## MODEL DEVELOPMENT AND FLOW ANALYSIS

Computer simulation models capable of replicating the runoff quantity and quality processes are typically used for comprehensive analysis of stormwater management systems. Once calibrated and verified, they provide an opportunity to estimate the hydraulic, hydrologic and water quality responses of the basin for both short- and long-term precipitation data, and the effect of proposed pollution abatement procedures. These models are also used to assist in determining water quality problems, quantify storm volumes, estimate pollutant and hydraulic loading to watersheds, and for detailed designs of pollution and flood control. The limitations of this study confined the modeling effort to two selected watershed basins in the City of Apalachicola. The model used for this study was the Environmental Protection Agency (EPA). Stormwater Management Model (SWMM) (Huber and Dickinson, 1988). This model was initially developed for the EPA by the University of Florida, Metcalf and Eddy, Inc., and Water Resources Engineers, Inc. XP-SWMM, developed by XP-Software, is a commercial version of the EPA SWMM model.

The version of the XP-SWMM (version 2) utilized in this study can simulate every aspect of urban drainage, from routing drainage design, to sophisticated hydraulic analysis, to non-point source runoff quality studies, using both single-event and long-term continuous simulation. Water quality can also be simulated and the output from continuous simulation can be analyzed statistically. XP-SWMM's positive features compared to other stormwater models are summarized as:

- the model's reputation and accessibility
- inclusion of a graphical user interface for model construction
- flexibility and accuracy to represent the runoff and flow routing features in the basin
- ability to perform continuous long-term and single-event simulation
- capability to simulate water quality
- capability to simulate non steady state system hydraulics.

In accordance with the scope of the project, the stormwater model was applied only to two selected drainage basins within the City of Apalachicola, although stormwater was monitored for water quality in other municipal areas of the study area. The model was applied to quantify runoff and pollutant loading to evaluate existing nonpoint source controls and drainage system capacities. Of particular interest in this study was the ability to use the model to quantify pollutant loading when only a limited number of stations and storm samples are available.

The City of Apalachicola basins selected for this study are well suited for simulation with the XP-SWMM model. Most of the components of the hydrologic processes occurring in the basin can readily be obtained to use in the model, such as rainfall, evaporation, surface runoff, flow through conduits, open channels and ponds, base-flow and water quality in terms of pollutant concentrations and total loads. The basic model components include the physical characteristics of the basin such as topography, soil types, land use characteristics, and climate characteristics such as evaporation, temperature and precipitation, and were also readily obtained.

## Watershed Characteristics

The City of Apalachicola is a medium density urban residential community. Two drainage basins, routing stormwater to outfalls at Avenue-I and Battery Park, were chosen to represent the City. These watersheds are very flat, with slopes ranging from 0.001 feet per feet (ft/ft) to 0.045 ft/ft, with an average slope of 0.012 ft/ft. The soils are highly permeable, with a saturated hydraulic conductivity of 6.0 inches/hour. Stormwater is predominantly conveyed by overland flow through grassed swales and vegetated ditches into manholes located in each subbasin, then through a storm sewer system consisting of 68 pipes and two natural channels. A reconnaissance survey of the study area indicated that most of these storm sewers were clogged with sand, grass and debris, causing stormwater overflows. To identify potential flooding problems and to quantify storm volumes and pollutant loading to the Bay, the stormwater systems were modeled as though they were clean systems. This assumption allowed an evaluation of the maximum capacity of the system and illustrated the need for repairs.

