Small drainage basins and the probable maximum flood: A flood inundation study of an anticipated extreme storm event in West Central Florida

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Small Drainage Basins and the Probable Maximum Flood:
A Flood Inundation Study of an Anticipated Extreme Storm Event
in West Central Florida

by

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of the requirements for the degree of
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>iii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>iii</td>
</tr>
<tr>
<td>List of Pictures</td>
<td>vii</td>
</tr>
<tr>
<td>Abstract</td>
<td>viii</td>
</tr>
<tr>
<td>Chapter One – Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Goals of Study</td>
<td>3</td>
</tr>
<tr>
<td>Chapter Two – Literature Review</td>
<td>7</td>
</tr>
<tr>
<td>About the Area</td>
<td>17</td>
</tr>
<tr>
<td>Theory</td>
<td>23</td>
</tr>
<tr>
<td>Geographic Information Systems</td>
<td>25</td>
</tr>
<tr>
<td>Research Questions</td>
<td>27</td>
</tr>
<tr>
<td>Chapter Three – Study Area</td>
<td>28</td>
</tr>
<tr>
<td>Sefler Drainage Basin</td>
<td>31</td>
</tr>
<tr>
<td>Specific Area</td>
<td>34</td>
</tr>
<tr>
<td>Study Area Lakes</td>
<td>36</td>
</tr>
<tr>
<td>Land-Use</td>
<td>37</td>
</tr>
<tr>
<td>Future Land-Use</td>
<td>39</td>
</tr>
<tr>
<td>Zoning</td>
<td>40</td>
</tr>
<tr>
<td>Study Area Characteristics</td>
<td>41</td>
</tr>
<tr>
<td>Temperature</td>
<td>41</td>
</tr>
</tbody>
</table>


LIST OF TABLES

Table - 1 Norma Lake Levels 34
Table - 2 Landuse – Baker Canal by Percent 36
Table - 3 Zoning by Percent of Area 40
Table - 4 Soil Types 42
Table - 5 Model Output Table 108
Table - 5 Model Output Table – continued 109
Table - 6 Comparison of Flood Areas 112
Table - 7 Flood Area Landuse by Percent 113
LIST OF FIGURES

Figure - 1. Leading Cause of Cyclone Deaths 10
Figure - 2. Record Maximum Precipitation in U.S. 15
Figure - 3. Hurricane Track 1921 19
Figure - 4. Physiographic regions of maximum flood flows 23
Figure - 5. Study Area Location Map - Florida 30
Figure - 6. Study Area Location Map - County 31
Figure - 7. Specific Study Area 33
Figure - 8. Study Area Lakes 35
Figure - 9. Study Area Land Use - Map 37
Figure - 10. Expected Land Development Map 38
Figure - 11. Study Area Zoning 39
Figure - 12. Study Area Soils 43
Figure - 13. Ground Water Contours 45
Figure - 15. Two Ft. Contours 56
Figure - 16. Five Ft. Contours 57
Figure - 17. Five Ft. Contours over Two Foot Contours 58
Figure - 18. Digitized Two Foot Contours 59
Figure - 19. Rating Curve
Figure - 20. Maximum 24 hour rainfall
Figure - 21. National Flood Frequency (NFF) flow data
Figure - 22. Parameters for NFF Flow Data
Figure - 23. PreRAS prompt of HEC-GeoRAS
Figure - 24. Geometric Data Diagram
Figure - 25. Steady Flow Input Data
Figure - 26. Steady Flow Boundary Input
Figure - 27. HEC 100yr flood over Hillsborough 100yr flood
Figure - 28. Hillsborough 100yr flood over HEC 100yr flood
Figure - 29. FEMA Flood Risk Area
Figure - 30. HEC 100yr flood over HEC 500 yr flood
Figure - 31. HEC 500yr flood over HEC 100yr flood
Figure - 32. HEC 100yr flood depth
Figure - 33. HEC 500yr flood depth
Figure - 34. Probable Maximum Flood
Figure - 35. PMF at Muck Pond Rd.
Figure - 36. PMF South of State Highway 92
Figure - 37. Enlarged Map of PMF S. Hwy 92
Figure - 38. PMF North of Wheeler Rd.
Figure - 39. PMF at Lake Shore Ranch Subdivision
Figure - 40. PMF at Long Pond and Lake Valrico
Figure - 41. Enlarged Map of Lake Valrico 99
Figure - 42. Cross-section at outfall 100
Figure - 43. Cross-section S. of State Rd. 92 101
Figure - 44. Cross-section at Lake Weeks 101
Figure - 45. Cross-section between Long Pond and Lake Hooker 102
Figure - 46. Cross-section at Lake Valrico 102
Figure - 47. Cross-section at head-waters of study area 103
Figure - 48. Profile Baker Canal at PMF level 104
Figure - 49. Profile Tributary 1 105
Figure - 50. Chart- Top width of PMF 106
Figure - 51. Chart- Velocity of PMF 107
Figure - 52. Land-use within PMF zone 116
<table>
<thead>
<tr>
<th>Picture</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture – 1</td>
<td>Baker Canal N. of Muck Pond Rd.</td>
<td>46</td>
</tr>
<tr>
<td>Picture – 2</td>
<td>Baker Canal S. of Muck Pond Rd.</td>
<td>47</td>
</tr>
<tr>
<td>Picture – 3</td>
<td>Baker Canal N. of State Rd. 92</td>
<td>48</td>
</tr>
<tr>
<td>Picture – 4</td>
<td>Baker Canal S. of State Rd. 92</td>
<td>49</td>
</tr>
<tr>
<td>Picture – 5</td>
<td>Baker Canal under County Rd. 574</td>
<td>50</td>
</tr>
<tr>
<td>Picture – 6</td>
<td>Lake Valrico – Water-front Home</td>
<td>51</td>
</tr>
<tr>
<td>Picture – 7</td>
<td>Lake Valrico – New Construction</td>
<td>52</td>
</tr>
</tbody>
</table>
SMALL DRAINAGE BASINS AND THE PROBABLE MAXIMUM FLOOD:  
A FLOOD INUNDATION STUDY OF AN ANTICIPATED EXTREME STORM  
EVENT IN WEST CENTRAL FLORIDA  
Philip A. Ranalli  
ABSTRACT  
A major tropical storm will strike in the area of West Central Florida. In  
anticipation of this storm, this study seeks to predict the specific areas within the Baker  
Canal drainage basin that will be inundated as a result of this expected event. There are  
few references concerning extreme flooding in small drainage basins within existing  
literature.  

For the purposes of this study this event was considered to be a Probable  
Maximum Flood (PMF) as defined by Crippen and Bue (1977). The Hydrologic  
Engineering Centers’ Geographic River Analysis System was used to develop water  
surface elevations and flow rates. Maps depicting this potential flooding at various flood  
stages were produced using the Environmental Survey Research Institute’s geographic  
Information mapping program ArcView3.3.  

This investigation produced estimates of the surface area of a Probable Maximum  
Flood and the estimated flood inundated 23.7% of the study area. The estimated extent of  
Probable Maximum Flood indicates that the flood will affect one thousand and seventy  
six (1,076) homes and other structures. The study found that eight hundred and sixty  
three (863) acres or 27% of the land within the PMF flood zone is listed for future
development by the County Planning Commission. When this projected development area is added to existing developed land area a total of 85% of all developed land within the estimated flood area will be submerged and subject to damage.

An extreme flood study on a small drainage basin prior to the event can be a viable tool for mitigation planning if it is recognized that there are variables that can produce a relatively large range of error. The potential for this type of study is in its’ comparison with an actual event affecting the same area. If the predicted study and the real event study agree within reasonable limits then, maximum flood investigations on small basins could be considered a useful tool in hazard reduction.
CHAPTER ONE

INTRODUCTION

Flood research is usually confined to investigations after the fact. The physical event occurs, social changes begin to take place, cultural changes follow or occur simultaneously, and then research into these alterations begins. Research is an attempt to record the history of the event and its affects upon the population. The basic theory is that if history is known and understood the same errors will not be repeated and losses will be minimized or mitigation against damage will be more efficient. Unfortunately such has not been the case. Time after time disasters have occurred, and been studied. The event is then repeated again and again at intervals of several months to tens of years, and is perhaps studied again and again. The history we have been writing has not been heeded to the extent necessary such that it has lessened the frequency or the severity of disasters over all.

Perhaps a different line of inquiry may be more effective. Consider the situation that exists now on the West Coast of Florida. A major tropical storm is expected, exactly when and where this will occur is not predictable. However, worst case scenarios are possible based on population densities, proximity to the storm, and storm duration and severity. If sufficiently rigorous studies could be performed, prior to this event, on these areas and these studies could be determined to be practically adequate, planning for evacuation and mitigation could be greatly enhanced. At the very least public awareness
of the magnitude of forthcoming destruction would be increased and further urbanization in hazardous areas may be lessened.

It appears that the general public underestimates or is not aware of the potential extent and duration of inland flooding that would occur in a significant storm event (NOAA 2003a). It is possible that the social and economic impacts on the population are also underestimated. Since the causal factors related to the social and economic impacts of severe inland flooding are not widely disseminated, preventative action related to education and mitigation planning cannot be taken in an effective manner.

This thesis details the methodology necessary to investigate the effect of a Probable Maximum Flood (PMF) event in a small drainage basin in West central Florida. The reason for the study, the overall goals, specific goals, positive and negative aspects of the theories used, the study area, expected results, and order of execution will be discussed.

The overall goal of the study is to determine the extent of potential flooding in a chosen area of West central Florida. This investigation will attempt to incorporate a modified Positivist theory to determine the physical extent of an extreme flood event. If a follow up study of the actual storm event compares favorably with the present study, perhaps this will encourage additional interest in potential storm events in small drainage basins and foster further comparisons. Significant correlation between studies of potential and actual storm flooding may enable efficient mitigation of extreme flooding. Technology has advanced to a degree such that it is now possible to model a potential extreme storm event. The study will be evaluated as to its use as a model for similar small
drainage basins that may be subject to flooding as a result of widespread storm precipitation.

GOALS OF THE STUDY

This study is methodological investigation that seeks to determine if an extreme flood area can be successfully estimated using an easily and inexpensively acquired flood program. The specific goals of the study are to determine the portion of the land surface of the study area that will be submerged by a Probable Maximum Flood (PMF), and to map this flooded area in ways that will allow analysis. The specific questions that will be examined are:

• Is the easily acquired and inexpensive flood program, Hydraulic Engineering Center’s River Analysis System (HEC-RAS), a viable solution to flood inundation on a small drainage basin?
• What is the area of the study basin that will be inundated by a Probable Maximum Flood?
• What are some of the significant effects of a Probable Maximum Flood on the study area? Extensive analysis will not be attempted in this thesis.

These short-term goals are preliminary to much longer-term goals that are related to a post flood study of the extreme flood event. The pre flood predictions are intended to set the stage, as it were, for a possible post flood study. It would be advantageous to establish conditions as they existed prior to a severe flood rather than attempt to discern these
conditions after they have been altered by action of the floodwaters. It is expected that a pre flood data set would be invaluable in a post flood study situation.

The pre flood prediction of the area inundated will be compared to the area actually flooded in an actual event. When the event will occur is not known but the occurrence is assured and a post flood study will most assuredly be initiated if the event is of considerable magnitude.

A long-term goal is to demonstrate that predictive small drainage basin studies of extreme floods are a viable alternative to post flood investigations. A successful comparison of pre flood prediction and post flood inundation will be a strong indication that in this case at least and possibly in other cases as well, that predictive flood studies of extreme events are viable in small basins.

If the pre flood predictions are deemed practically adequate they can be useful for planning purposes such as recommendations as to how rapid the flooding may develop. For example enhanced zoning regulations of areas seen to be particularly vulnerable to severe flooding could be enacted.

