>(b)*10^{-2}</td>
</tr>
<tr>
<td>Peace R. – Bartow</td>
<td>20</td>
<td>14.11</td>
<td>5</td>
<td>4.99</td>
</tr>
<tr>
<td>Peace R. – Ft. Meade</td>
<td>24</td>
<td>9.41</td>
<td>4</td>
<td>2.34</td>
</tr>
<tr>
<td>Peace R. – Arcadia</td>
<td>17</td>
<td>27.48</td>
<td>2</td>
<td>6.26</td>
</tr>
<tr>
<td>Bowlegs Creek – Ft. Meade</td>
<td>-21</td>
<td>52.09</td>
<td>-7</td>
<td>8.72</td>
</tr>
<tr>
<td>Charlie Creek – Gardner</td>
<td>19</td>
<td>34.30</td>
<td>2</td>
<td>3.86</td>
</tr>
<tr>
<td>Joshua Creek – Nocatee</td>
<td>17</td>
<td>44.18</td>
<td>5</td>
<td>4.59</td>
</tr>
<tr>
<td>Payne Creek – Bowling Gr.</td>
<td>32</td>
<td>33.84</td>
<td>8</td>
<td>10.17</td>
</tr>
<tr>
<td>Upper Horse Creek – M. Hd</td>
<td>-8</td>
<td>52.92</td>
<td>0.2</td>
<td>4.87</td>
</tr>
<tr>
<td>Horse Creek - Arcadia</td>
<td>27</td>
<td>40.21</td>
<td>2</td>
<td>5.65</td>
</tr>
<tr>
<td>South Prong A. R. - Lithia</td>
<td>15</td>
<td>39.87</td>
<td>3</td>
<td>12.55</td>
</tr>
<tr>
<td>Alafia R. - Lithia</td>
<td>13</td>
<td>33.71</td>
<td>0.8</td>
<td>11.85</td>
</tr>
<tr>
<td>Little Manatee R. – Wim.</td>
<td>29</td>
<td>43.36</td>
<td>1</td>
<td>12.80</td>
</tr>
<tr>
<td>Manatee R. – M. Head</td>
<td>22</td>
<td>50.72</td>
<td>3</td>
<td>5.54</td>
</tr>
<tr>
<td>Myakka R. - Sarasota</td>
<td>28</td>
<td>50.51</td>
<td>2</td>
<td>12.45</td>
</tr>
<tr>
<td>Withlacoochee R. - Holder</td>
<td>-0.1</td>
<td>21.35</td>
<td>-4</td>
<td>11.69</td>
</tr>
</tbody>
</table>

The polynomial coefficients for the P-10, P-50 and P-90 trendlines indicate a positive or a negative trend during the 1980-2000 period. A positive coefficient indicates that more streamflow can be expected to occur for the same increment of rainfall. A negative coefficient indicates that less streamflow can be expected for the same increment of rainfall. The only two basins were all three trendlines were negative was for the Bowlegs Creek and Withlacoochee River watersheds. No cause has been established. Negative coefficients are also shown in Table 25 for the P-90 flow in the Peace River at Bartow, at Ft Meade, the South Prong of the Alafia River, the Little Manatee River at
Wimauma, and the Myakka River at Sarasota. The only other negative coefficient was for the P-10 trendline in the Upper Horse Creek Basin.

The highest positive rate of change for the P-10 trendlines was seen in the Payne Creek Basin, while the lowest positive values was in the Alafia River Basin. The highest positive value in for the P-50 trendlines was in the Payne Creek Basin, while the lowest positive values were in the Upper Horse Creek Basin. The highest positive value for the P-90 trendlines was seen in the Alafia River at Lithia, while the lowest positive value was for the Peace River at Arcadia. To illustrate this, Table 26 below shows the differences between each percent exceed, with the differences reported in degrees.

Looking at the Figures in Appendix I, it appears that the basin where phosphate mining occupies a significant portion of the total land surface, the P-10, P-50 and the P-90 trendlines have a distinctly different pattern that the other (agricultural) basins in the Peace River and Alafia River Basins. To more visually express this difference, the angle (in degrees) between the three lines was measured and is presented in Table 27. The angle between the P-90 and P-50 trendlines is shown in the first column. The angle between the P-50 and P-10 trendlines is shown in the second column. The angle of the trendlines between the P-90 and P-10 are shown in the third column. It is obvious from the Table that the third column number is the sum of the numbers in the first and second column.