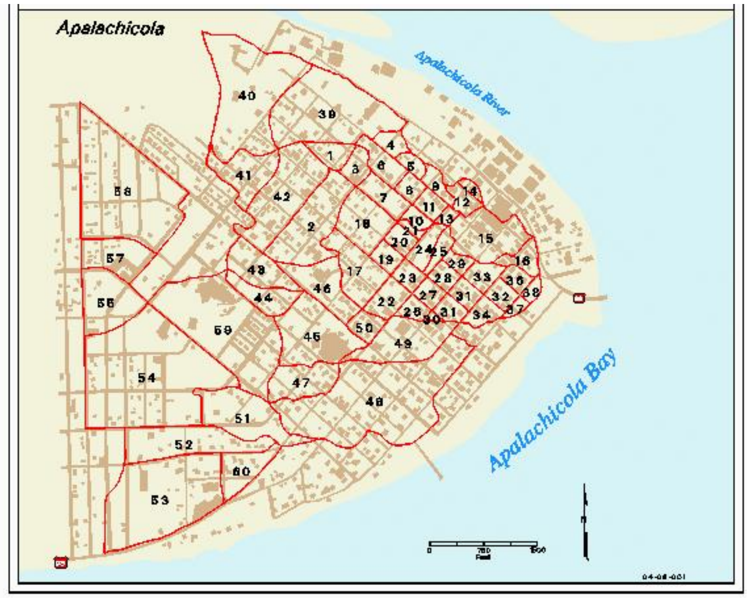

Figure 39: Subbasin Delineation

The first step in the construction of the hydrologic model consisted of dividing the study area into watersheds. For the purpose of this study, two watershed areas were selected to represent the City of Apalachicola. Major watershed delineations were based upon the topography of the study area, utilizing 2-ft contour maps. Each watershed was divided into subbasins as shown in Figure 39, according to storm sewer collector lines. Division into subbasins also assisted in identifying different land uses and problem spots. The surface area for the Avenue-I watershed is approximately 126 acres, and the Battery Park watershed is approximately 51 acres. The Avenue-I outfall watershed was subdivided into 22 subbasins (subbasins 1 through 14, and 17 through 24). The Battery Park watershed was subdivided into 16 subbasins (subbasins 15, 16 and 25 through 38).

## Climate

The City of Apalachicola's climate is typical of the Gulf Coast, with high humidity, hot summers and mild winters. The Southeast Regional Climate Center's records for the periods of 1961-90 indicated an average temperature of 68° F. Table 9 provides the average monthly minimum, average monthly maximum and monthly average temperatures from 1961 to 1990 for the City of Apalachicola.

**Table 9 –Average Temperatures for the City of Apalachicola. (1961-90)**

| | Avg Min (F) | Avg Max (F) | Avg Temp (F) |
|---|---|---|---|
| **January** | 43.9 | 60.5 | 52.2 |
| **February** | 46.1 | 62.9 | 54.5 |
| **March** | 52.6 | 68.6 | 60.6 |
| **April** | 59.2 | 75.6 | 67.4 |
| **May** | 66.0 | 82.1 | 74.1 |
| **June** | 72.2 | 87.3 | 79.8 |
| **July** | 74.3 | 88.5 | 81.4 |
| **August** | 74.2 | 88.5 | 81.3 |
| **Septemer** | 71.4 | 85.9 | 78.6 |
| **October** | 61.4 | 78.9 | 70.2 |
| **November** | 53.1 | 70.7 | 61.9 |
| **December** | 46.8 | 63.9 | 55.4 |
| | | | |
| **Annual Avg** | 60.1 | 76.1 | 68.1 |

Temperature is an important factor in estimating the evaporation component of the total precipitation in the basin. Temperature variations are directly related to evaporation patterns over the study area. Table 10 lists the pan evaporation values used in the model to simulate evaporation.

**Table 10 -- Average Monthly Evaporation**

| Evaporation (Inches) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monthly Avg. | 1.8 | 2.4 | 3.6 | 4.5 | 5.1 | 5.4 | 5.1 | 4.8 | 4.5 | 3.6 | 2.4 | 1.8 | 45.0 |

The total average annual precipitation for the City of Apalachicola was approximately 55 inches during the years 1961-90. The highest average rainfall occurred during the months of July, August and September, with an average precipitation of 7.5 inches for these three months. April and May had the lowest average monthly precipitation of 2.7 inches. Table 11 summarizes the average monthly precipitation at Station 080211 for the period of 1961-90. The missing data for this period was about 0.05 percent.

**Table 11 --Average Monthly Rainfall (Inches) for the City of Apalachicola.**
**(Station ID Number 080211)**

| Rain (Inches) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monthly Avg. | 3.90 | 3.79 | 4.25 | 2.72 | 2.67 | 4.55 | 7.35 | 7.50 | 7.54 | 3.40 | 3.20 | 4.08 | 54.96 |

**Soils**

The soil types within the basin influence the amount and rate of stormwater runoff from a watershed. Water losses due to infiltration are important in the overall water budget of the study area, and must be accurately estimated. Infiltration loses in the SWMM model can be computed with a choice of two traditional methods: Horton's or Green-Ampt formulation. In this study, the Green-Ampt method was chosen, because its parameters (saturated hydraulic conductivity, suction and initial moisture deficit) are more physically based than those in Horton's formula, and can be easily obtained through available soil surveys. (U.S. Department of Agriculture, Soil Conservation Service, 1994)