Predicted flooding of a severe nature will be of interest in investigations of risk assessment and economic impact. In a predicted flood, the multifaceted factors involved in economic estimations of flood damage can be pursued at leisure and without undue pressure from various relief agencies or flood victims as normally occurs in the aftermath of an actual event. Questions as to lost opportunity, direct or indirect losses, long or short term losses, offsetting benefits, and tangible or intangible losses could be considered and compared and then recorded for further comparison at the time of the actual occurrence.
If it can be shown that the physical extent of a disaster can be pre-recognized, and convincingly and accurately mapped, within practical adequacy, a powerful tool will have been developed for the mitigation or prevention of extreme events.

First, a region is selected in which a particular hazard is known to be active at some interval such that the population is not eminently aware. Then the real but expected events are modeled and mapped prior to the event. The end result could encourage efficient preemptive mitigation, if nothing else it could beget a heightened awareness by the population, and land-use planners, not only to the potential of a disaster but also to their possible interaction with the event.

The political implications, of this education of the population, are not without fallout and pitfalls. An educated public may demand a higher standard of disaster management than is now present. It is also possible that when the event does occur, an educated public may hold political appointees responsible for inadequate planning. Any of these possible situations could result in reluctance to support such studies. Nevertheless, the possibilities are profound, and it behooves the geographic community to pursue potentially beneficial methods of investigation.

Risk assessment is more convoluted than economic impact. However this case of Probable Maximum Flood does eliminate magnitude as a factor of variability. Probability remains extremely low, but flood damage rises rapidly as magnitude increases. Thus economic risk remains high, and high risk drives disaster investigations.

The long-term goals are dependent upon the occurrence of a severe flood within a reasonable time frame. If an excessive amount of time passes between a pre-flood prediction and post-flood investigation, much of the pre-flood physical data will be dated,
and the social occupation of the basin will have changed. If the pre-flood study is not
done, we will however, have missed a rare opportunity.
CHAPTER TWO

LITERATURE REVIEW

It has been said that extreme disasters are a relatively normal occurrence in the overall experience of mankind. Through long experience humans have become mentally equipped to endure and survive catastrophes. After all, a natural disaster only exists if it can be said to have affected a human society in a negative manner. In society’s desire to prevent or mitigate disasters it has been noted that efforts must be initiated prior to the event if success is to be expected (Tobin and Montz 1997).

Flood damage continues to increase in the United States despite widespread efforts to mitigate flood hazards and regulate development in flood-prone areas. The National Weather Service (NWS) has maintained a relatively long-term record of flood damage throughout the United States. These records are estimates of physical damage to property, crops, and public infrastructure. Estimates for individual flood events are often quite inaccurate; however, when estimates from many events are accumulated the average of the errors become proportionately smaller (Pielke et al 2002). In 1991 United States monetary losses, as a result of flooding, were estimated at $1.698 billion. By 2001 the National Weather Service (NWS) estimated that annual monetary damage from floods had increased to $7.158 billion. An exceptional year for floods was 1993, when losses amounted to $16.364 billion (Pielke et al 2002). In the period from 1903 to 1997 the United States alone has experienced nine thousand and thirteen deaths from flooding
or an average of about 95 deaths per year (NWS 1997). UNESCO notes that during the period from 1973 to 1997, worldwide, sixty-six million people suffered flood damage (UNESCO 2001). Floods make up in excess of thirty percent of all disasters world wide, but it is the relatively few extreme floods that are responsible for the highest amounts of damage and deaths (Tobin and Montz 1997).

Clearly floods and flooding are worthy of our interest. It is the extreme flood that inflicts the most severe damage and causes the majority of loss of human life. Extreme floods are of interest to planners, designers, and engineers as they relate to the expected useful life, design, and construction techniques of bridges, dams and other structures. Extreme floods are also of interest to geographers and planners as they relate to landuse as demanded by expanding populations (Cohon et al 1988). This interest is particularly high where the large-scale risk of loss of human life is possible.

There are many types and magnitudes of disaster. When large numbers of human lives are lost it is most often caused by only a relatively few and extreme natural disasters. These disasters are usually termed severe natural disasters. On any given natural watercourse a flood of some magnitude occurs on average every 2.33 years (Dunne and Leopold 1978). Most of the time these floods cause inconvenience and some relatively minor property damage. Larger floods occur less often and are described as 10, 25, 50, 100, or 500- interval year floods. The 10yr flood, having a 10% chance of occurring in any one year, the 100yr. flood, a 1% chance, and the 500yr, flood a 0.2% chance of occurrence per year. The greater the expected return period the larger the expected flood. Floods in the 100-year (1% chance per yr.) to 500-year (0.2% chance per yr.) range are considered rare and extreme. Floods do however; occur at much greater
average time periods such as the 1,000-year (0.1% chance per yr.) flood. In the United States, historic flood records do not exist for periods exceeding 100 years except in rare instances. This inhibits the extrapolation of flood magnitudes from historic records to extreme levels that are known to occur, but for which there are few data. Nevertheless, extreme floods are of intense interest. For this reason, the magnitude of these exceptional floods must be estimated in some way (Lane nd.).

Floods of very great magnitude occur so rarely that they provide few opportunities for study. When very large floods do occur, physical conditions often prevent or inhibit well-designed scientific investigations. It is, however, the extreme flood that is of greatest danger or greatest natural hazard. Historically, floods have been the third largest cause of death due to natural hazards worldwide. Tropical cyclones are ranked first as disasters causing the most deaths. It is noted that a very high percentage of deaths due to rotating storms are caused by the flooding of low-lying areas (Tobin and Montz 1997).

It should also be noted that for the last 30 years inland flooding has been the most important factor in loss of life (See Figure 1) caused by tropical storms within the United States (NOAA 2003b). High rainfall rates are not necessarily associated with high wind speeds. Many record rainfall depths have been related to less intense storms that move slowly, or stall over an area. Numerous examples of intense rainfall resulting from tropical storms have been recorded at considerable distance from coastal areas. In 2001 hurricane ‘Allison’ produced heavy rainfall from Louisiana to Massachusetts resulting in 41 deaths and $5 billion dollars in damage. In 1999 ‘Floyd’ moved slowly along the East Coast resulting in 56 deaths of which 50 were caused by inland flooding. In 1994
‘Alberto’ dropped 21 inches of rain in parts of Georgia, and caused 33 deaths. The year 1979 saw ‘Claudette’ produce 45 inches of precipitation in Texas. ‘Agnes’ (1972) caused 122 deaths and $6.4 billion in damages. Fifty-nine percent of all deaths attributed to tropical storms from 1970 to 1999 (See figure 1) have been the result of freshwater flooding in inland areas (National Hurricane Center 2002).

![Leading Causes of Tropical Cyclone Deaths in the U.S 1970-1999](image)

Fig – 1 Inland flooding is the cause of 59% of all tropical storm related deaths over the last thirty years.

The Probable Maximum Flood (PMF) is defined as the most severe flood that is considered reasonably possible at a site as a result of rare but ideal hydrologic and meteorological conditions. PMFs are referred to as ‘probable’ due to their extremely long, and necessarily unspecified, return period or probability of occurrence. It is not possible, due to the extreme magnitude and rarity of such floods, to assign a confidence
of error to the size or the return period of an extreme flood (USGS 2002). It should be noted that it is not only extreme floods that cause property damage and loss of life. Flood depths of only one meter at a velocity of one meter per second are considered sufficient to cause structural damage in large areas and possible loss of human life (Ward 1978).

It appears from the existing literature that studies related to extreme flooding have not been pursued in relation to relatively small drainage basins. Extreme floods are primarily of interest in relation to the engineering and construction of major examples of infrastructure. In these considerations the primary concern is the design and construction of the edifice such that all reasonable possibility of catastrophic failure has been considered and mitigated. The possibility for catastrophic inland flooding, in the context of the small drainage basin, is very real.

Estimating the extent of flood probabilities on the order of one in one thousand or lower would require extrapolation far beyond any flood or meteorologically related data set available. Of the many methods available that could be used to estimate extreme floods, (Cohon et al 1988) states that there are three general types, the most common and widely used is the ‘probable maximum precipitation’ (PMP). The largest rainfall event that can be reasonably conceived for the region is converted into stream flow and a flood hydrograph is constructed. This hydrograph is termed the ‘Probable Maximum Flood’ (PMF) (Cohon et al 1988). A PMF is defined by Ward (1978), as the flood resulting from the Probable Maximum Precipitation (PMP) falling on a drainage basin when it is in a state of saturation. It is also possible to collect historic and paleoflood data, and use these data in flood frequency analysis to establish a frequency curve that can be extrapolated. Paleoflood data, on the other hand, may be affected by climate change; thus the
extrapolation of such data may no longer accurately represent local conditions (Dunne and Leopold 1978). As a third general method, mathematical models of extreme storms can be constructed, from which runoff amounts can be established. In the methods using historic flood data and runoff models there are few documented cases in which these methods have been used to estimate floods of return periods in excess of one hundred years (Cohon et al 1988).

In a general sense design floods may be estimated either by what is termed deterministic methods, in which floods are seen to result from a specified precipitation falling within the drainage basin, or as probabilistic in nature, in which floods are seen as random events investigated by statistical analysis. There is little apparent advantage to one general method over the other when attempting to estimate extreme floods. Both suffer from the same shortage of historic data upon which to base the estimates. Due to relatively short length of historical records, which record less than one hundred years of flood data, both methods may be forced to use a short range of data to extrapolate a long flood return period (Ward 1978).

The probable maximum flood in a region can also be depicted by a graph on which recorded maximum floods are plotted against drainage area. Smooth curves enveloping the plotted points (envelope curves) are drawn such that all of the points indicating maximum floods are below the curve. Since the curve represents a flood at least as large as the largest historic flood, probability levels cannot be assigned. It is thought that envelope curves encompassing the largest flood events in a region tend to become more reliable as the area and period of observation increase (Phillips and Hjalmarson 1996). This type of graph has been generated by Crippen and Bue (1977)
for seventeen regions within the Conterminous United States, and is used by the United States Geological Survey (USGS) and others to estimate Probable Maximum Floods for drainage basins of comparable size.

Probable Maximum Floods are considered as engineering factors related to large dams or bridges, or more recently for evacuation plans for coastal areas threatened by tropical storms (USGS 2002). The five hundred-year flood is usually the largest flood used as a measure of extreme flooding by governmental agencies. It is chosen primarily as a result of economic considerations. Flood-plains are desirable locations for human occupation, but floods are costly in terms of loss of property and loss of human life. At some point the desirability of flood-plain occupation begins to outweigh the potential cost in property and lives. The Federal Emergency Management Agency (FEMA) defines this point at the level of the one hundred-year flood. Areas outside the one hundred-year flood zone are considered suitable for occupation even though it is expected that at extended periods of time some of these areas will experience flooding (FEMA 2003). Major structures such as large or important bridges, large dams, or levees protecting large populations are constructed to withstand the five hundred-year flood. These areas are considered more vulnerable for increased human mortality due to high population exposure (USGS 2002).

There is a considerable difference between the expected runoff created by a five hundred-year flood and the runoff created by a Probable Maximum Flood. The 500-year flood-peak discharges will likely be considerably less than the envelope-curve values, assuming that several watersheds in a given region have experienced at least one flood exceeding the 500-year value during the period of data collection. For example, the 500-
year flood of 12,800 cubic feet per second at the Fenholloway River (Florida) is relatively small compared to the Probable Maximum Flood envelope-curve value of 101,000 cubic feet per second for the same location (USGS 2002). While flood events of this extreme magnitude are very rare, they are not totally unexpected; nevertheless they are not addressed in existing literature in relation to small drainage basins.

West Central Florida is statistically due to experience a major tropical storm. The state of Florida has experienced fifty-seven hurricanes from 1900 to 1996. Twenty-four of these storms were category three or higher on the Saffir-Simpson scale. On average Florida has been the landfall site for a major tropical storm every four years for the last century (NCEP 2003).