### Table 27. Difference in Angles Between Percent Exceed Trendlines.

<table>
<thead>
<tr>
<th></th>
<th>Angle P90 to P50</th>
<th>Angle P10 to P50</th>
<th>Angle P90 to P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace R. Bartow</td>
<td>2.5</td>
<td>10</td>
<td>12.5</td>
</tr>
<tr>
<td>Peace R. Ft Meade</td>
<td>2</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Peace R. Zolfo Springs</td>
<td>3</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Peace R. Arcadia</td>
<td>2.5</td>
<td>14.5</td>
<td>17</td>
</tr>
<tr>
<td>Bowlegs Creek nr Ft Meade</td>
<td>2</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Charlie Creek nr Gardner</td>
<td>2</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Joshua Creek Nocatee</td>
<td>2</td>
<td>20.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Payne Creek @ Bowling Green</td>
<td>4</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Up Horse Creek nr Myakka Hd</td>
<td>2.5</td>
<td>20.5</td>
<td>23</td>
</tr>
<tr>
<td>Horse Creek nr Arcadia</td>
<td>3</td>
<td>20.5</td>
<td>23.5</td>
</tr>
<tr>
<td>S Prong Alafia R. nr Lithia</td>
<td>5</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Alafia R. @ Lithia</td>
<td>3</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>L Manatee R. nr Wimauma</td>
<td>3.5</td>
<td>22.5</td>
<td>26</td>
</tr>
<tr>
<td>Manatee R. nr Myakka Hd</td>
<td>2.5</td>
<td>25</td>
<td>27.5</td>
</tr>
<tr>
<td>Myakka R. nr Sarasota</td>
<td>5</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>Withlacoochee R. @ Holder</td>
<td>2</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

The highest angle separation in the non-coastal watersheds (Peace and Alafia) is for Payne Creek (4-17-21) and the South Prong of the Alafia River (5-16-21) Basins, both containing a high percentage of mined/reclaimed lands. The lowest angles were for the Peace River at Bartow (2.5-10-12.5) and at Ft. Meade (2-10-12). In the agricultural basin with the largest percentage of irrigate acreage, which is Joshua Creek the angle separations were 2-20.5-22.5. In the agricultural basin with the least irrigation in Charlie
Creek the angle separation was 2-20-22, nearly identical to the Joshua Creek Basin. The same pattern could also be seen in the Horse Creek Basin (3-20.5-23.5). The three coastal basins once again show different patterns than those shown by the predominantly inland Peace River and Alafia River Basins.

**Unit Streamflow in SWUCA Basins**

The unit streamflow for all the streams in the SWUCA is presented in Figure 23 below. For reference, this figure shows the drainage basin names, including the four gaging stations used for Peace River. The steepest declines are under the coastal surface water basins of the Little Manatee, Manatee and Myakka Rivers, as shown in Figure 24. On Figure 24 are the basin boundaries as well as the 20-year mean unit streamflow in cfsm. The unit streamflow for the inland basins such as the Peace River and the Alafia River have values ranging from a low of 0.41 cfsm in the Peace River at the Ft. Meade gaging station to a high of 0.87 cfsm in the South Prong of the Alafia and Payne Creek Basins. The unit streamflow values for the coastal basins ranged from a low of 1.07 cfsm at both the Manatee and Myakka Rivers to a high of 1.13 cfsm in the Little Manatee River at Wimauma.

**Figure 23. Location of SWUCA Stream Drainage Basins and Peace River Gaging Stations.**
Assessment of Land Use and Unit Streamflow

In an effort to qualify and check on the import of irrigation water from the Floridan Aquifer onto the land surface, SI first looked at the percentages of irrigated agriculture and mining in each basin and compared these from basin to basin and also compared them to the unit mean streamflow in cfsm. The correlations worked well for
the basins in the Peace River watershed but seem to underestimate the unit mean streamflows in the coastal basins. As a second check, SI assumed that the pumpage from the underlying confined aquifer systems would reduce the groundwater levels. Therefore SI examined the May 2000 potentiometric surface shown in Figure 25. This exemplifies the impact of irrigation pumpage on the potentiometric surface in the Upper Floridan Aquifer changes from year to year. May 2000 was selected merely as an example. The contour lines of the potentiometric surface show a potentially significant withdrawal of groundwater from the Upper Floridan aquifer exemplified by the depression in the potentiometric surface below mean sea level.