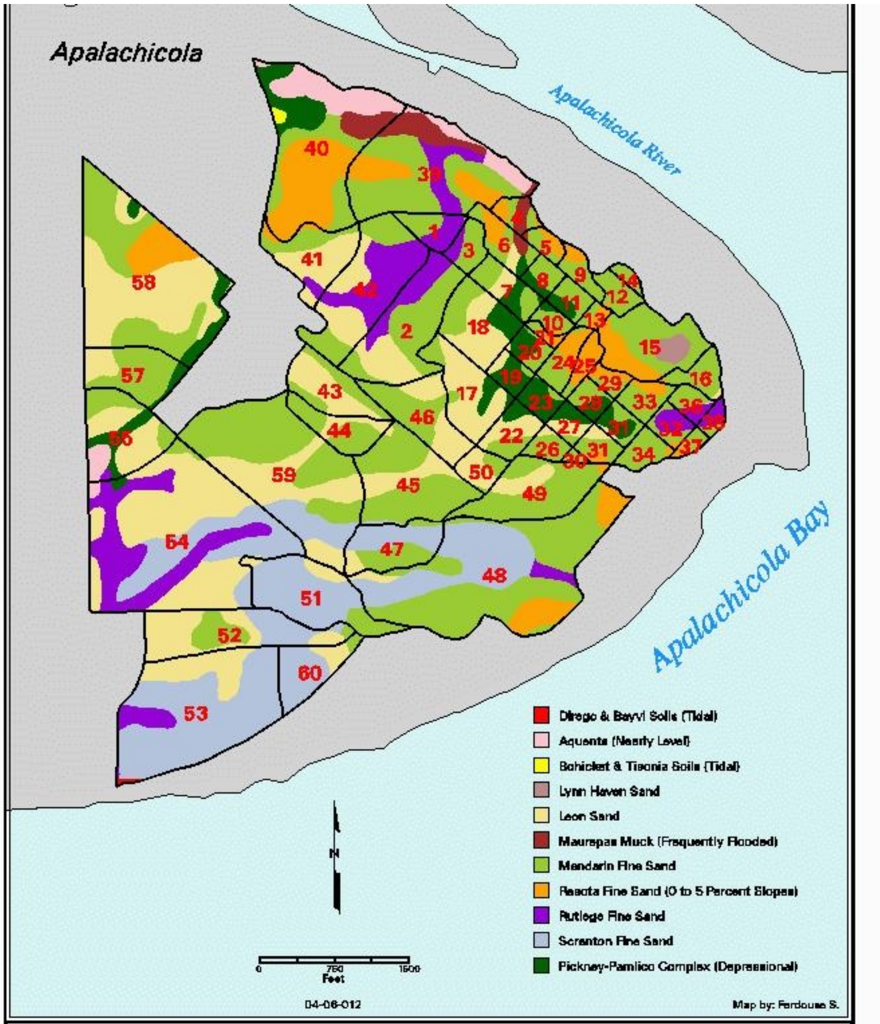

Figure 40: Soil Classes

According to the Soil Conservation Service, eleven general soil types characterize the City of Apalachicola study area. As shown in Figure 40, the most dominant soil types are Leon Sand, Mandrain Fine Sand, Resota Fine Sand, Rutlege Fine Sand and Scranto Fine Sand. The permeability for these soils ranges from 3 to 15 inches/hour. Other significant soil types in this area are Dirego & Bayvi Soils, Aquents, Bohicket & Tisonia Soils, Lynn Haven Sand, and Pickney-Pamlico Complex. Physical characteristics of these soil types are available from SCS surveys. Descriptions of these soils are provided in Appendix D.

## Model Development

As previously discussed, the SWMM model is primarily an urban runoff simulation model, designed to simulate the runoff of a drainage basin for any prescribed rainfall pattern. For demonstration and planning purposes, the tasks faced in this project were to calibrate the model and determine the long-term distribution of stormwater flows in urban portions of the study area, namely two drainage basins within the City of Apalachicola. Local short-term data from the Northwest Florida Water Management District gauge stations were used to calibrate the model. A 31-year rainfall record from the City of Apalachicola Municipal Airport statement was used as a long-term data set in order to investigate the long-term distribution of stormwater flows.

### Surface Runoff

Surface runoff was simulated using the Runoff Block of the SWMM model. The runoff parameters utilized in the runoff block simulation were estimated as follows:

**Area --** The area (in acres) for each subbasin was obtained utilizing the basin map developed by the District's Geographic Information System (GIS) system, overlaid by the subbasin boundary map digitized from the 2-ft contour map of the City of Apalachicola.

**Percent Impervious Area --** This parameter was obtained by overlaying an impervious area map on the subbasin map using the District's GIS system. See Figure 41. The SWMM model requires the value of percent impervious area to be calculated using directly connected impervious areas only. This value of imperviousness is always less than the value calculated using both directly and indirectly connected impervious areas. The values used for percent impervious utilized in the model were obtained from the total impervious areas in the basin in order to overcome one of the limitations of the SWMM model in running the long-term precipitation record, which is a tendency to underestimate the long-term runoff volumes from subbasins.

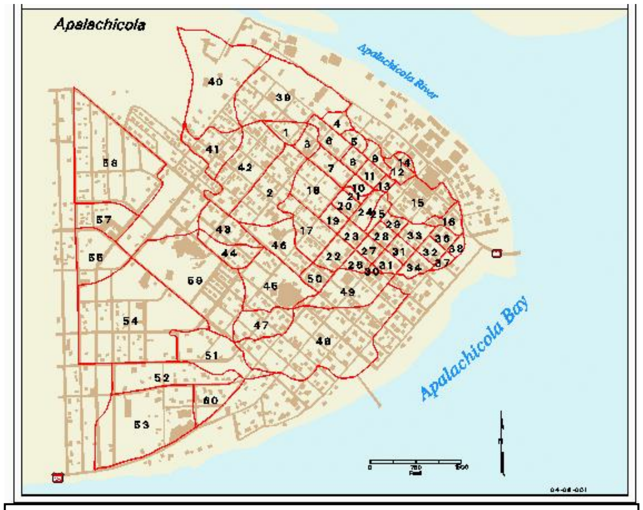

**Figure 41: Impervious Surfaces in Apalachicola**

**Slope –** As with impervious area, average slope values were obtained using the District's GIS system on a slope map generated with the GIS. The elevations to generate this map were obtained from a 2-foot contour map of the basin.