In the United States inland flooding has been the primary cause of tropical cyclone-related fatalities over the past 30 years (NOAA 2003b). Precipitation is generally heaviest with slower moving storms (less than 10 mph). The heaviest rain usually occurs to the right of the cyclone track in the period 6 hours before and 6 hours after landfall. However, storms can last for days, depending on the inland weather features with which they interact. Large amounts of rain can occur more than 100 miles inland where flash floods and mudslides are typically the major threats (NOAA 2003b).

The record amount of rainfall for the State of Florida in a twenty-four hour period is 38.7 inches (See figure 2). This record rainfall was due to an unnamed hurricane that lingered just off shore of Yankeetown Florida for several days in 1950 (NOAA 2003c).
West Central Florida has been affected by tropical storms on the average of once every 3.77 years in the last one hundred and thirty two years. Hurricanes have passed within forty miles of Tampa Florida, on average, every thirty-three years (Unknown.a). In spite of the seemingly large number of tropical storms that have passed in close proximity to the study area, the general public is not aware of the potential extent and duration of the inland flooding that would occur in a significant storm event. Eighty to ninety percent of the population now living in hurricane-prone areas has never experienced the core of a "major" hurricane (NOAA 2003a).
Flooding, has historically, been studied after the event has occurred. Since a severe storm event will occur, it seems reasonable to attempt a study that models the inundated area prior to the event rather than wait to determine what occurred after the fact. It appears that the literature related to flooding, severe flooding, hurricane induced flooding, etc. has not addressed the inundated area resulting from a Probable Maximum Flood event in drainage basins of relatively small size.

Post flood studies have been pursued in numerous instances in efforts to provide learning opportunities from a historical perspective. In general these efforts while successful in the physical sense have not met with considerable success in areas of population education and flood mitigation. The same residents often repopulate flood-plain areas, event after event. Extreme flood events are not totally explained by physical processes. Disasters of this type are as much related to social and cultural forces than they are to hydrological and meteorological events. Nevertheless, “there is little argument that the physical characteristics of extreme events are important” (Tobin and Montz 1997).

It is not expected that a study of potential flooding will materially alter the human desire to rebuild or remain in the area, but in areas that are under development a visual depiction of anticipated flooding may impact social and cultural decisions. The post flood study that is usually done will be doubly useful in comparison with this examination of potential flooding.

The advent of computers and related software has removed many of the barriers to quantification. Quantification now has a new outlook; landscapes formally impossible to generate (within reasonable cost and time constraints) can be produced in minutes by
Geographic Information Systems (GIS) software. Calculations that in the recent past would have taken a team of mathematicians’ weeks or months can now be done in seconds. Combined with software algorithms that can generate filled contour maps as well as the ability to overlay map transparencies, GIS technology has given new life to quantitative positivist methodology (Johnston 1997). Precipitation models are now available that can be used in conjunction with relatively new flood models that allow predictions of flood extent based on channel elevation. Such a study would have considerable value as an educational tool used to enlighten the public in way that may save lives or mitigate physical damage by allowing informed site selection for homes or businesses (Jaeger 2002).

ABOUT THE AREA

There are nearly 45 million permanent residents in the area along the United States coastline where hurricanes are most prevalent. The area experiencing the most growth has been the state of Florida, but extensive growth has been seen from Texas to the Carolinas (NOAA 2002). The last hurricane to pass within twenty miles (direct hit) of West Central Hillsborough County was an unnamed, category two, storm (See figure 3) that occurred in 1921 (unknown.b). At that time the population of Hillsborough County was approximately 9% of its present size (Census 2003).

The landfall of a major tropical storm on the West Coast region of Florida will have a major impact resulting in severe inland flooding. Etheridge (2001) notes that forty-eight deaths and nearly $3 billion worth of property damage occurred in inland communities as a result of Hurricane Floyd. In the thirty years prior to 1999, six hundred
deaths have been attributed to hurricanes and tropical storms. Eighty two percent of these deaths were by drowning and the American Meteorological Society states that more than half of these drownings occurred in inland counties while coastal storm surge accounted for six fatalities. It is Etheridge’s (U.S. Representative and a member of the House Science Committee) opinion that inland flood forecasting and warnings must be improved.

In West-central Florida several factors contribute to this hazardous environment. The relatively flat topography, Karst drainage, and extended period of time that has elapsed since the last serious inland flood combined with the extensive population growth within the area tend to increase the potential for a major disaster far in excess of what is generally expected. Areas that appear to be excellent housing or business locations for the exploding populations are often, in reality, lakes that are usually dry due to Karst topography. Many of these areas will be submerged in a Probable Maximum Flood. The lack of relief in the area inhibits the rapid runoff of surface water. The Florida climate entices retirees to relocate into the area in large numbers. Many of these individuals have minimal knowledge of Karst topography. Waterfront property is also highly desirable as a location for home construction. In general, property values are lower in Florida than in many areas of the Northeastern States. These enticements lead to development of land areas that appear to be suitable in relatively dry conditions. Many of these areas have been subdivided that begin to exhibit partial flooding at times of slightly above average rainfall amounts. These areas react to the increased urbanization and its attendant reduced infiltration capacity and increased overland flow, due to road paving and building construction, by flooding of the naturally low areas within the development.
Often this flooding does not occur for several years after the development is completed. The homeowner is surprised by the unexpected flood and seeks redress from the local governmental agency. Thus the County is often saddled with the considerable cost of mitigating what is a normal phenomenon.

Fig.- 3 An unnamed category 2 hurricane passed within 20 miles of the study area in 1921. Source: Unknown,(b) 2003.
The general lack of awareness related to severe inland flooding may be in part, due to a dearth of experience on the part of local government concerning severe storm event precipitation amounts. More likely local and state governments are following the recommendations of the Federal Emergency Management Agency by allowing construction on land deemed to be outside the one hundred-year flood-plain. This may have resulted in political actions by local government in issuing building permits for vulnerable areas that exhibit a lack of rapid natural drainage due to Karst topography and little relief. An example may be the relatively new subdivision at the South end of Lake Wheeler (See figure 39). The fact that this area is a few tenths of a foot above the calculated one hundred-year flood may be of little solace to homeowners if that level is even slightly exceeded. The issuance of a building permit implies that some agency has determined an area is suitable for a particular use, this expectation can result in the population being unprepared for extensive inland flooding.

Probable Maximum Flood (PMF) curves as defined by Crippen and Bue (1997) will be used to determine the magnitude of a severe flood on the study area, a small drainage basin in West Central Florida. As populations increase and property at higher elevations becomes more expensive and less available, land at lower elevations becomes more desirable. Flooding of relatively small drainage basins has been historically of minor importance due to their usually sparse population. Investigations related to very large flows have tended to concentrate on larger river basins that contain densely populated areas. In an effort to establish a method in which a very large or maximum flood could be estimated for smaller basins, Crippen and Bue (1997) extracted 883
extreme flood sites from thousands of recorded floods throughout the conterminous United States. The chosen sites drain areas less than 10,000 square miles. The sites were then grouped into regions having similar rainfall intensity and physiographic type (See figure 4) (Fenneman 1931, 1938). Extreme floods from each region were then plotted on graphs and envelope curves were calculated that allow estimates of maximum flood as they relate to basin size. Typically these curves indicate flood volumes two to three times larger than the largest flood recorded from similar sized basins in the region. Due to the extreme magnitude of these floods and corresponding rarity no return period can be calculated (Crippen and Bue 1997).

“The Probable Maximum Flood (PMF) is defined as the flood that may be expected from the most severe combination of meteorological and hydrologic conditions that are reasonably possible in a particular drainage area” (Ohio nd). The Probable Maximum Flood (PMF) results directly from a Probable Maximum Precipitation (PMP) event. Extreme events such as floods resulting from dam failures or ice jams are not considered Probable Maximum Floods. Drainage areas with the same Probable Maximum Precipitation may have different Probable Maximum Floods. This is possible due to the differing characteristics of drainage basins. Characteristics affecting Probable Maximum Floods include channel slope, soil type, landuse, size and shape of the watershed. These variables must be taken into consideration along with Probable Maximum Precipitation. Thus the Probable Maximum Flood, rather than the Probable Maximum Precipitation, must be used as a design criterion for critical areas. Both meteorological methods and historical records are used to determine the greatest amount of precipitation that is theoretically possible within a region. The historical data consist of
precipitation amounts measured at rain gages throughout the region, or rainfall measured in a region with similar meteorological and topographical characteristics. Rainfall data gathered in either manner can be maximized through "moisture maximization". Moisture maximization is a process in which the maximum possible atmospheric moisture for a region is applied to rainfall data. This increases the apparent rainfall depths, bringing them closer to their potential maximum, Once the Probable Maximum Precipitation has been determined a flood hydrograph can be constructed that represents the Probable Maximum Flood (Ohio nd).

The consequences of a prolonged or extreme precipitation event are not well understood by the general populous, and it is expected that inland flooding during a Probable Maximum Flood will be so severe that property damage and loss of human life may be high. The magnitude of this expected event is such that an effort should be made to develop a predictive procedure that will encourage mitigation prior to extreme flood events. It is expected that a graphical depiction of areas inundated as a result of an extreme flood would be of interest to planners, civil engineers, and elected officials responsible for the development of businesses and subdivisions that may be in potential danger.

This study will not attempt to establish a flood extent from a precipitation event. It will instead use flood flow velocities and volumes established by the Probable Maximum Flood (PMF) curves established by Crippen and Bue (1997) as they relate to the physiographic regions in the United States (See figure 4).
Physiographic Regions of Maximum Flood Flows

Fig. 4 Regions within the United States that have similar meteorological and topographical characteristics.

THEORY

The study will use a moderate version of positivism known as Post-positivism, Critical Realism. This version of positivism has served as a replacement for Logical Positivism. Logical Positivism (logical empiricism) is based on the verification theory, which holds that statements or propositions can be meaningful only if they can be, without exception, empirically verified. In Post-positivism, Critical Realism, the concept of complete verification would be replaced with the idea of gradually increasing confirmation as a result of numerous successful experiments or models (Trochim 2000).
Logical empiricism holds that all knowledge begins with observation. This leads to empirical generalizations among observable phenomenon. As ideas progress, theories are formulated deductively to explain the generalizations, and new evidence is required to confirm or reject the theories (Malhotra 1994). It has been argued that if the positivist version of verification is taken to mean the complete establishment of truth, then universal statements could never be verified, and truth could never be determined (Peet 1998). However, using Post-positivism, Critical Realism, statements may be confirmed to be adequate for practical purposes by the accumulation of successful empirical tests. Thus science can progress through the accumulation of such tests (Trochim 2000).

In addition to the problem of verification, Logical Empiricism and Post-positivism, Critical Realism both encounter difficulties due to the insistence that science rests on the basis of uninvolved objective observation on the part of scientists. There are at least two problems here. The first is that observations are always subject to measurement error and social and political pressures often color results. The second problem concerns the fact that observation is preceded by theory, and theory often leads to results that support the theory. This calls into question the lack of impartiality on the part of researchers, and the claim that science is based on objective observation (Malhotra 1994).

It is realized that the study of an anticipated event cannot be classified as scientific in the Positivist sense. Following a strict Positivist methodology would require the actual observation of the flood event. The quantification of this anticipated event will be estimates from computer models, (based on regionalized maximum flood data) rather than actual flooding (based on recorded data). This type of study is however now
possible due to the development of advanced flood models. These models have been tested against available historic data to the extent that they have been determined to be adequate for practical purposes. This is an advanced outlook on flooding that is relatively new, but has been used on large drainage areas such as that of the Rhine River (Jaeger 2002).

GEOGRAPHIC INFORMATION SYSTEMS

The investigator of the physical study must keep in mind the limitations of GIS generated information and refrain from treating these data as highly accurate due to the computers ability to deliver decimal place results. These results must be accompanied by well-defined explanations as to the range of accuracy in which the information should be considered (Lo. 2002). The researcher has an ethical responsibility to present the study in such a way that the conclusions reached are not expressed as hard facts, but as estimates based on verified information. Conclusions must have been arrived at via a specified path that is well documented, such that others can evaluate the endeavor in light of their own experience or experiments (Peet 1988).