It is interesting to note that the unit mean cfs in the three coastal basins is significantly higher by 45% than those in the inland areas in the Alafia and Peace River Basins. This is a very strong indication that importation of groundwater for irrigation is supporting the flow of surface water in streams.

For our analysis of the impact of mining and reclamation on streamflow, SI focused on the areas where significant mining has occurred such as the South Prong of the Alafia and the Payne Creek drainage basins and compared these to the areas where no mining has occurred. Table 28 presents the total area of each basin, the areas of irrigated agriculture, mining and others and show the percentage of irrigated agriculture or mining in each basin. Table 29 lists the unit mean 21-year streamflow in cfs and the percentages of irrigated agriculture and/or mining in each basin.

It is immediately clear that the information on Upper Horse Creek in Table 28 appears to be somewhat of an anomaly with 0.65 cfs, which is significantly lower than the unit flows in the South Prong of the Alafia or Payne Creek. The answer to this observation came from IMC when we presented the results of the statistical analyses of our double-mass plots. This information is discussed later in this report. For now it is sufficient to say that the analyses for the Upper Horse Creek Basin did show that water was being deflected from the basin. IMC personnel confirmed this. The reason is that IMC was not permitted to construct a NPDES outfall on Horse Creek until recently. Water from the mining operations in the Upper Horse Creek Basin was diverted to the Payne Creek Basin starting in 1988. The discharge increased proportionally to the expansion of the mined areas, which was approximately 500 acres per year. Using the 21-year average approximation for the Upper Horse Creek Basin of 0.65 cfs and comparing this to the average of the South Prong and Payne Creek Basins of 0.85 cfs, a good case can be made that the diversion on a long-term basis accounted for (0.85 - 0.65 cfs) x 13 mi² = 2.6 cfs or 1.68 MGD.
Note: Red-hatched area is below MSL.

Figure 25. Potentiometric Surface Map of SWFWMD Showing Floridan Aquifer Elevations in Feet—May 2000.
Table 28. Total, Mined, Irrigated and Other Areas in Each Sub-Basin.

<table>
<thead>
<tr>
<th>Basins/Basins</th>
<th>Area (mi²)</th>
<th>Percent Irrigated or Mined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Irrigated Agriculture</td>
</tr>
<tr>
<td>Predominantly Irrigated Agriculture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bowlegs Creek</td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td>Charlie Creek</td>
<td>330</td>
<td>49</td>
</tr>
<tr>
<td>Joshua Creek</td>
<td>120</td>
<td>37</td>
</tr>
<tr>
<td>Predominantly Mined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Prong</td>
<td>103</td>
<td>3</td>
</tr>
<tr>
<td>Payne Creek</td>
<td>122</td>
<td>10</td>
</tr>
<tr>
<td>Upper Horse Creek</td>
<td>41</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 29. Comparing Unit Streamflow to Percentage of Irrigated or Mined Areas.

<table>
<thead>
<tr>
<th>Basins/Basins</th>
<th>Percentages</th>
<th>Unit Streamflow vs. Unit Rainfall</th>
<th>Percent Irrigated or Mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominantly Irrigated Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bowlegs Creek</td>
<td>0.58</td>
<td>17.3</td>
<td></td>
</tr>
<tr>
<td>Charlie Creek</td>
<td>0.66</td>
<td>14.7</td>
<td></td>
</tr>
<tr>
<td>Joshua Creek</td>
<td>0.78</td>
<td>30.7</td>
<td></td>
</tr>
<tr>
<td>Predominantly Mined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Prong</td>
<td>0.82</td>
<td>73.30</td>
<td></td>
</tr>
<tr>
<td>Payne Creek</td>
<td>0.88</td>
<td>71.8</td>
<td></td>
</tr>
<tr>
<td>Upper Horse Creek</td>
<td>0.65</td>
<td>35.9</td>
<td></td>
</tr>
</tbody>
</table>