**Manning's n for Pervious Area --** This parameter is generally not of major significance in calibration of the model. It was estimated from literature values, land cover maps and vegetation characteristics.

**Depression Storage in Pervious and Impervious Areas --** These parameters depend on the type of land cover in the subbasin. They represent the volume of rainfall trapped in depressions and surfaces of the ground for impervious areas, and for pervious areas the volume of water captured by ground vegetation cover. They were estimated following the guidelines in the SWMM model user's manual (Huber and Dickinson, 1988).

**Soil's Capillary Suction, Saturated Hydraulic Conductivity and Initial Moisture Deficit --** These three parameters are used in the Green-Ampt formula to compute infiltration in a particular subbasin. For each subbasin in the runoff model, the average value for each of these parameters was obtained by overlaying the county's Soil Survey map (U.S. Department of Agriculture, Soil Conservation Service, 1994) on the subbasin delineation map. For a subbasin with more than one soil type, the average value of each parameter was obtained utilizing a weighted average.

The values obtained for the above parameters, and the lengths, diameters and slopes of the sewers and channels obtained by field survey, are provided in Appendix E. The physical characteristics of the conduits making up the storm sewer/channel network are provided in Appendix F. The storm sewer/channel network for each of the watersheds was overlaid on the land use maps using the District's GIS system, and are presented in Figures 42 and 43.