Geographic Information Systems (GIS) are “computer based systems for managing geographic data and using these data to solve spatial problems.” A more general statement is that GIS allows data to be changed into information (Lo. 2002).

In general GIS is used to create map layers that can be viewed at various levels of transparency. These layers which may consist of a base map depicting the political boundaries of an area overlain with a layer showing road locations, a drainage layer, a topographical (contour) layer, and a land-use layer. Various analyses may be carried out
comparing the effects of one layer upon another. For example one layer may be used to filter another layer. The political layer may be used to filter the land-use layer such that it is possible to list what land-use parcels are contained within a particular political (county, city, flood zone, zip code) boundary (Lo. 2002).

Geographic data are represented in either vector or raster format. Vector data is delineated by points, lines (arcs), or polygons. Vector data are referenced by x-y coordinates related to a specific map projection. Raster data is delineated by subdividing the general area in question into small square areas. Each of these small squares represents a particular attribute.

Data in vector format lends itself to the geographical analysis of individual objects. It is most suited for use in applications such as transportation planning, natural resource management, cartography, and land title information. Whereas data in raster format is most useful in applications that relate to surfaces such as temperature, rainfall, elevation, landuse, or environmental considerations. Raster data usually relates to relatively large areas at the regional or national level, while vector data lends itself to relatively smaller areas at the local level. Raster and vector data can be displayed in the same map projection. This allows layers with point, line, surface and polygon data to exist in the same map (Lo 2002).

The ability to store, retrieve and analyze spatial data makes GIS unique among data base management systems (DBMS). GIS data were stored using what was termed a geo-relational data model. In this model, graphical data were stored in one database that referenced containment, connectivity, and adjacency, while at the same time attribute data were stored in a separate but related database. More recently GIS uses an object-
relational model as a storage and retrieval method. In this model graphical and attribute
data are stored in the same database, thus simplifying search and retrieval. In this model
attribute data are stored in a modified relational database and graphical data are stored in
an added column, often named ‘shape’. This ‘shape’ column contains references to
geographical data, for example, data type, number of points, x-y coordinates. Software
is designed to search and access these ‘shape references’, and allow the manipulation of
data by activities such as insertion, deletion, or reformatting. Data processing is also
supported that allows display, computation, summarization, and plotting (Lo. 2002).

The results of this thesis will be incorporated into a Geographic Information
System (GIS) to enable analysis related to human occupation. Although it should be
noted that extensive analysis is not the focus of this endeavor nevertheless some analysis
will be demonstrated for the purpose of example.

RESEARCH QUESTIONS

• Is the easily acquired and inexpensive flood program, Hydraulic Engineering Center’s
  River Analysis System (HEC-RAS), a viable solution to flood inundation on a small
  drainage basin?

• What is the area of the study basin that will be inundated by a Probable Maximum
  Flood?

• What are some of the significant effects of a Probable Maximum Flood on the study
  area?
CHAPTER THREE

STUDY AREA

The study site is a sub-basin within the Selfer Drainage Basin located in Hillsborough County Florida. The location of this study area was selected primarily due to its physical characteristics and accessibility. West Central Florida is chosen as the general physical region because it exhibits relatively unique Karst topography with little topographical relief, and a climate with a potential for wet and prolonged storm events. Drainage in Karst topography is mainly accomplished by direct infiltration into a limestone substratum or by numerous short creeks that empty into lakes that have little or no outlet. The surface water in this topography infiltrates into the limestone substrata or evaporates. There are few major rivers that carry large amounts of surface water to the sea. The Karst topography thus insures that surface water recedes slowly. Outflow is often a relatively small factor in floodwater removal.

The local, political, region (county) resides in the large physical region of West Central Florida. The populace is composed of a mostly economic middle class, English speaking population. The area under study (the particular area of Hillsborough County) is to be considered more than an area surrounded by lines, it is the product of human history and as such is continually changing (Pudup 1988). It is recognized that regions are always incomplete and ongoing and that changes occur simultaneously and at different scales. Processes of geographic and social change are continually reshaping
regions, and the regions are constantly adjusting to change (Bosman 2000). Thus, the area under study will be investigated in a manner such that any conclusions reached will be considered valid only for the specific, and relatively short time during which no significant geographical, social or cultural changes occur (Johnston 1997).

In a large sense the spaces pertinent to this proposed study may be seen as a nested set of social, political and physical regions. They begin with the largest region possible within the definition of geography, the earth, then North America, the Southeastern United States, Florida, West Central Florida, Hillsborough County, and finally the relatively small area of study, named the Selfer Drainage Basin (Baker Canal) near the center of the County. (See figure 5)

The level of existing ground water has a major effect on floodwater removal. High ground water levels prior to a storm event will result in lower infiltration rates, increased flooding, and slower recession levels (Owen 1998).
The study area is located in West-Central Florida in the County of Hillsborough. Data Source: Hillsborough 2002.
SELFER DRAINAGE BASIN (Baker Canal)

A Probable Maximum Flood study is particularly suited to West Central Florida. This area is statistically overdue to experience a major tropical storm event. It is geographically a Karst region that has a moderately dense population that exhibits a mix of urbanization and agriculture. The general study area is in a 30 sq. mi. catchment located in central Hillsborough County (Selfer drainage basin) (See figure 6).

Selfer Drainage Basin with Limits of Specific Study Area Indicated

Fig. – 6 Selfer Drainage Basin Scale - 1in. = 3.5mi. The Selfer Drainage Basin is approximately 7 miles South-east of the University of South Florida.

The relief, while relatively minor in the region is particularly flat along the North-South axis of the basin. East to West the relief is much greater and varies from a 60ft
elevation at the West divide to 40ft +/- at the outflow canal, and then to 70ft +/- at the eastern divide. This produces an elongated and flat-bottomed bathtub shaped basin with one outfall channel exiting to the North. In addition to the minor relief there are four standing lakes and one ephemeral lake within the basin that attenuate the water flow. Outside the basin, runoff passes through a large wetland area as it enters a large lake (Lake Thonotosassa) several miles North of the basin where it is further attenuated by a control structure (dam) prior to entering the Hillsborough River. The Hillsborough River then empties into Hillsborough Bay, which connects to the Gulf of Mexico. The Southwest Florida Water Management District (SWFWMD) indicates that the average stage for Lake Thonotosassa is approximately 35.3 ft. This stage can increase to 36.2 ft for the 2.33 year flood event, and further increase to 42.0 ft during the 100-year flood event (Hillsborough 2002).

SPECIFIC AREA

The specific area of investigation will be the area of the Selfer (Baker Canal) Drainage Basin from Muck Pond Rd. South to the CSX Rail Road embankment North of State Hwy. 60. There is no natural flow of surface water from the area South of the RR embankment into the Selfer basin, and North of Muck Pond Rd. the topography flattens and other basins contribute runoff such that modeling becomes uncertain (See figure 7).
Fig. 7 Note the R.R. embankment that delineates the Southern end of the study Area and Muck Pond Rd. lining the Northern end of the Study Basin. Source: Hillsborough 2002.
STUDY AREA LAKES

The four major lakes that are within the study area basin include Lake Valrico, Long Pond, Lake Hooker and Lake Weeks. Lake Valrico is 124 acres in extent and drains a sub-basin of approximately 1055 acres. The deepest area (9ft) is in the center of the lake. The average depth is 4 feet and the average lake level is 44.0 feet above sea level. Long Pond is 55 acres in area, and drains a sub-basin of 726 acres. The lake has an average depth of 7 feet and the average lake level has been 41.3 feet. Lake Hooker and Lake Weeks are both about 53 acres in area. Lake Hookers’ sub-basin covers about 890 acres with the historic lake level at 42.5 feet. The sub-basin for Lake Weeks is much smaller at approximately 298 acres, and the average water level has been 41.2 feet. (See table 1 and figure 8) There are numerous smaller lakes and ponds in the Selveser basin that are both natural and manmade (Hillsborough 2002).

Table – 1

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Lake Valrico</th>
<th>Long Pond</th>
<th>Lake Hooker</th>
<th>Lake Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acres</td>
<td>124</td>
<td>55</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Drainage Area</td>
<td>1055</td>
<td>726</td>
<td>890</td>
<td>298</td>
</tr>
<tr>
<td>Avg. Depth</td>
<td>4</td>
<td>7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Max. Depth</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Average Elev.</td>
<td>44</td>
<td>41.3</td>
<td>42.5</td>
<td>41.2</td>
</tr>
</tbody>
</table>

Lake Data at Normal Water Levels
This map depicts study area lakes and surrounding areas of low elevation. The low areas surrounding Lake Hooker are subject to flooding during normal precipitation events.
LAND-USE

The Selfer drainage basin can be characterized as being made up primarily of rural and rural-residential land-uses. Land-use is nevertheless, diverse, with approximately thirty-three percent of the basin engaged in various agricultural activities, while nearly twenty-nine percent is residential. Five percent of the basin is subject to frequent flooding (See table 2). The majority of the residential landuse is low to medium density. Most of the commercial areas are located near the major roads such as Interstate 4, and State Road 60 (Hillsborough 2002). Following page contains a Landuse map of the study area, (See figure 9).

Table - 2

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Acres</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>4495</td>
<td>33.5</td>
</tr>
<tr>
<td>Residential</td>
<td>3941</td>
<td>29.3</td>
</tr>
<tr>
<td>Forest</td>
<td>1385</td>
<td>10.3</td>
</tr>
<tr>
<td>Open land</td>
<td>1095</td>
<td>8.1</td>
</tr>
<tr>
<td>Commercial</td>
<td>891</td>
<td>6.6</td>
</tr>
<tr>
<td>Wetlands</td>
<td>698</td>
<td>5.2</td>
</tr>
<tr>
<td>Water</td>
<td>690</td>
<td>5.1</td>
</tr>
<tr>
<td>Mined land</td>
<td>148</td>
<td>1.1</td>
</tr>
<tr>
<td>Underbrush</td>
<td>97</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>13440</td>
<td>100</td>
</tr>
</tbody>
</table>

Landuse by percentage within the Study Area. Data dated 1999
Source: Hillsborough 2002
The Selfer drainage basin is not heavily developed at this time. The Hillsborough County Planning Commission is predicting increased development in the near future. It is expected that much of the open or agricultural land (41% of the total land area) will be
developed into residential and light industrial or commercial use (Hillsborough 2002).

(See figure 10)

Fig. – 10  Open and agricultural land areas are slated for development. Data dated 1999. Data Source: Hillsborough 2002
ZONING

The area of interest is zoned by Hillsborough County as is seen in figure 11. Zoning by percent of area is listed in table 3.

Fig. – 11  The majority of land in the study area is zoned for agriculture or residential use. Data Source: Hillsborough County. nd.
<table>
<thead>
<tr>
<th>Study Area</th>
<th>Zoning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acres</td>
</tr>
<tr>
<td>Residential</td>
<td>25.9</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.1</td>
</tr>
<tr>
<td>Agricultural</td>
<td>71</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Study area zoning by percent of land area. Source: Hillsborough County. nd.

STUDY AREA CHARACTERISTICS

The climate of the Selfer drainage basin, humid subtropical. Annual average precipitation is around 53 inches. Approximately 60% of this total falls during the four-month rainy season that extends from June through September. This is a time when the summer heat allows rising thermals inland of the peninsula. These thermals encourage a Westerly sea breeze that meets the moist Easterly moving across the State from the Atlantic Ocean. The collision of these fronts results in the formation of cumulonimbus clouds that develop into the nearly daily thunderstorms that create Central and South Florida’s rainy season. These summer events, which can be very localized, are highly variable in both intensity and volume. The larger thunder storm events and those associated with tropical systems can cause flooding in areas where the topographical relief is small. During the winter months rainfall is associated with the cold fronts that move from the northern part of the country and travel south through the region. It should be noted that some of the largest single rain events and associated flooding have occurred.
in the winter and spring months. These exceptional rainfall events are more often seen when the El Nino-Southern Oscillation is in effect (Hillsborough 2002).