A mine ownership map is presented in Figure 26. It lists the total areas as well as the areas within the Payne Creek Basin. The CF Industries South Pasture mine is partially outside the Payne Creek Basin boundaries. The two NPDES outfalls discharge to Payne Creek. Recent NPDES discharge data show only discharges during two of the 11 years of record. These discharges were in 1997 (0.14 MGD) and in 1998 (2.33 MGD). For the same time period NPDES discharges from the CFI North Pasture mine averaged approximately 0.6 MGD from a 1676 acre mine. Using this information to estimate the maximum possible import by the South Pasture mine into Payne Creek, SI calculated an average inflow of 2.25 MGD.

The Cargill Fort Meade mine has 9626 acres within the Payne Creek Basin. The Ft. Meade mine drains surface water through two NPDES outfalls. One discharges to Whidden Creek and the second to Bryant’s Branch. No discharges occur to Payne Creek. The average discharge is estimated at approximately 3.13 MGD. It should be noted,
however, that we estimate that surface water from approximately 60% of the Ft. Meade mine inside the Payne Creek drainage basin is exported from the basin. This amounts to 2.25 MGD.

Figure 26. Map of Mines Within the Payne Creek Drainage Basin with Area Estimates.
Based on the preceding, it appears reasonable to estimate the surface water imports and exports into and from the Payne Creek drainage system as follows:

**Table 30. Import to, and Export from, the Payne Creek Drainage Basin.**

<table>
<thead>
<tr>
<th>Import from:</th>
<th>Export to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Horse Creek Basin</td>
<td>1.68 MGD</td>
</tr>
<tr>
<td>CF South Pasture Mine</td>
<td>2.25 MGD</td>
</tr>
<tr>
<td>Total In:</td>
<td>3.93 MGD</td>
</tr>
<tr>
<td>Whidden Creek/Bryants Branch</td>
<td>2.89 MGD</td>
</tr>
<tr>
<td>Total Out:</td>
<td>2.89 MGD</td>
</tr>
</tbody>
</table>

Based on the numbers it was estimated that the net surface water flow into the Payne Creek Basin is 1.04 MGD (1.6 cfs). Using this number as an adjustment for the unit mean cfsm for the Payne Creek Basin, the adjusted 20-year Payne Creek Basin unit mean streamflow is 0.87 cfsm. Similarly, the adjusted unit mean cfsm for the Upper Horse Creek Basin will be 0.69. A comparison between the adjusted values and the unit mean long-term streamflow values for both basins is rather insignificant.

**Unit Streamflow of Percent Exceedance Trendlines**

The P-10, P-50, and P-90 unit streamflow coefficients in cfsm were calculated for each stream in the SWUCA for the 1980 to 2000 period. To facilitate comparisons, the data were presented in map form in Figures 27 through 29.

The unit streamflow for the P-10 in all the streams in the SWUCA is presented in Figure 27 below. From the map it is clear that the unit P-10 streamflow for the inland basins such as the Peace River and the Alafia River have values ranging from a low of 1.09 cfsm in the Peace River at the Ft. Meade gaging station to a high of 2.11 cfsm in the Joshua Creek Basin. The values for the coastal basins ranged from a low of 2.59 cfsm at the Little Manatee River to a high of 2.70 cfsm in the Myakka River at Sarasota.
Figure 27. Unit Streamflow P-10 1980-2000 Average cfs m for SWUCA Streams.

The unit streamflow for the P-50 in all the streams in the SWUCA is presented in Figure 28 below. From the map it is clear that the unit P-50 streamflow for the inland basins such as the Peace River and the Alafia River have values ranging from a low of 0.21 cfs m in the Bowlegs Creek and Charlie Creek Basins to a high of 0.56 cfs m in the
South Prong of the Alafia River Basin. The values for the coastal basins ranged from a low of 2.59 cfsm at the Little Manatee River to a high of 2.70 cfsm in the Myakka River at Sarasota.