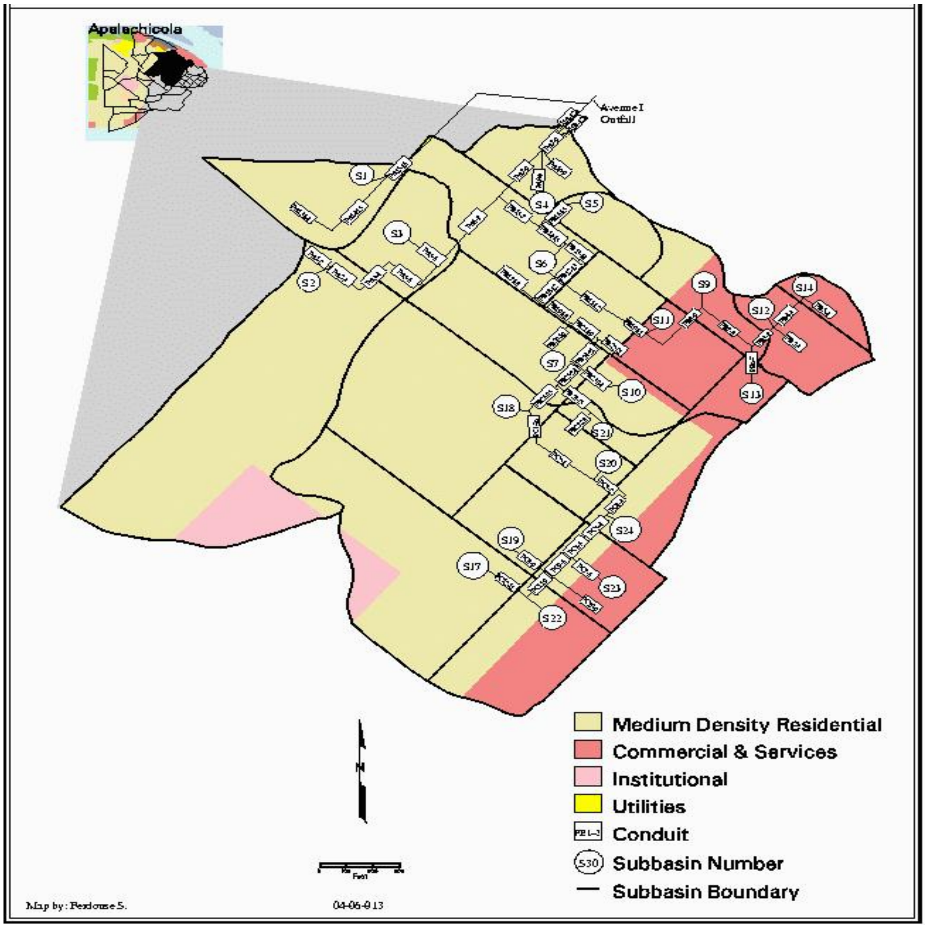

**Figure 42: SWMM Model Diagram Superimposed Onto the Avenue I Watershed**

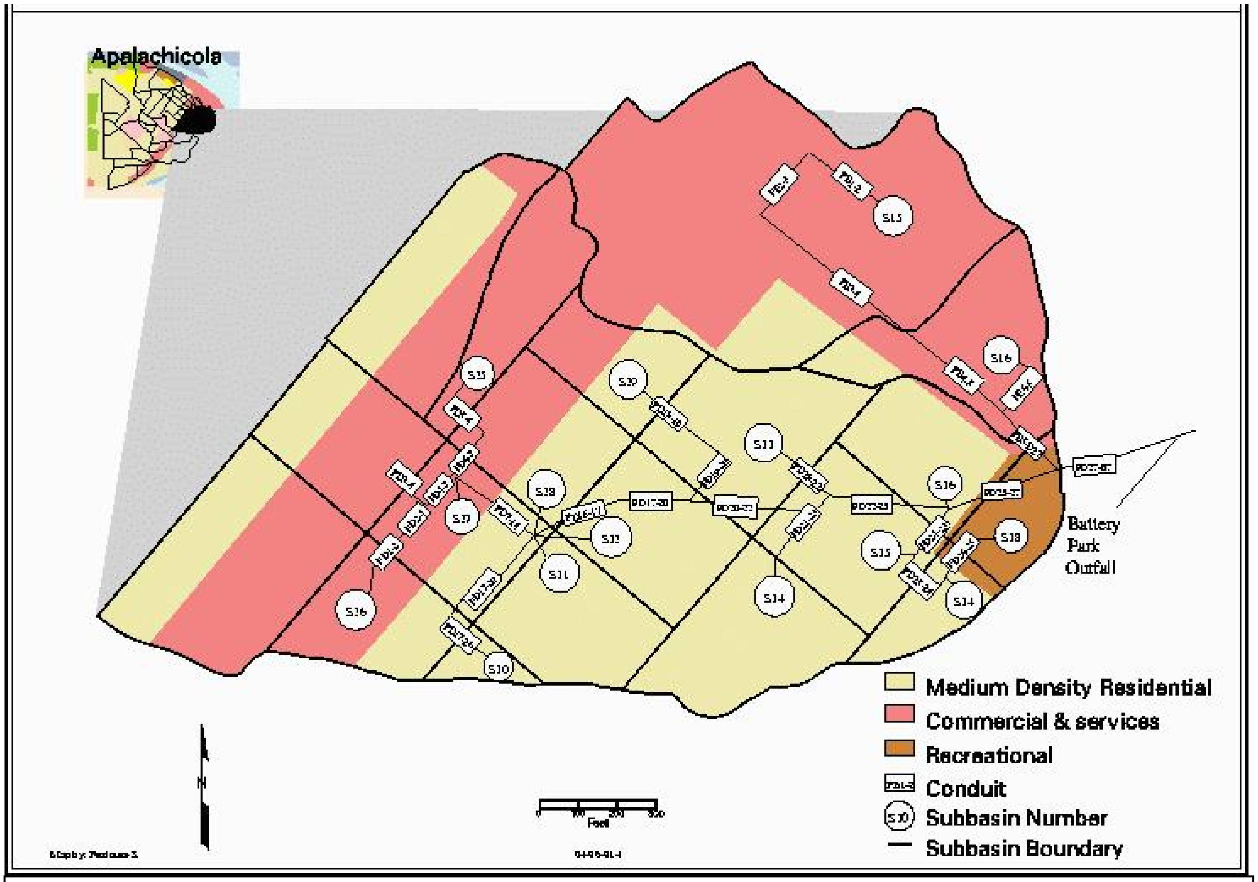

Figure 43: SWMM Model Diagram Superimposed Onto the Battery Park Watershed

### Flow Routing

Most of the flooding problems in the City of Apalachicola are associated with storm sewer surcharge, due to inadequate conveyance capacity and to clogging of storm sewers with sand and vegetation. The TRANSPORT block of the SWMM model, although capable of routing the flows accurately through the storm system cannot, due to its limitations, be used in determining surcharge and other dynamic conditions that may occur in real life situations. Some of these dynamic flow conditions are flow reversals, backwater flow and looped sewer connections. For this reason, the EXTRAN routing module was chosen to simulate surcharge and backwater conditions in the City of Apalachicola study watershed.

The EXTRAN routing model is also capable of reading hydrographs generated by the RUNOFF block. However, the main drawback of using a dynamic routing model such as EXTRAN is the computational effort required to achieve stable solutions. Instability of the solution is characterized by oscillating hydrographs and large continuity errors. Stability in the solution depends on factors such as length of the shortest pipes, size of the conduits, and length of the simulation time step. When instabilities arise during the solution, the simulated time interval must be reduced until stability is reached again. This may employ a computational time step of a few seconds for highly unstable situations. Routing capabilities of the EXTRAN model include flow routing through pipes, manholes, weirs, orifices, pumps, storage basins, outfall structures, tidal or flap gates and natural channels. Histories of flow discharges, velocities, and water surface elevations can be simulated at selected nodes (manholes) or conduits.