**TEMPERATURE**

The annual mean temperature in Hillsborough County is 72°F. The average monthly temperature ranges from a low of approximately 60°F in January to a high of approximately 82°F in August. Typical summer temperatures range from lows in the high 70's to afternoon highs that reach into the high-90's, but rarely exceed 100°F. Summer humidity that often reaches 90 percent and can increase the apparent heat index. The low winter temperatures generally range from above freezing to the 40's, and only occasionally drop into the low 20's or high teens. High winter temperatures generally reach the upper 60's or low 70's for most of the winter season, but tend lower during passages of numerous cold fronts (Hillsborough 2002).

**EVAPOTRANSPIRATION**

Estimates of actual evapotranspiration rates vary between 39 and 48 inches per year. Tampa Bay Water (an intergovernmental agency) estimates that lake evaporation rates average approximately 56 inches per year. Potential evapotranspiration estimates range as high as 78 inches per year (Hillsborough 2002).

**GEOLOGY**

The Selfer drainage basin lies in an area of Karst topography. At depth there exists a thick layer of consolidated but highly fractured carbonate rock. At the surface lies
a varying depth of unconsolidated silt, sand and clay. These surface deposits range between twenty to fifty feet in depth (See table 4 and figure 12).

The underlying carbonate rock is composed of limestone and dolomites formed in the Tertiary period. In descending order, the various limestone strata are named as follows. “Tampa Member of the of the Arcadia Formation of the Hawthorn Group, Suwannee Limestone, Ocala Group, Avon Park, Oldsmar, and Cedar Key Formations. A lithographic change from limestone and dolomite to a sequence of gypsiferous dolomite begins in the lower portion of the Avon Park Formation and continues into the Oldsmar and Cedar Key Formations. The top of this lithologic change marks the middle-confining unit of the Floridan aquifer system. The middle confining unit is generally considered the base of the freshwater production zone of the Upper Floridan aquifer” (Hillsborough 2002).

Table – 4

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Acres</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Sand 0 to 12 degree</td>
<td>4901</td>
<td>36.7</td>
</tr>
<tr>
<td>Water</td>
<td>498</td>
<td>3.7</td>
</tr>
<tr>
<td>Fine Sand Depressional</td>
<td>1397</td>
<td>10.5</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>6549</td>
<td>49.1</td>
</tr>
<tr>
<td>Total</td>
<td>13345</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Hillsborough 2002
Fig. - 12  This map graphically indicates the fine sand composition of the soil within the study area.  Data Source: Hillsborough 2002
Surficial Aquifer

The majority of the surficial aquifer is composed of various grades of medium to fine-grained sand. This aquifer averages approximately 30 feet in depth, but depth is variable as a result of the Karst nature of the region. It is of considerable interest that the water table is relatively close to the surface, usually not more than several feet deep. This fact limits the infiltration capacity of the basin and results in early saturated overland flow during rainfall events. Infiltration is the primary influence on water table elevation, with annual highs in most years occurring during the wet season and annual lows occurring near the end of the dry season. Ground water generally flows from the Northeast toward the Southwest across the Selfer drainage basin. (See figure 13) The surficial aquifer is partly isolated from the Upper Floridan aquifer that lies beneath it by a layer of mixed clays and silts. This layer of confining material is discontinuous due to the karst topography of the area. Numerous areas exist in which the clay layer is absent or perforated such that water from the surficial aquifer is able to percolate downward into the Upper Floridan aquifer (Hillsborough 2002).
This map depicts the surface contours of the Upper Floridan Aquifer. Note the converging contours in the vicinity of the study area. Source - USGS
BAKER CANAL PICTURES

The following pictures depict the Baker Canal at various locations beginning at the study area out-fall and progressing upstream toward the headwaters of the basin. These photographs are dated September 2003.

Baker Canal North of Muck Pond Rd.

Pic – 1  Note the pasture area at upper right of the photograph. This area is subject to flooding beginning at flow rates of only 300cfs. Hillsborough County has dredged this part of the Canal in 2002. Water level is slightly higher than yearly normal at approximately elevation 38.5ft.
Baker Canal South of Muck Pond Rd,

Pic – 2  Note the vegetation growth along the banks. This area of the Canal has not been dredged as recently as the area North of Muck Pond Rd. This area also easily overflows its banks. In September and December 1997 the Hillsborough County Engineering Dept. recorded an estimated 50yr flood at this location.
Baker Canal North of State Road 92

Pic – 3 This area has been dredged in 2002. Water level is normal for September.
Baker Canal South of State Road 92

Pic – 4  Note the lack of bank side vegetation due to dredging. Water level is at normal levels mostly due to ground-water seepage. Flow rate is approximately 200cfs.
Pic – 5  The flow seen in this photograph is normal and due to ground water through-flow from the basin. The picture is taken from the RR Bridge just South of County Rd. 574. Both of these roads are over topped by the Probable Maximum Flood.
Lake Valrico – Water-front home.

Pic – 6 Lake level is normal for the end of what is known as the ‘rainy’ season.
Lake Valrico – New home construction.

Pic – 7  This is not flood stage. The lake level is normal for September.
CHAPTER 4

METHODOLOGY

This study is methodological investigation that seeks to determine if an extreme flood area can be successfully estimated using an easily and inexpensively acquired flood program. The study seeks to produce this extreme flood estimate in a small (22sq.mi.) drainage basin and map this flood in a way that enables analysis. Extensive analysis is not a goal of this investigation. Every effort to obtain the most up to date input information was made as it is realized that erroneous data may produce propagation errors that could have a detrimental effect on the generated flood areas. A relatively small percentage error in a base data may affect final results in a cumulative manner. As with any computer model, the limitations of the program and its underlying hydraulic computations must be understood. Information generated cannot be treated as inviolate because of the apparent accuracy of calculations (Hoggan 1997).

It must be repeated that this study did not attempt to establish a flood extent from a precipitation event. The study did use flood flow velocities and volumes established by the Probable Maximum Flood (PMF) curves for physiographic regions as defined by Crippen and Bue (1997). (See figure 4)
DATA ACQUISITION

The study focused on potential flooding due to a rainfall event such as a slow moving tropical depression or hurricane. As is common with hydrological studies a good deal of quantitative data was amassed. The area of the drainage basin was determined from USGS quadrangle maps. Contour and Digital Elevation Models (DEMs) of the basin, profiles and cross-sections of the channels, and lake levels, were procured from Southwest Florida Water Management District (SWFWMD) and Hillsborough County records. Records of historic flows and their accompanying rainfall events have been collected along with ground water flows and water table elevations. Bridge opening dimensions, culvert type and size, and channel conditions related to Manning numbers have been collected by field survey. Roadway elevations were established from profiles developed by the Hillsborough County Engineering Department. Roadways will act as weirs when overtopped by floodwaters. Data related to the magnitude of the 100, and 500yr. flood peaks were gathered along with Probable Maximum Flood peak flows from Crippen and Bue (1997). A rating curve (flow in relation to stage) is also under construction at the Muck Pond basin outfall (see Fig 19).

A basic data requirement for this type of study is an elevation data set that can be used to create a Triangulated Irregular Network (TIN). The Hillsborough County Engineering Department, Storm Water Division provided a digital two-foot contour set that covered a large portion of Hillsborough County (See figure 15). This data set
included road elevations. Normal lake surfaces and bottoms were digitized where necessary. This contour information was gathered from various sources and surveys done over a period of years by Hillsborough County, Southwest Florida Water Management, and private surveys. A much better, one foot ortho corrected Lidar, data set exists but was not available for this investigation. Small areas that were deficient in elevation data were overlaid with a five-foot contour data set (See figure 16,17). Two-foot contour lines with values within one foot of the five-foot contours were then digitized following the five-foot contour line shape. While this procedure did induce some error into the two-foot contours, the area of absent data is minimal and the error must be less than one foot. This error is deemed acceptable due to the small physical area in relation to the data sets over all size. The final contour data set used in the study appears in figure 18. This data set was used to create the Triangulated Irregular Network (TIN) that the flood program used to determine the hydraulic head between cross-sections along the channel.
Two Foot Contours of Study Area

Note: Areas deficient in Contours

Fig. - 15 The arrows indicate several areas in which the two foot contours are absent. Source: Hillsborough County
Fig- 16 Five foot data set used to digitize contour lines into the two foot contours such that they could be used by the USGS flood program.
Source: Hillsborough County
Five Foot Contours Superimposed over Two Foot Contours

Fig-17  The two foot contours (Black) falling within one foot of elevation of the five foot contours (Red) were digitized following the Red 5ft contours. Source: Hillsborough County

Figure 18 represents the final two-foot contour data set. An area to the North of the outfall (downstream) has been included. The flood program requires additional data downstream in cases where water surface boundaries are unknown. In such cases the
program user must estimate a water surface elevation. This estimate induces an error in the vicinity of the estimate. Thus, the estimate must be made at a distance sufficiently downstream such that the program will have had time and distance to correct the
computations at the area of interest, which in this case is the outfall of the study area (Brunner 2002). For a complete discussion of the process by which the extent of the flood surface is determined please see Chapter Five – Computation Procedure.

GENERAL METADATA

The Probable Maximum Flood (PMF) has been established within the state of Florida from an analysis of major floods impacting Florida and the extreme Southeastern United States. Relatively long historic records exist for this area of generally low geographic relief. Transposition of these data is possible from basins having historic records to similar basins where major storms of the same type have a similar probability of occurring (Ward 1978). Factors such as homogeneous regions having few topographical or meteorological anomalies tend to allow the transposition of weather related data.

The Probable Maximum Flood (PMF) will be established from flood-envelope curves developed by Crippen and Bue (1977) and Crippen (1982). The maximum flood experienced at 883 sites throughout the conterminous United States have been grouped by region, physiographic type (Finneman, 1931, 1938) and regional rainfall intensity as defined by the US Weather Bureau 1961. These extreme floods have been graphed and envelope curves computed that allow estimates of maximum floods to be made at other drainage basins within the appropriate region. These curves approximate the maximum flood-peak discharge that has been regionally experienced for a given size watershed. Basins range in size from 0.2-sq. mi. to 10,000-sq. mi. (Crippen and Bue 1997).
Canal profiles and historic lake levels have been established by County surveys. These data were used to establish the percentage fall per mile of the drainage canal. Precipitation would be expected to be reasonably consistent over the surface of this relatively small basin due to the high volume of rainfall being modeled. For the purpose of this investigation rain fall rates are high and of relatively short duration. As a result evapotranspiration will be a minimal factor in flood-wave generation. Infiltration will also be minimal due to the normally high level of the Floridan aquifer throughout the drainage basin and the fact that Probable Maximum Floods are predicated on the assumption that basin surfaces are saturated prior to the event.

Figure 19, compiles recently collected data from the Baker Canal that relates stage to flow at the Muck Pond Road Bridge (basin outfall). Historic stage data is available but corresponding flow data has not been collected.

POSSIBLE PROBLEMS

Runoff into the channel will be high for this basin, but due to the very low relief along the channel, quick channel runoff will not provide substantial reduction in peak flood levels. Two drainage basins just North of the Muck Pond Road Bridge flow in an East to West direction. Relief along this axis is on the order of ten times that of the
Stage Verses Flow Rate at Study Area Outfall

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</tbody>
</table>

Fig. - 19  Note the highest flow of 257cfs at elevation 39.65ft. The road surface Elevation is only 43.96ft.

Selfer (Baker Canal) Basin, and runoff from these basins enters the same channel as the Selfer basin. During periods of high runoff it is possible that a hydraulic head develops at the confluence of the Selfer basin and basins to the North. Outflow from the Selfer (Baker Canal) basin could be reduced at these times and it is possible that at the very high flows that are being modeled, back-flow conditions may exist for intermittent periods.
In addition to the above mentioned flow restrictions, the bridge opening at Muck Pond road is relatively small which will cause the road surface to act as a weir at very high flows. Under these conditions Hoyt and Langbein (1955) note that the basin flood-plain may act as a reservoir as it accumulates surface runoff much faster than the channel is able to discharge volume through its relatively small and restricted outlet. Hoggan (1997) notes that pronounced back-flow or a significant loop effect (discharge becomes a factor in water surface elevation) can aversely impact results generated by the Hydraulic Engineering Center’s (HEC) computer program.