Figure 28. Unit Streamflow P-50 1980-2000 Average cfsm for SWUCA Streams.

The unit streamflow for the P-90 in all the streams in the SWUCA is presented in Figure 29 below. From the map it is clear that the unit P-90 streamflow for the inland
basins such as the Peace River and the Alafia River have values ranging from a low of 0.04 cfsm in the Peace River at Bartow and Ft. Meade to a high of 0.19 cfsm in the Payne Creek Basin. The values for the coastal basins ranged from a low of 0.08 cfsm at the Manatee River to a high of 0.23 cfsm in the Little Manatee River in Wimauma.

Figure 29. Unit Streamflow P-90 1980-2000 Average cfsm for SWUCA Streams.
From the maps it is clear that in the inland river basins, the basins with the highest percentage of mined phosphate lands, which are in the Payne Creek and South Prong of the Alafia River the unit cfsm values are distinctly and markedly higher. This pattern is also true for the P-90 and P-50 maps. Both basins also have the second highest P-10 values. It is therefore reasonable to conclude that phosphate mining certainly does not diminish streamflow, but in fact increases streamflow. The unit cfsm value for both the Payne Creek and South Prong Basins are 40% higher than the unit cfsm value for the Peace River at Arcadia, notwithstanding the fact that the flow from the Payne Creek tributary clearly increases the flow in the Peace River at Zolfo Springs. This is illustrated by a jump in the unit cfsm value from 0.41 cfsm at the Ft Meade gaging station to 0.58 at the Zolfo Springs gaging station.

Comparisons Between Linear Trend and Unit Streamflow

The results of the straight trendline fit of the double-mass analyses provide a graphical presentation of the comparative higher or lower flows that have been observed during the 1980 through 2000 time period by examination of the angle of the trendline. This is mathematically expressed in the “a” coefficient associated with the “x” variable in the \( y = ax + b \) equation. A summary of the “b” coefficient is presented in Table 31.

Table 31. Linear Trendline Coefficients and Unit Mean Streamflow.

<table>
<thead>
<tr>
<th>River/Gauging Station</th>
<th>Linear Trend “b” Coefficient</th>
<th>Unit Mean Streamflow (cfsm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace River @ Arcadia</td>
<td>0.1617</td>
<td>0.62</td>
</tr>
<tr>
<td>Bowlegs Creek @ Ft. Meade</td>
<td>0.1713</td>
<td>0.58</td>
</tr>
<tr>
<td>Charlie Creek @ Gardner</td>
<td>0.1784</td>
<td>0.66</td>
</tr>
<tr>
<td>Joshua Creek @ Nocatee</td>
<td>0.2174</td>
<td>0.78</td>
</tr>
<tr>
<td>Payne Creek @ Bowling Green</td>
<td>0.2635</td>
<td>0.88</td>
</tr>
<tr>
<td>Upper Horse Creek @ Myakka Head</td>
<td>0.1799</td>
<td>0.65</td>
</tr>
<tr>
<td>Horse Creek @ Arcadia</td>
<td>0.2364</td>
<td>0.79</td>
</tr>
<tr>
<td>Myakka River @ Sarasota</td>
<td>0.3022</td>
<td>1.08</td>
</tr>
<tr>
<td>Manatee River @ Myakka Head</td>
<td>0.2965</td>
<td>1.12</td>
</tr>
<tr>
<td>Little Manatee River @ Wimauma</td>
<td>0.2982</td>
<td>1.12</td>
</tr>
<tr>
<td>South Prong Alafia River @ Lithia</td>
<td>0.2278</td>
<td>0.82</td>
</tr>
<tr>
<td>Alafia River @ Lithia</td>
<td>0.216</td>
<td>0.8</td>
</tr>
<tr>
<td>Withlacoochee River @ Holder</td>
<td>0.1114</td>
<td>0.42</td>
</tr>
</tbody>
</table>

There is very good agreement \( (R^2 = 0.9689) \) between the values for the Linear Trendline “a” Coefficients and the Unit Mean Streamflow values, as shown in Figure 30.
Impact of Slope on Unit Streamflow

Upon suggestion, SI further investigated the relationship to determine if there was a simple physical explanation, in this case, that basins with higher slope would have more overland runoff. To accomplish this, SI used the USGS five-foot topographic contours to determine the highest elevation in each drainage basin, then measured the distance to the gauging station (lowest elevation point) and did a rudimentary slope calculation using Equation 7. In this equation, $S$ is slope in ft per mile, $E_h$ is the highest elevation point in the basin in feet, $E_g$ is the gauging station elevation in feet and $D$ is the approximate distance from $E_h$ to $E_g$ in miles.

$$S = \frac{E_h - E_g}{D}$$

Equation 7.