The EXTRAN routing block uses a link-node representation of the storm sewer/channel system. This discrete representation of the system is necessary to numerically solve the gradually varied unsteady flow equations that form the mathematical basis of the model. The discretized storm sewer/channel system is idealized as a series of sewer reaches or links connected together by nodes or manholes. Each link transmits flow from node to node which are treated as storage elements. Inflows, such as inlet hydrographs generated in the RUNOFF block, and outflows take place at the nodes. The resulting routed flows and water surface elevations can be printed or plotted at any junction, pipe or outfall node for a selected period or for the entire simulation.

### Model Calibration

The calibration of the RUNOFF/EXTRAN model for the two watersheds consisted of matching observed and simulated stage elevations at the Avenue-I and Battery Park outfalls. The model could not be calibrated directly to flow, as the rating curves developed for these two outfalls were affected by tidal influences from the bay. The bay was used as a boundary condition in order to remove the tidal influence data from the model. The tidal data was obtained from a tide gauge station in Apalachicola Bay near the St. George Island causeway, which measures at ten-minute intervals. There was no significant lag in tidal data from this station to the modeled site. It was also observed that wind direction and differences in atmospheric pressure that occurred during storm events influenced the data measured. The stage elevations were measured at both of these outfalls with automated data collection equipment, also at ten-minute intervals. The continuous rainfall data from the Battery Park (S526) rain gauge station was used to calculate the simulated stage from the SWMM model. The rainfall data was recorded in increments of one hundredth of an inch at ten-minute intervals. Since the model was not calibrated to directly to discharge, the model parameters were also compared to those of similar watersheds. Subbasin width, depression storage and the NGVD correction factor were the parameters adjusted to calibrate the model. Of these three, the model appeared to be most sensitive to subbasin width.

The period of November 30, 1996 to December 4, 1996 was chosen as a calibration period. During this time interval, there was a distinct storm with a total rainfall of 1.57 inches. The calibration hydrographs are shown in Figures 44 and 45. The results show an excellent fit between the observed and simulated water elevations for the Avenue-I watershed; however, they indicate a small difference in the peak discharge for the Battery Park watershed. The model predicted that this storm produced 153,000 cubic feet of runoff at the Avenue I outfall, and 92,200 cubic feet at the Battery Park outfall.