COMPUTER PROGRAMS

Floodwater level predictions were generated using the Hydrologic Engineering Center’s River Analysis System 3.1 (HEC-RAS 3.1) computer program developed for the United States Army Corps of Engineers. The goal of the Hydrologic engineering Center (HEC) is to support the United States water resources management activities. “The Hydrologic Engineering Center is an organization within the Institute for Water Resources. It is the designated Center of Expertise for the US Army Corps of Engineers in the technical areas of surface and groundwater hydrology, river hydraulics and sediment transport, hydrologic statistics and risk analysis, reservoir system analysis, planning analysis, and real-time water control management” (HEC 2003). Programs are developed for the Army Corps of Engineers but are available to the public and may be freely downloaded from the http://www.hec.usace.army.mil/default.html web site. The HEC-RAS 3.1 program is improved over HEC-RAS 2.0 in that it is able to compute unsteady flows, and it allows the user to interact with the program through a graphical
The user interface (GUI). The program provides storage and data management as well as graphic capabilities (HEC 2003).

Niemeyer (2002) mentions that Magilligan and Stamp used the HEC program to compare runoff, over time, within a Georgia drainage basin. Gergel, et al, (2002) used the HEC program to study the effects of levee removal on the Wisconsin River. HEC has been developing computer programs for hydrologic engineering and planning analysis procedures since its inception in 1964. HEC-RAS has been used as standard modeling software in the estimation of flood stage and extent in hundreds of hydrological studies (HEC 2003). A series of basin cross-sections represent floodplain topography and Manning Numbers provide roughness coefficients. An algorithm solves a one dimensional energy equation between the cross-sections. Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method (Brunner 2002).

The Hydrologic Engineering Company’s River Analysis System (HEC-RAS) incorporates two methods by which flood levels can be estimated. The user must choose either Steady Flow or Unsteady Flow regimes. Steady Flow was chosen for this study primarily due to the minimal slope of the basin bottom. “The Steady Flow regime is designed for application in flood-plain management and flood insurance studies to evaluate floodway encroachments. This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river reach or a full network of channels.” The accuracy of the model depends upon the accurate input of Geometric Data, Boundary Conditions, and the
limitations of the Solution Scheme. The output must be checked by the operator to insure that reasonable results are produced by the system (Brunner 2002).

**COMPUTATION PROCEDURE**

Water surface elevations are determined at each cross-section by an iterative solution of the Energy equation and the Energy Head Loss equation as described below. Computations begin downstream and proceed upstream. Downstream surface elevations are usually not known and must be assumed.

1. For a subcritical profile – choose a known or assumed water surface elevation upstream.

   Subcritical is defined as a water surface elevation above the hydrologic critical level.
   Critical level is that water surface elevation where in the energy head is minimal (Brunner 2002).

2. Based on #1 determine the total conveyance and velocity head.

3. From #2 compute S and solve the Energy Head Loss equation.

4. From #2 and #3 solve the Energy equation for the water surface (WS).

5. Compare the value of WS with the value assumed in step #1; repeat steps 1 – 5 until the values agree to within .01 feet of the upstream elevation (Brunner 2002).

The equation for Expansion and Contraction losses is:

\[
[1] \sim \ h_{ce} = C \left| \frac{a_1 V_1^2}{2 g} - \frac{a_2 V_2^2}{2 g} \right|
\]
Where: $C =$ the contraction or expansion coefficient (Brunner 2002).

Which is used in the Energy equation.

The Energy equation is:

$$[2] \sim Y_2 + Z_2 + \frac{a_2 V^2}{2g} = Y_1 + Z_1 + \frac{a_1 V^2}{2g} + h_e$$

Where $Y =$ Depth of water at cross sections
$Z =$ Elevation of the main channel invert
$V =$ Average velocities
$a =$ velocity weighting coefficients
$g =$ gravitational acceleration
$h =$ energy head loss  (Brunner 2002).
The Energy Head Loss equation is:

\[
[3] \sim h_e = L S_f + C \left| \frac{a_2 V^2}{2g} - \frac{a_1 V^1}{2g} \right|
\]

Where:  
- \( L \) = Discharge weighted reach length  
- \( S \) = Friction slope between two sections  
- \( C \) = expansion or contraction loss coefficient (Brunner 2002).

PMF magnitudes will be generated using the National Flood Frequency Program (NFF) (USGS Water-Resources Investigations Report 02-4168).

The HEC-RAS program is based on five assumed factors.

- The flow varies gradually.
- The flow is one-dimensional but is corrected for horizontal velocity changes.
- The channel slope is relatively small.
- The average friction slope between cross-sections is constant.
- The boundary conditions are static (Hoggan 1997).
There are five steps in the development of a hydraulic river study using HEC-RAS 3.1. The first step is the creation of a project file. Next, the river network is defined and geometric data such as basin cross-sections, river and reach delineations are created. Flow and boundary conditions are then input prior to developing the analyses and reviewing the results (Hoggan 1997). In order to facilitate these five steps HEC-RAS operates in conjunction with the Hydrologic Engineering Centers Geographic River Analysis System (HEC-GeoRAS), a companion program also developed by the Hydrologic Engineering Center for the US Army and an extension to the ArcView 3.3 Geographic Information System (GIS). Hec-GeoRAS enables the development of an import file that consists of user created and named rivers and reaches with station identifiers, cross-sections of the drainage basin with roughness coefficients, levee alignment, elevation and location, along with ineffective flow areas and storage areas. After this file is generated and imported into HEC-RAS, hydraulic structure information such as culvert size and type with Manning numbers, channel slope, beginning and ending surface elevations, or flood hydrographs, may be input prior to processing that produces water surface and velocity data. This output file may then be used in ArcView GIS for further analysis (Ackerman 2002).

It is within the ArcView program that flood inundation mapping takes place. A Triangulated Irregular Network (TIN), generated from the two foot contour data, was overlaid with the flood inundation depiction generated in HEC-RAS. One-meter aerial photographs from the Hillsborough Tax Assessors office were layered such that the existing streets and subdivisions are visible. Lakes and bank-full channel boundaries have also been layered to enable the reader to easily discern the extent of flooding. Maps
were created such that flooding depth is evident. All data related to a particular analysis is accessed from a series of files recognized by file extensions that are native to HEC-RAS and HEC-GeoRAS. These files consist of Project Files (.PJR), Plan Files (.P01 to .P99), Run Files for each plan (.001 to .099), Geometric Data Sets (.G01 to .G99) and Steady-flow or Unsteady-flow Data Sets (.F01 to .F99).

HEC-GeoRAS provides a mouse operated drawing object that allows the river network to be created on top of a contour map of the drainage basin. Each river and river-reach is named at this time. A drawing object is also provided that allows basin cross-sections to be drawn. These cross-sections must cross the river centerline at near right angles and must extend to elevations higher than the maximum flood elevation. Cross-sections must also be close enough together to indicate geographic features such as connecting drainage canals or ditches. Structures such as bridges, culverts, weirs and other hydraulic features are then added and stored in the Geometric Data File. Profiles, discharge values and boundary conditions are entered and stored in the Flow-Data File (Hoggan 1997).

OPERATIONAL PROCEDURE

Data related to surface contours were then formed into a triangulated irregular network (TIN) and were imported into a Geographic Information System (GIS). An extension to the GIS ArcView; the Hydrologic Engineering Centers Geographic River Analysis System (HEC-RAS) was then used to develop a geospatial data file. HEC-RAS is a two-part program composed of HEC-GeoRAS for preprocessing and HEC-RAS, which develops water surface elevations and flow rates. The pre-processing area of the
program (HEC-GeoRAS) uses a digital elevation model (DEM) in the form of a Triangulated Irregular Network (TIN) to produce an import data file describing and naming rivers, and reaches, with station identifiers and cross-sectional bank stations. Reach lengths for stream centerline and right and left riverbank limitations are delineated at this time. Manning roughness coefficients can also be introduced into the import file. The extension allows the input of the alignment and location of levees, ineffective flow areas, and storage areas. The import file produced by the pre-processing feature of HEC-GeoRAS is then loaded into the HEC-RAS program.

Hydraulic boundaries are input into the HEC-RAS program at cross-sections locating the beginning and end of each reach and at any point where a flow change would be expected. HEC-RAS then produces water surface profile and velocity data sets in an output file used by the post-processing section of HEC-GeoRAS. The water surface profile data is used within ArcView GIS to develop a water surface TIN, and the intersection of the water surface TIN with the terrain model TIN provides flood visualization. The results can be projected in two-dimensional or three-dimensional views. These data can then be utilized in map production (Ackerman 2002).

Flood hydrographs and PMF magnitudes used in the HEC program were generated using the National Flood Frequency Program (NFF). USGS Water-Resources Investigations Report 02-4168 incorporates this computer program that allows the user to input drainage basin size, slope, and lag time (See figure 22,23). These inputs are then used within the program to estimate the magnitude and frequency of floods for ungauged sites within the United States or its possessions. The return frequency of these estimated floods ranges from two-year to five hundred-year return periods. Estimates of 100-
500-year flood discharges are used by the Federal Emergency Management Agency (FEMA), and National Park Service in defining floodplains. Floodplain boundaries based on the 500-year flood are used mostly for planning purposes to identify areas that would be inundated by an extreme flood. The various Departments of Transportation at the State level have begun to evaluate the risk of their bridges being subjected to scour damage during floods on the order of 100- to 500-year or greater return periods (USGS 2002). The National Flood Frequency (NFF) program will also provide the Crippen and Bue (1977) envelope curve values for seventeen regions within the conterminous United States, including region three. Region three contains basins that are comparable in hydrological and meteorological characteristics and also in size to the study area.

Very large floods or Probable Maximum Floods (PMF) are estimated in several ways, but the most common are either floods based on the maximum flood experienced on a similarly sized basin located in the same region, or floods based on the Probable Maximum Precipitation (PMP).

The extreme flood used in this study is based on the maximum observed flood for a given size watershed. These data are taken from flood-envelope curves developed by Crippen and Bue (1977) and Crippen (1982). The curves were developed by plotting the maximum known flood discharges for a given drainage area in seventeen flood regions of the conterminous United States. The flood-envelope curves approximate the maximum flood-peak discharge that has been regionally experienced for a given size watershed. These values do not have probability of exceedance due to their extreme nature (USGS 2002). These extreme flood values will be used in the estimation of area inundated within the Selfer (Baker Canal) drainage basin.
The Hydraulic Engineering Center (HEC) program was run in Steady Flow mode and the Canal was considered an open channel. At Probable Maximum Flood magnitudes all road crossings will be submerged and the roadways will act as smooth-topped weirs. Roughness coefficients were adjusted for submerged drainage structures.
CHAPTER FIVE

RESULTS

The Hillsborough County Engineering Department has completed an extensive hydrologic study of this general area in an attempt to develop a comprehensive mitigation plan that will accommodate a 25-year flood event. This study which used the EPA Stormwater Management Model (SWMM) modified by the County staff, (model HCSWMM4.31B) also defines the County’s estimate of the 100-year flood extent. The relatively short historic length of hydrologic data usually limits flood studies to the 100-year flood. The County estimate is the most current and localized flood information available. The estimates of floods up to the level of the 100-year flood, in this paper, were compared to the Hillsborough County 100-year flood. It is noted that the estimate of flooding extent as calculated by Hillsborough County is based on the predicted 100 year rainfall event which is eleven and one-half inches (11.5in.) of rainfall in a twenty-four hour period (See figure 20) (NOAA 2003c).