The results of these analyses are presented below in Table 32.
Table 32. Table of Slope Calculations (ft./mi.) with 21-Year Unit Mean Streamflow (cfsm) for Comparison.

<table>
<thead>
<tr>
<th>Station</th>
<th>Highest Pt. (ft)</th>
<th>Gaging Station Elev. (ft)</th>
<th>Distance Highest Pt. to GS (miles)</th>
<th>Approx. Slope ft/mile</th>
<th>Mean 21-Yr cfsm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withlacoochee Trilby</td>
<td>300</td>
<td>55</td>
<td>7</td>
<td>35.00</td>
<td>0.41</td>
</tr>
<tr>
<td>Bowlegs</td>
<td>200</td>
<td>100</td>
<td>3</td>
<td>33.33</td>
<td>0.59</td>
</tr>
<tr>
<td>Payne</td>
<td>175</td>
<td>55</td>
<td>5</td>
<td>24.00</td>
<td>0.88</td>
</tr>
<tr>
<td>L Manatee</td>
<td>160</td>
<td>5</td>
<td>8</td>
<td>19.38</td>
<td>1.12</td>
</tr>
<tr>
<td>Alafia</td>
<td>260</td>
<td>20</td>
<td>18</td>
<td>13.33</td>
<td>0.8</td>
</tr>
<tr>
<td>Peace Bartow</td>
<td>295</td>
<td>100</td>
<td>15</td>
<td>13.00</td>
<td>0.42</td>
</tr>
<tr>
<td>Peace Ft Meade</td>
<td>295</td>
<td>80</td>
<td>18</td>
<td>11.94</td>
<td>0.4</td>
</tr>
<tr>
<td>S Prong Alafia</td>
<td>190</td>
<td>60</td>
<td>14</td>
<td>9.29</td>
<td>0.83</td>
</tr>
<tr>
<td>Peace Zolfo</td>
<td>295</td>
<td>40</td>
<td>33</td>
<td>7.73</td>
<td>0.58</td>
</tr>
<tr>
<td>Withlacoochee Holder</td>
<td>300</td>
<td>0</td>
<td>39</td>
<td>7.69</td>
<td>0.42</td>
</tr>
<tr>
<td>Charlie</td>
<td>180</td>
<td>20</td>
<td>23</td>
<td>6.96</td>
<td>0.66</td>
</tr>
<tr>
<td>Horse Myakka</td>
<td>140</td>
<td>70</td>
<td>12</td>
<td>5.83</td>
<td>0.65</td>
</tr>
<tr>
<td>Peace Arcadia</td>
<td>295</td>
<td>10</td>
<td>53</td>
<td>5.38</td>
<td>0.62</td>
</tr>
<tr>
<td>Joshua</td>
<td>95</td>
<td>10</td>
<td>18</td>
<td>4.72</td>
<td>0.78</td>
</tr>
<tr>
<td>Myakka</td>
<td>115</td>
<td>15</td>
<td>24</td>
<td>4.17</td>
<td>1.08</td>
</tr>
<tr>
<td>Manatee</td>
<td>135</td>
<td>45</td>
<td>23</td>
<td>3.91</td>
<td>1.12</td>
</tr>
<tr>
<td>Horse Arcadia</td>
<td>140</td>
<td>20</td>
<td>33</td>
<td>3.64</td>
<td>0.79</td>
</tr>
</tbody>
</table>

The stations are ordered from largest amount of slope to smallest amount of slope and when looking at the mean cfsm in the last column, there does not appear to be any correlation. In fact, the Manatee and Myakka Basins have two of the highest mean 21-year cfsm and have the second and third lowest slopes, respectively. Due to these results, the conclusion can be drawn that there is no predictable impact of larger versus smaller slopes on the amount of runoff coming to the streams.
PRELIMINARY ANALYSES OF MINING EFFECTS ON DEEP RECHARGE

One of the issues concerning the impact of phosphate mining on streamflow focused on the possible effects of mining/reclamation on deep recharge to the underlying aquifers. It has been hypothesized that mining would or could possibly reduce the hydraulic confinement between the surficial aquifer and the underlying intermediate and Floridan Aquifers.