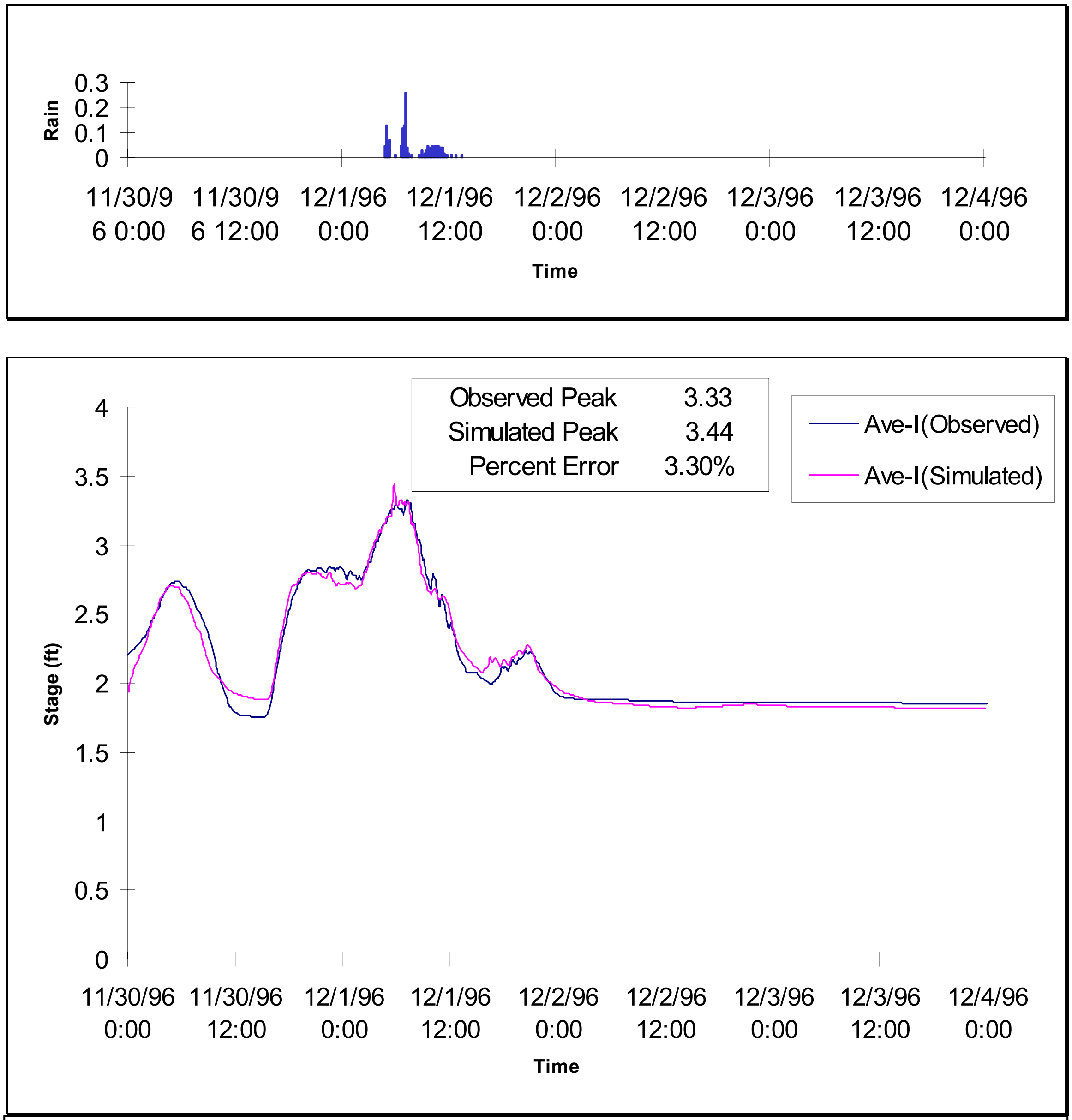

**Figure 44 -- Calibration Chart for Avenue-I**

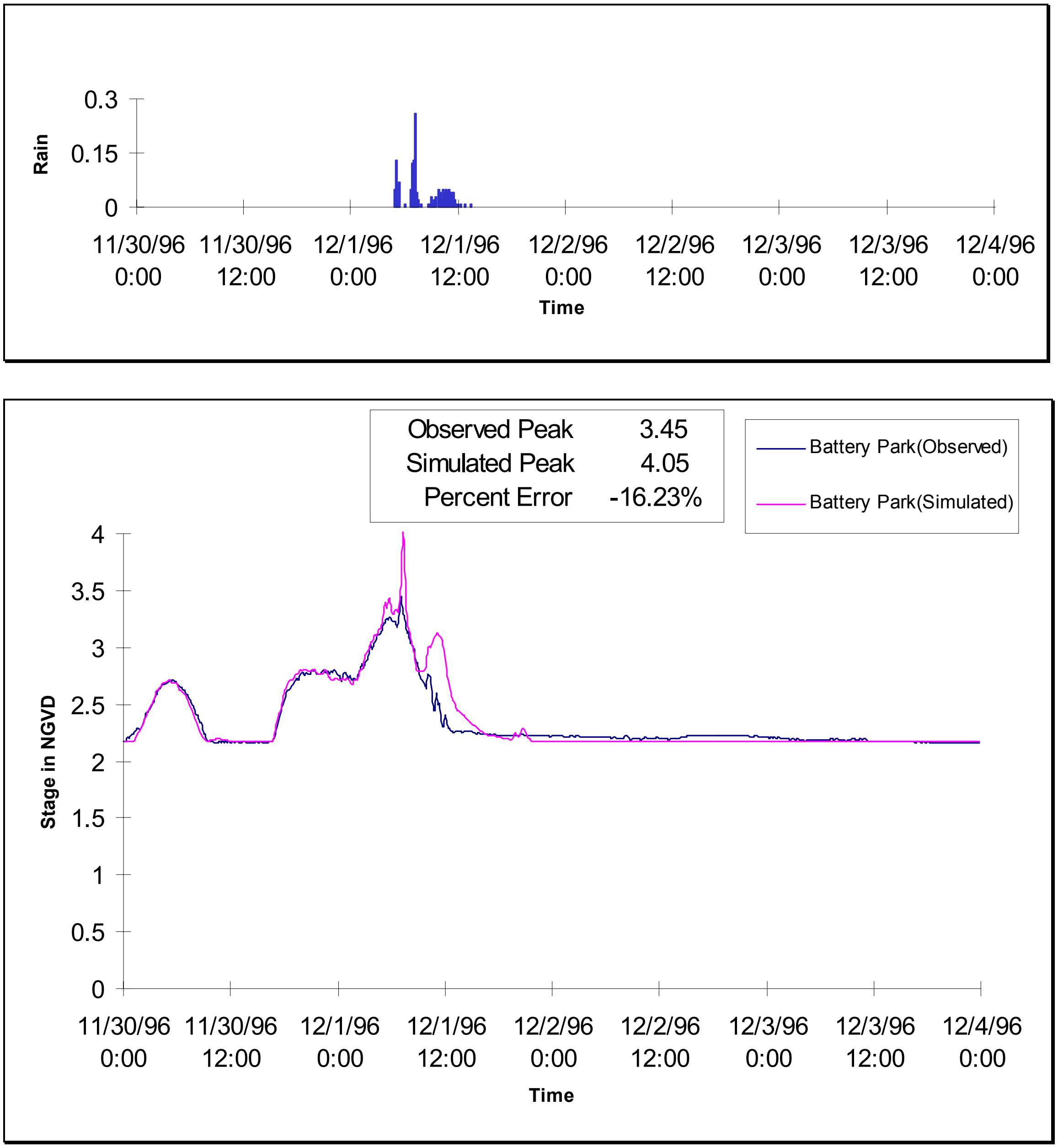

**Figure 45 -- Calibration Hydrograph for Battery Park**

## Long Term Simulation Results

Accurate identification of stormwater quality related problems and economic design of stormwater treatment facilities in urban areas can depend on the knowledge of the long-term response of the basin. Standard engineering methods based on synthetic design storms to route peak discharges through a system provide very little information concerning storm volumes. Long-term continuous simulation, on the other hand, can provide useful information for the placement and design of cost effective runoff controls. This section describes the methodology used to estimate runoff volumes from each subbasin of the two watersheds, and an estimation of annual pollutant loadings from the city into Apalachicola Bay.

The model was used in conjunction with the long-term data to estimate annual runoff from each subbasin of the Avenue-I and Battery Park watersheds. For this purpose, the RUNOFF block of the model was simulated for 31 years of hourly rainfall data, recorded at the Apalachicola Municipal Airport for the period of 1962 to 1992. From these precipitation data, the RUNOFF block produced yearly runoff from each subbasin. Average runoff and average volumes for all the subbasins were estimated and the results are presented in Appendix G.

Average annual runoff volumes were used to estimate annual pollutant loadings from the subbasins. The pollutants estimated include: total suspended solids, total Kjeldahl nitrogen, nitrate+nitrite, phosphorus, orthophosphate, magnesium, and zinc. The concentrations of these pollutants were measured from the storm samples collected at the Avenue-I and Battery Park outlets. The average annual pollutants were estimated using the average concentration and average annual runoff, and the results are presented in Appendix H.

## Synthetic Storm Simulation Results

A number of synthetic design storms were routed through the model to study flooding in the study area. Because there was no specific information available regarding the location and length of flooding in the city, no critical storms were identified. Instead, the term “critical storm” was defined for this study in terms of length of flooding at a selected number of junctions where street flooding is known to occur. One- and three-hour duration storms with return periods of 5, 10, 25, and 50 years were input into the RUNOFF block of the SWMM model, then routed through the EXTRAN block. Table 12 provides the rainfall amounts and intensities for these storms. The 25-year 24-hour storm (a synthetic storm of 24-hour duration with a return period of 25 years) is widely used as a “standard” design storm for public works stormwater drainage structures.