INPUT DATA for CALCULATIONS

Flood estimates of events of greater return periods than 100 years do not generally have historic local data with which they can be compared. The 500-year flood is the largest flood that is used for planning, management, and design. This flood discharge has
a 0.2 percent chance of being exceeded in any given year. The 500-year flood is the most extreme flood discharge usually used in the flood-frequency programs of the US Geological Survey and of the US Army Corps of Engineers (USGS 2002). Floods that are expected to occur in excess of 100 year return periods are seldom estimated by regression equations due to short historical records of flooding (Bridges 1982). For this reason flood magnitudes and hydrographs for return periods exceeding 100 years will be calculated from Crippen and Bue (1977) envelope curves. These data are available through the USGS National Flood Frequency Program (See figure 21).
Fig. 21 Information input into the upper panel results in peak flows for recurrence intervals. Note the flows for 100yr, 500yr, and Maximum flood flow.

The parameters in the upper panel of figure 21 are produced by the input in the window as shown in figure 22.
The 100-year, 500-year and the Probable Maximum flood flows are of particular interest in relation to this study. As can be seen from figure 21 these flows are 1240cfs, 1950cfs, and 41,900cfs respectively. These data were supplied to the HEC-GeoRAS program in order to generate an initial input file. This file consists of designated names for the River, names, lengths and stationing for each reach of the River, and cross-sections at relevant points along the various reaches, all of which are integrated with a Triangulated Irregular Network (TIN) that supplies elevation data for the calculations. Figure 23 illustrates the ‘preRAS’ portion of HEC-GeoRAS, which prompts for the creation of the River centerline, the left and right river banks, flow-paths, and cross-section lines. When these features have been correctly created, the program will assign reach lengths, stationing, three dimensional centerline elevations, and three dimensional
cross-section elevations. The Import File is then created, which can be used in the HEC River Analysis System.

Prompt Window for HEC Program

When the import file is imported into HEC-RAS, a geometric data file is created as seen in figure 24. This file generates a depiction of cross-sections that are stationed along the river reaches with the stationing beginning at the lowest elevations and proceeding upstream (North to South) and three shorter tributaries in a West to East orientation. The outfall of the study area is at station 16,943.87. Data downstream
(North) of this station is necessary so that the program will have enough information to minimize any error induced by the estimation of projected flows.

Diagram of Geometric Import Data File

![Diagram of Geometric Import Data File]

Fig – 24  This Input File is the basis upon which all calculations are Processed. The Green lines represent cross-section lines where elevations from the topography via a Triangulated Irregular Network are obtained. The program uses the difference in elevation between cross-sections to calculate energy losses and ultimately flood surface extent.
Steady Flow data input into the HEC program

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Fig – 25  The flow data for each of the river and tributary reaches for the 100yr (PF1), 500yr (PF2) and PMF (PF3) must be correctly input into the HEC flood program prior to any surface calculations.

It is possible to calculate numerous flood profiles, or scenarios using the same geographic input file. In this instance, three profiles – PF 1, PF 2 and PF 3 represent an estimate of the 100yr, 500yr, and Probable Maximum Flood respectively. Note the values of 1240, 1950 and 41,900 cfs on line four of figure 25. These are the flow rates from the USGS National Flood Frequency Program for a basin of this size and slope in Crippen and Bue’s physiographic area number three. These data along with the required boundary data shown in figure 26 produce the inundation maps shown in figures 27, 28.
Boundary Conditions (limits)

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Fig – 26 Boundary data is obtained from the two foot contour data set and is used in conjunction with the input flow data by the HEC program. WS = water surface elevations.

Upstream boundaries are established from ground elevations while downstream elevations are estimates used by the flood program to enable initial computations.
CHAPTER SIX

DISCUSSION

In discussing the research question: Is the easily acquired and inexpensive flood program, Hydraulic Engineering Center’s River Analysis System (HEC-RAS), a viable solution to flood inundation on a small drainage basin? A comparison of the HEC estimate with Hillsborough County’s estimate is examined below.

The Hillsborough County Stormwater Division of the County Engineering Department has completed a comprehensive study of five major basins within the County boundaries. Total cost of this comprehensive study was approximately twelve million dollars. The Baker Canal (S helfer) basin was included in the study. The basic goal of the County investigation was to determine the necessary steps needed to mitigate a twenty-five year event such that a minimum number of structures and county roads would be affected. In the pursuit of these goals an estimate was made of the extent of the 100yr flood within the specific study area of this thesis. The flood inundation map shown in figure 27 is a graphic depiction of the HEC 100 year flood estimate (green) superimposed over the 100 year flood as estimated by the Hillsborough County Engineering Department, Storm Water Division (purple). With the exception of several separated areas to the East, the HEC estimate differs less than 1.5% in area from the Hillsborough County prediction. These Eastern areas result from the high rate of precipitation, 11.5 inches in a 24hr. period, used in the Hillsborough County Storm Water Management
Model (SWMM) and the inherent differences in design goals of the HEC and SWMM programs. The HEC program leans primarily toward river analysis and uses recorded or estimated flow rates as its primary input. The SWMM program is a stormwater management tool that uses precipitation amounts as a basis for peak flow rates. These shallow surface areas in the Eastern area of the basin cannot be duplicated in the HEC model, running in Steady Flow Mode, regardless of the flow numbers used in the tributaries from these areas. (See figure 25, row 7,16) Relief along the basin center is in the range of 1 to 1.5ft. per mile, while relief from the centerline toward the East in approximately 30ft. per mile. The HEC program routes surface water in this area downslope into the channel area. The SWMM program tends to indicate short-term storage. For the purpose of flood estimation of areas that may exhibit shallow flooding the SWMM model appears to be superior. The HEC program has produced a comparable estimate of channel flooding in a very short time with a minimum of financial expenditure.
Fig. – 27   Except for the separate areas to the East the Hillsborough estimate is virtually hidden by the HEC flood estimate.

For comparison figure 28 is the reverse of figure 27, showing the Hillsborough 100yr flood superimposed over the HEC 100yr flood.
Fig. – 28  In this map the HEC 100yr flood estimate is virtually hidden behind the Hillsborough County 100yr flood estimate.
Numerous iterations of the input process in the HEC program in Steady Flow Mode result in similar results as seen above. When properly entered into the HEC program the target flow rate of 1240cfs for the 100yr flood results in very close agreement with the Hillsborough County estimates. Below in figure 29, the FEMA estimate of areas at risk of flooding are displayed for comparison with the HEC and Hillsborough estimates. Note the similarities, and the areas to the East of the main channel in the Hillsborough estimate that are nearly absent in the FEMA and HEC estimates.

Comparison of Three 100yr Flood Estimates

Fig. – 29  Note the minimal size of the separated areas to the East of the main channel in the Study Area and FEMA flood estimates compared to the Hillsborough estimate.
Having established the relevance of the HEC model, to the study basin, by comparing the 100yr flood area generated by both the SWMM and HEC models and finding them in agreement within reasonable tolerance, it is now possible to proceed with estimates of flood levels at extended return periods. It is recognized that the 100yr flood is of a much smaller magnitude than the PMF flood to which this study aspires but the 100yr flood is the best and most recent flood estimate available with which the model can be compared.

FLOOD AREA

In discussing the research question: What is the area of the study basin that will be inundated by a Probable Maximum Flood? Estimated flood areas are examined on the following pages. Figure 30 indicates that there is little difference in surface area between the HEC, Steady Flow 100yr flood over the HEC 500yr flood. For comparison figure 31 shows the reverse of figure 30. There is a flow rate difference of 710cfs. Figures 32 and 33 are of interest in that they indicate a difference of 0.06ft in maximum flood depth at Muck Pond Rd. (outfall). Table 5 (pg. 106) indicates only a 0.02ft. increase in surface elevation between the 100yr, and 500yr. flood levels. Velocities are very low at 0.02 to 0.03fps. The 100yr flood is estimated to extend 6,527ft. in width while the 500yr flood is only slightly larger at 6,534ft wide. This table also indicates that the flood meets program requirements that state that the flow be “steady and slowly varied” (Brunner 2002) (See table 5).
Fig. – 30 Comparing the HEC 100yr and 500yr flood estimate results in very little apparent difference.
Fig. – 31    The reverse of figure 30 also indicates very little apparent difference between the HEC 500yr and HEC 100yr flood estimate.
Fig. – 32 In this enlarged view of 100ft flood depths note the maximum depth at the intersection of Muck Pond Rd. and the Baker Canal (basin outlet).
Fig. – 33  In this enlarged view of 500ft flood depths note the maximum depth at the intersection of Muck Pond Rd. and the Baker Canal (basin outlet).
The USGS National Flood Frequency Program (NFF) indicates that the Probable Maximum Flood Flow for this basin, in this physiographic area (region 3 Crippen and Bue) is 41,900 cfs. The input flow rates for this profile (PF-3) are listed in figure 25. A map showing the estimated area of inundation resulting from this maximum flood is shown in figure 34.

Fig – 34  This map illustrates the major goal of the study.
The Probable Maximum Flood area covers 3,146 of the 13,251 acres that comprise the study area or 23.7% of the study area basin. Under normal conditions only 4.3% of the basin area is occupied by lakes or steams. This estimate of the extent of a Probable Maximum Flood indicates that the flood will affect a number of homes and structures. Figures 35 to 40 illustrate the extent of the estimated flood in relation to recent aerial photographs.

EXAMPLE ANALYSIS

In discussing the research question: What is the significance of the Probable Maximum Flood on the study area? Maps are displayed that demonstrate some analysis possibilities. Even though most of the land area in the vicinity of the study area outfall (Fig – 38) is agricultural, the flood extent estimate indicates that approximately 207 buildings will be inundated. In all cases a field survey will be necessary in order to determine an exact number of structures that may be affected. North of Muck Pond Rd and outside the study area lies the Pemberton Creek subdivision; an additional 70 to 80 buildings in this subdivision appear in the inundated area. This subdivision has experienced flooding, that was estimated by Hillsborough County to be at the 50yr level, in 1997.

A large shallow ephemeral lake dominates the estimated PMF flood zone South of State Highway 92. This lake is the treeless area in the center of figure 36; there are no structures within this dry lakebed. Rainfalls of two inches per twenty-four hour period will result in flooding of parts or all of this ephemeral lake depending on existing ground
water levels. Approximately 98 structures will be affected by the estimated PMF in the area depicted in figure 36. The majority of these structures are in an area surrounding the

Fig. – 35  The Probable Maximum Flood area at the basin outfall (Muck Pond Rd).
small-unnamed lake in the center left of the figure. See figure 37 for an enlarged map of this area.

Fig. – 36 Note the large ephemeral lake in upper center of the figure and the small Lake in the upper left central area of the figure. The majority of the structures in this figure surround this small-unnamed lake.
In this enlarged map of the small unnamed lake the development surrounding the lake is apparent.
Fig. – 38 Lake Hooker is the dark area to the left of the lower central portion of the figure and Lake Weeks is in the upper left area of the figure. The majority of the structures in this area are located near the bottom of the figure South of Lake Hooker.

Approximately 245 structures are within the estimated PMF flood zone in this figure. One hundred and seventy-four buildings out of the two hundred and forty-eight
structures that compose the Lake Shore Ranch subdivision (bottom left) are within the estimated PMF flood zone. See figure 39 for an enlarged map of this flood area.

Fig. – 39 This is an enlarged area of the Lake Shore Ranch Subdivision indicating the estimated Probable Maximum Flood boundary as it cuts across the development.
Figure 40 illustrates the Probable Maximum Flood area in the vicinity of Lake Valrico and Long Pond. Lake Valrico is situated in the bottom center of figure 40, while Long Pond is left of center in the upper portion of the figure.

Approximately 526 structures are within the estimated PMF zone in figure 40. The number of inundated structures is derived from counts of structures visible in the overlaid aerial photographs. A field survey would be necessary to determine the actual number of structures that exist inside the estimated PMF zone. An enlarged map of the area appears in figure 41.
PMF Area – Lake Valrico, Long Pond

Fig. – 41 Developed area around Lake Valrico (South) and Long Pond (North). The dredged canal between the lakes is visible as a tan colored and dog-legged line.