In this overall comprehensive study, any increases or decreases to recharge in the surficial aquifer due to mining or any other anthropogenic effects are included in the measured outflow from the individual basin. Because we focused our analyses on using the measured surface water flows at the exits of the drainage basins, the recharge effects/impacts are already included in the overall analysis.

Therefore, possible effects of recharge from the surficial aquifer to the Floridan Aquifer within the drainage basins were examined as shown in Figure 31 with two approaches. The first was to look at water level trends in long-term Floridan Aquifer monitor wells that are measured by the USGS and SWFWMD (locations in Figure 31). The periodic measurements for each year were averaged to a single annual water level value and then plotted on a cumulative graph versus time in years. These are called “single-mass plots.” The attached graphs (Figures 32 to 36) generally show a straight line in the accumulated water level data, indicating no significant change with time over the period of record.

The second approach was to look at the possible magnitude of hypothetical decline in deep recharge within the Payne Creek Basin. Under the extreme hypothesis of zero recharge beneath clay settling areas, we determined that CSAs account for about 20% of the total basin area for Payne Creek. The generally accepted deep recharge amount in the SWUCA area is 1 to 2 inches per year. The remaining 80% of the basin would not have any change in deep recharge. Using the 2-inch value, the possible reduction in deep recharge in the Payne Creek Basin would be 20% times 2 inches or 0.4 inches of reduced deep recharge. At the conversion rate of 1 inch equals 0.073 cfsm, the possible reduction in deep recharge would show up as an increase in flow from the Payne Creek Basin of 0.03 cfsm. This amount is not enough to explain the large yield of the Payne Creek Basin. Conversely, the increase in recharge and the subsequent decrease in streamflow would be 0.03 cfsm.

Based upon these two approaches, there is no conclusive evidence of the supposed reduction in deep recharge due to mining and reclamation operations in the Peace River Basin.
Figure 31. Location of Drainage Basins and Regional Long-Term Monitor Well Clusters.
Figure 32. Cumulative Groundwater Level of Floridan Aquifer at Gardinier Monitor Well.

Figure 33. Cumulative Groundwater Level of Floridan Aquifer at ROMP 40 Monitor Well.
Figure 34. Cumulative Groundwater Level of Floridan Aquifer at ROMP 45 Monitor Well.

Figure 35. Cumulative Groundwater Level of Floridan Aquifer at ROMP 59 Monitor Well.
Figure 36. Cumulative Groundwater Level of Floridan Aquifer at ROMP 60 Monitor Well.
CONCLUSIONS AND RECOMMENDATIONS

SATELLITE LAND USE STUDY CONCLUSIONS

The main conclusion that can be drawn from the water budget and satellite imagery analysis portion of the study is that while it may be impossible to account for every single input and export of water into and from the Joshua and Payne Creek drainage basins successfully (particularly over an extended period of time), the overall water budget spreadsheet model provide a reasonable match between the modeled and measured streamflows. Analyzing satellite imagery from 1985 through 2000 has created a large and useful land-use classification database. The results of these analyses were multiplied by Evapotranspiration/Evaporation factors that were selected from other published reports. The resultant model-predicted streamflows were generally lower than the measured streamflows. Results of this study show relatively good success when comparing to the SWFWMD GIS database and a definite correlation to the changes of land use within the two study basins. As part of the model verification process, the rainfall falling onto the Joshua Creek and Payne Creek Basins as well as the streamflows during the 1985 through 2000 period were compared. This analysis revealed that while slightly more rain fell onto the Joshua Creek Basins than on the Payne Creek Basin, streamflow from the Payne Creek Basin was slightly larger. This observation led to the preliminary conclusion that the change in land-use associated with phosphate mining clearly did not reduce streamflow.