The simulation results indicate that the present stormwater system in Apalachicola, even making the assumption of a clean system in modeling the study area, is inadequate to meet the demands of street and storm sewer flooding. A synthetic storm of one-hour duration and five-year return period (1.4 inches of rainfall) surcharged 31 junctions in the Avenue-I watershed, and 19 junctions in the Battery Park watershed. Another synthetic storm of 24-hour duration and 25-year return period (10.2 inches of rainfall) surcharged 25 junctions in the Avenue-I watershed, and 10 junctions in the Battery Park watershed. Because the Apalachicola system is old, and characterized by undersized piping, sedimentation of sand, and vegetation, the actual flooding problem can reasonably be expected to be greater than the simulated results. The peak flows generated by the synthetic storms at the Avenue-I and Battery Park outfalls are shown in Table 12. The surcharged and flooded times at different junctions for each of the design storms are provided in Appendix I.

**Table 12. Peak Flows at Selected Apalachicola Locations in Cubic Feet per Second (cfs)**
**Existing Conditions**

| **Storm Event** | | **Ave - I** | **Battery Park** |
|---|---|---|---|
| Return Period Duration | Total Rainfall(Inches) | **Outfall** (cfs) | **Outfall** (cfs) |
| 5YR-1HR | 1.400 | 50.90 | 42.50 |
| 5YR-3HR | 4.000 | 64.10 | 47.00 |
| 10YR-1HR | 1.545 | 56.40 | 42.50 |
| 10YR-3HR | 4.500 | 67.60 | 48.80 |
| 25YR-1HR | 1.794 | 63.90 | 45.80 |
| 25YR-3HR | 5.300 | 72.80 | 51.20 |
| 25YR-24HR | 10.181 | 38.73 | 27.66 |
| 50YR-1HR | 1.993 | 72.00 | 47.70 |
| 50YR-3HR | 5.700 | 75.20 | 51.20 |

The stormwater model analysis presented here could easily be expanded to evaluate alternatives to alleviate the problems identified. Possible alternatives to alleviate flooding could include increased storage to serve a dual purpose of water quality and quantity treatment, as well as rerouting and resizing dilapidated and eroding conveyances. These results merely identify the suspected locations of flooding, and suggest the magnitude of the problem. Additional sampling and modeling efforts would be required to verify the model predictions with observations of street flooding, and to apply the model for possible solutions to these problems. It is quite possible that a stormwater storage and treatment facility located within Subbasin 2 would alleviate the problem.