The following are several filled cross-sections from the model computations, beginning at the outfall and proceeding up stream (See figures 42 to 47).
Figure 42 indicates several separate conveyance areas East of the main channel. These areas have hydraulic connections to the main channel as indicated in figure 34. The conveyance areas appear to be separated due to the routing of the cross-section for this river station. The cross-section does not cross the channel in a straight line but is dog-legged (see figure 24) so as to include pertinent topography as is indicated in figure 42. These cross-sections are exaggerated at a ratio of 50 to 1 in order that the vertical relief along the cross-section can be easily discerned at this scale. Cross-sections are aligned such that important relief will be included in the program calculations and they must span the channel area from elevations higher than the maximum water surface. Cross-sections
must also be close enough together such that the hydraulic head between them is evident at the shallow relief exhibited by the main channel.

Ephemeral lake South of State Highway - 92

Fig. – 43 Cross-section at river station 23648.18 (South of Hwy. 92).

Lake Weeks

Fig. – 44 Cross-section at river station 35035.09 (Lake Weeks).
Area between Long Pond and Lake Hooker

Fig. – 45      Cross-section at river station  38655.71 (High Point between Long Pond and Lake Hooker).

Lake Valrico

Fig. – 46      Cross-section at river station  43112.09 (Lake Valrico).
Head-waters of the Study Area

These cross-sections illustrate the estimated Probable Maximum Flood level at each location.

Profiles have also been generated that graphically illustrate the estimated Probable Maximum Flood levels along the flow-line of the Canal as well as at each overbank location. For clarity the overbanks are not visible (See figure 48).
River station 16943.87 is the outfall (top of road embankment) at Muck Pond Rd.

River station 38655.71 is the high point between Long Pond and Lake Hooker.

The profile indicates a relatively rapid change in elevation between the high point and the next downstream cross-section. This is still within the Hydraulic Engineering Centers River Analysis (HEC-RAS) program parameter due to the minimal flow rate for the basin as a whole and minimal volume in this area (See Figure 45). Figure 49 illustrates the flow-line profile of Tributary 1. This tributary enters Lake Valrico from the East.
The Tributary’s Probable Maximum Flood surface is indicated by the dashed red line. Note that the maximum depth of the Tributary is just over 3ft.

The tributary appears relatively deep at its’ outfall due to the junction point location, which is a considerable distance from the lake shoreline toward the center of the lake.

A graph depicting the width of the top of the estimated Probable Maximum Flood area along the alignment of each cross-section is shown in figure 50.
The arrow indicates the outfall location. Note the widening of the flood area just down-stream of this point.

Figure 51 illustrates the velocities at each cross-section. The velocity is uniformly low for the main channel. This meets the requirements of the Hydraulic Engineering Centers River Analysis (HEC-RAS) program parameters that call for a “steady and slowly varied flow” (Brunner 2002).
Probable Maximum Flood Velocities at Main Channel

Fig. – 51  Note the relatively high velocity between Long Pond and Lake Hooker. The volume at this point is minimal (See figure 45).

Table 5 enumerates Total Calculated Flow, Minimum Channel Elevation, Flood Surface Elevation, Channel Slope, Velocity in the Channel, Flow-Area, and Top Flow Width for each of the profiles 100yr (PF 1), 500yr (PF 2) and Probable Maximum Flood (PF 3) at each cross-section location.
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Model – Summary Output Table - continued on next page
Table – 5 Model – Summary Output Table PF 1, PF 2, and PF 3, are the flood profiles for the 100yr, 500yr, and Probable Maximum Flood respectively. Maximum model flow for each of these profiles is at river station 16943.87.

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Table – 5 Model – Summary Output Table PF 1, PF 2, and PF 3, are the flood profiles for the 100yr, 500yr, and Probable Maximum Flood respectively. Maximum model flow for each of these profiles is at river station 16943.87.
CHAPTER SEVEN

CONCLUSION

The primary goals of the study were to model a Probable Maximum Flood in the study area and map the inundated area. This was accomplished but it must be emphasized that this inundated area is an estimate and as such is subject to many variables over which there are little or no control. The size of a Probable Maximum Flood, as calculated by Crippen and Bue 1997, is itself an estimate in which there is considerable variability. There is also very little history related to this type of study and most importantly a Probable Maximum Flood has not occurred, within the study area, with which the estimate can be compared. Until such time as confirming data is available this estimate must be viewed as being considerably larger or smaller in area than an actual event. By definition confidence limits cannot be placed on the magnitude of a Probable Maximum Flood, thus it is not possible to estimate a plus or minus percentage error for the inundated area. The study can be considered to be, in theory, practically adequate only when an actual event occurs and an investigation of that event can be compared to this study and the results indicate reasonable agreement.
GENERAL PROCEDURE

The general procedure that was followed in the production of this study model was as follows.

1. It was realized that a very large inland flood was possible in the local area.
2. Information as to the extent of maximum flood inundation was not available.
3. The study area basin had been extensively investigated for flooding of a less severe event.
4. Computer software was available that would allow an estimate of a Probable Maximum Flood.
5. Suitable data was available.
6. Computer programs and data were collected.
7. The basin was modeled and an estimate of inundation established.

FLOOD IMPACT

The model estimates that the average fall per foot in the main channel is slightly over .0003 foot per foot or approximately 1.53ft per mile. This resulted in low flow velocities averaging 1.8fps (See table 5). These low flow velocities will result in much of the affected area remaining in a flooded state for considerable lengths of time. Damage rises in proportion to the length of time structures are submerged. Thus while the flood flow may not move well built structures off of their foundations, the extended period of submergence could be expected to raise damage estimates.

Early in the study there was some concern that the basin flood-plain might act as a reservoir as it accumulated surface runoff faster than the channel is able to discharge
volume due to the minimal channel slope. There was also a possibility that pronounced back-flow (discharge becomes a factor in water surface elevation) might adversely impact results generated by the Hydraulic Engineering Center’s (HEC) computer program. The basin does indeed seem to act as a reservoir as is seen in the very slow flow velocities listed in table 5. There is however no evidence of back-flow in significant amounts as table 5 and figure 48 indicate a small but continuous fall in the PMF flood surface.

The length of the Main Channel centerline is 43,729ft or 8.3miles. The length of Tributary 1’s centerline is 20,251ft or 3.8miles. The Study Area covers 13,251 acres while the modeled area including the area North of the outfall necessary for program calculation includes 18,787.4 acres. Table 6 compares the Hillsborough and HEC estimates of flood area to the total area including area added the North for calculation purposes. This estimate of a Probable Maximum Flood (PMF) indicates that 3,146 acres (23.7%) of the 13,251 acres that comprise the study area will be inundated.

Table 6

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</table>

Comparison of Flood Areas in calculations to Total Area calculated.
A count of the structures that are visible in recent aerial photographs of the estimated extent of Probable Maximum Flood zone indicates that the flood will affect one thousand and seventy six (1,076) homes and other structures.

The Hillsborough County Planning Commission is predicting that much of the open or agricultural land (41% of the total land area within the Study Area) will be developed into residential and light industrial or commercial use (Hillsborough 2002). Eighty-five percent of estimated Probable Maximum Flood area is listed, as currently developed, open, or agricultural land (See figure 52). Table 7 enumerates the areas of existing and proposed land development in the PMF zone.

Table 7

<table>
<thead>
<tr>
<th></th>
<th>Existing Development</th>
<th>Proposed Development</th>
<th>Existing Water</th>
<th>Development Not Proposed</th>
<th>Total in Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acres</td>
<td>670</td>
<td>863</td>
<td>1133</td>
<td>480</td>
<td>3146</td>
</tr>
<tr>
<td>% of Total</td>
<td>21.3</td>
<td>27.4</td>
<td>36.0</td>
<td>15.3</td>
<td>100</td>
</tr>
</tbody>
</table>

Landuse Within the Study Area.
This map provides a visual impression of the landuse within the Probable Maximum Flood area. Eight hundred and sixty three (863) acres or 27% of the land within the PMF flood zone is listed for future development. A considerable area within the PMF flood zone.
zone is already occupied by residential and commercial development. Six hundred and seventy (670) acres or 21% of the PMF zone is currently listed as residential or commercial development. Under normal weather conditions existing lakes, ponds, reservoirs, and canals submerge one thousand one hundred and thirty three (1,133) acres or 36% of the PMF zone. Only 15% of the useable land area within the PMF zone is not currently either developed or listed for development (See table 7). The majority of this 15% is mixed hardwood coniferous forest.

The implication of this prediction of increased floodplain use by a governmental development agency is of considerable interest. This tendency for government not only to allow but encourage development is areas of possible catastrophic flood is a driving force behind increased disaster losses. On the surface, development of this floodplain can be justified in that the Probable Maximum Flood, if it ever occurs, will likely occur some time in the distant future. In the meantime the County will enjoy the taxes generated by development and the population of the floodplain will enjoy the use of the land. When the flood does occur increased losses will accrue due to the higher concentration of structures and infrastructure necessary to serve the floodplain population. If mitigation is to be effective it must be in place prior to the event. Land prices are less prior to development; thus it would seem reasonable to acquire land for parks or other public use in possible floodplain areas prior to development. This type of action would be true mitigation, it would occur prior to the flood event and minimize damage when the event occurs. It would seem that the lesson related to pre-planed mitigation rather than reconstruction has not been fully understood or implemented.
SUITABILITY OF METHODS USED

This model is dependent upon several assumed data sets. The accuracy of these data directly affects the accuracy of the model output. Nevertheless the model may have considerable worth as a predictor of maximum flood extent in many areas.

This type of study may be appropriate in areas such as West Central Florida. This area is populated with numerous shallow depressions that have not exhibited the tendency to retain substantial amounts of surface water for many years. These areas are drained by the Karst nature of the soil and underlying strata. In times of exceptional precipitation amounts these ‘dry’ lakebeds will become holding areas for large amounts of surface water. Due to the extended period in which these areas have remained dry and due to the increasing population from afar, few people either in the general population or in decision-making positions can recall events that lead to flooding in these depressions. In the ensuing years many of these areas have been subdivided for residential housing or business development. It is not expected that these developed areas would be abandoned if the potential for flooding were known but individual homebuyers and commercial builders may find this type of information useful when choosing areas in which to locate.

The study was inexpensive in that the NFF and the HEC program are in the Public Domain and thus available at no cost to users. Data is likewise often available at little or no cost, from local governmental agencies in many locations. The model can be applied to very small drainage basins. Crippen and Bue Probable Maximum Flood envelope curves include basins as small as 0.2 square miles.

This study focused on the area inundated by an estimated Probable Maximum Flood. However, in comparison to the County study of the 100yr flood inundation area
this study agreed within reasonable limits. As in any computation involving extrapolation from lower figures toward much higher numbers there is considerable concern as to the applicability of the information gained from such an exercise.

The County studied five drainage basins including the Selfer (Baker Canal) basin. Total cost of these studies was approximately twelve million dollars or an average 2.4 million dollars for each basin study. The County study has yielded large amounts of information in addition to area inundated and was initiated in order to determine cost and feasibility of mitigation against a twenty-five year event. This study and the County effort can be compared only on the basis of area inundated at the 100yr level and it must be reiterated that both of these studies at the 100yr level are estimates based on extrapolated data.

Having noted the considerable limitations of this investigation it seems reasonable to say that the methodology has merit in that is available at relatively low cost and usable on normal business computers. If the limitations are understood real-estate advisors as part of their service to prospective residential or commercial clients could undertake this type of study.

FOLLOW UP STUDY

The value of this investigation will be greatly enhanced if a major flood occurs within a time span such that the landuse and demographics of the basin have not appreciably changed. When a major flood event does occur in the study area there is little doubt that several studies will be initiated. These studies will then be available for
comparison with this preemptive investigation and a serious evaluation of this type of flood study can be accomplished. If it is found that the pre-flood model and post-flood data agree within a reasonable range then the usefulness of pre-flood investigations will be enhanced.
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