To provide a more detailed and more extensive analysis Schreuder, Inc. opted to expand the study significantly to include much more detailed analyses of the relationships between rainfall and streamflow for several basins in the Peace River, Alafia River, Little Manatee, Manatee and Myakka Rivers.

STREAMFLOW STUDY CONCLUSIONS

Conclusion 1

Although the size of the Payne Creek and Joshua Creek Basins are comparable and the rainfall over the Payne Creek Basin was less during the period studied than the rainfall over the Joshua Creek Basin, the total streamflow out of the Payne Creek Basin was higher than that from the Joshua Creek Basin.

Conclusion 2

The unit mean streamflow from basins where mining dominates is consistently higher than in basins where irrigated agriculture dominates. This was the case in both the Alafia and Peace River Basins. This clearly demonstrates that phosphate mining and
subsequent reclamation does not reduce surface water flow from the basins in which mining is taking place.

Conclusion 3

In the coastal river basins where the depression in the potentiometric surface of the Floridan aquifer shows significant pumpage occurring, the unit streamflow in cfsm is higher than the unit mean streamflow in either the Alafia or the Peace River Basin.

Conclusion 4

The contribution of streamflow from Payne Creek significantly increases the unit mean streamflow in the Peace River from 0.40 cfs/m at the Ft Meade gaging station to 0.58 cfsm at the next downstream gaging station at Zolfo Springs. This demonstrates clearly that additional surface water flow from tributary basins, where pumpage from the underlying confined aquifer system(s) or salvage of evapotranspiration losses is taking place, augments the surface water flow in the Peace River.

Conclusion 5

The polynomial trendline fits of the double-mass plots of unit mean streamflow versus unit rainfall for the 20-year period from 1980 through 2000 indicate a positive upward trend, indicating a trend in increased streamflow, except for Upper Horse Creek, Bowlegs Creek and the Withlacoochee River.

Conclusion 6

The results of the double-mass analyses confirm the fact that streamflows from predominantly mined/reclaimed areas have not been declining but in fact have been increasing at an even greater rate than those with predominantly irrigated agriculture.

This extensive analysis concludes that phosphate mining operations and irrigated agriculture have significantly contributed to additional streamflow in the SWUCA. This gain was achieved from the importation of groundwater pumped from the underlying confined aquifers and by salvaging water that would have been lost from the area as evapotranspiration.

Conclusion 7

Analyses of the 10, 50 and 90 percent exceedences of the flow frequency curves of the streams in the SWUCA for the 1980 to 2000 period clearly indicate a distinctly different distribution of streamflow from the mined (reclaimed) basins versus the other
basins. Phosphate mining operations tend to retain flood flows (P-10) for later release as median (P-50) and base flows (P-90).

**Conclusion 8**

The magnitude and distribution of streamflow from predominantly mined basins are very similar and both are distinctly different from other basins.

**RECOMMENDATIONS**

The satellite imagery and water budget results imply that the unique landforms and processes within the mined basin are in fact adding water (even in taking into consideration the NPDES discharges and pumpage). This is further supported by the extensive streamflow analysis looked at in the streamflow portion of this report, comparing mined basins, unmined basins and irrigated basins. Further work highly recommended would be to do a true baseflow separation analysis of the aforementioned types of streams and see if these conclusions remain unaltered.

This study established that streamflow distributions from predominantly mined/reclaimed phosphate basins are distinctly different from other basins. This conclusion was primarily based on streamflow separation using the 10, 50 and 90 percent exceedance criteria of flow frequency curves. These criteria, although widely used and accepted, are not the preferred method to accurately determine the overland runoff component from total streamflow. This is usually done using unit hydrograph separation technique.

Hydrograph separation analyses were beyond the scope of this project and therefore SI recommends that a follow-up study be considered to apply the hydrograph separation techniques to selected streams in the SWUCA. The streams recommended to be considered for such an analysis are: Peace River at Ft Meade, Peace River at Zolfo Springs, Payne Creek, Joshua Creek, Horse Creek and the South Prong of the Alafia River.
REFERENCES


