Chapter 5

The Feasibility of Using Continuous SWMM for Water Resources Conservation Planning

Michael F. Schmidt, Brett A. Cunningham, Brian W. Mack

The scope of watershed planning is changing to include not only water quality and flood control, but also management of wetlands and conservation of fresh water in a cost-effective manner. This chapter discusses the feasibility of using an analytical method that uses the United States Environmental Protection Agency (USEPA) Stormwater Management Model (SWMM) for continuous simulation. The potential for fresh water conservation by reducing overdrainage of a sand ridge and wetland system in central Florida is evaluated. The program goals are to conserve fresh water, hydrate wetlands, and increase aquifer recharge by increased infiltration to a sole source aquifer while minimizing flood impacts and maintaining or improving water quality. The analysis includes an average annual mass balance and the evaluation of costs and relative benefits to identify project feasibility. The results of this feasibility study are currently under review by the St. Johns River Water Management District (SJRWMD) and Volusia County, Florida. The technical review process is not complete, and this chapter is offered for conceptual consideration.

5.1 Introduction

The United States (US) Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) was applied to evaluate surface water conservation options for Volusia County, Florida shown in Figure 5.1 and the SJRWMD.

Schmidt, M.F., B. Cunningham and B.W. Mack. 1997. "The Feasibility of Using Continuous SWMM for Water Resources Conservation Planning." *Journal of Water Management Modeling* R195-05. doi: 10.14796/JWMM.R195-05.

© CHI 1997 www.chijournal.org ISSN: 2292-6062 (Formerly in *Advances in Modeling the Management of Stormwater Impacts*. ISBN: 0-9697422-7-4)

Figure 5.1 The study area, Volusia County, Florida.

Volusia County lies in east central Florida along the coast of the Atlantic Ocean. The study area is in the southwestern portion of the Tomoka River Watershed (28,466 acres or 11,571 ha) called the Tiger Bay area (Figure 5.2), which is named after a series of wetland strands. Volusia County's potable water supplies come from the Floridan Aquifer which is a sole source aquifer in the county due to the Atlantic Ocean, saltwater intrusion, and relic saltwater from the St Johns

Figure 5.2 The Tiger Bay area.

River (Figure 5.3). Therefore, incident rainfall on the county and its subsequent recharge into the aquifer are essential to the long-term replenishment of potable water. The county is characterized by a series of north-south sand ridges which provide recharge to the aquifer. Between these ridges, there is a series of waterbodies (coastal estuaries) and wetlands which provide a variety of water resource and wildlife habitat benefits.

Over the years, drainage projects have been implemented by the US Department of Interior, US Department of Defense (US Navy), Volusia County mosquito control, and the Florida Department of Transportation (FDOT) to allow development and to protect public health. These projects generally involved ditch cuts through the sand ridges to drain the wetlands. This reduces overall annual recharge to several areas, including Tiger Bay. Tiger Bay has been identified by the US Geological Survey (USGS) as having moderate recharge potential that could be increased with increased water storage. In recent years, impacts from saltwater intrusion have required relocation of municipal potable wellfields westward away from encroaching saltwater intrusion. In addition, recent environmental evaluations by the SJRWMD have indicated that groundwater levels are dropping and that there is an imminent threat to jurisdictional wetlands from the overdrainage. Therefore, there is an opportunity in the Tiger Bay area to establish compatible water conservation goals to potentially increase recharge to mitigate saltwater intrusion and for wetlands vegetation protection.

5.2 Methodology

This project requires the consideration of an average annual mass balance or water budget to properly understand both ground and surface water interactions and their responses to rainfall and runoff. The SJRWMD has prepared a regional groundwater model using the Modular Three-Dimensional Finite-Difference Groundwater Flow model (MODFLOW) for evaluation of current steady state groundwater conditions. A surface water modeling tool was needed to evaluate the random, unsteady nature of surface water interactions. The analysis of long term aquifer recharge and water conservation requires consideration of these phenomena including extreme conditions of droughts, floods, and back-to-back storm effects in a continuous manner. The EPA SWMM was chosen because it allows continuous simulation of physically-based hydrology through the RUNOFF block, and it allows dynamic evaluation of surface routing effects with the EXtended TRANsport (EXTRAN) block, especially for control structure modifications considered for the Tiger Bay Canal study area. This model was set up and calibrated as part of the Tomoka River Watershed Management Plan (WMP) by CDM (Camp Dresser & McKee Inc., 1995), and it was refined further for this study.

Figure 5.3 Groundwater features of the Tiger Bay study area.

The basic components of the mass balance considered were rainfall, evapotranspiration, runoff, infiltration, groundwater recharge, baseflow, and direct surface discharge. Each of the components in the mass balance is discussed in the following paragraphs.

5.3 Rainfall

Two National Oceanic and Atmosphere Administration (NOAA) weather stations were used to determine the average annual and average monthly rainfall volumes for the Tiger Bay study area. The stations selected included the DeLand and the Daytona Beach stations. The DeLand station is approximately 1.5 miles (2.4 km) from the western side of the study area and the Daytona Beach station is approximately 1.5 miles from the southern portion of the study area. However, the Daytona Beach station is the nearest raingage to over 90% of the study area, so that gage was the primary gage used for the analyses.

The DeLand station has intermittent daily rainfall records between 1900 and 1908, daily rainfall record between 1908 and 1986, and 15 minute interval rainfall records from February 1986 to the present. The Daytona Beach station has hourly rainfall data from 1938 to the present, with the usable data beginning in 1942.

The RAIN Block of SWMM was used to perform a statistical analysis of the rainfall data recorded at the Daytona Beach station for the 1942 to 1994 period of record. The evaluation showed that the average annual rainfall at the station is approximately 48.2 inches (1224 mm). The rainfall data available from the DeLand station was also reviewed. The average annual rainfall was determined to be approximately 55.0 inches (1,397 mm).

SWMM was calibrated to an average rainfall year and to a month within the average rainfall year using the USGS stage gage at Tiger Bay, results from SJRWMD's regional groundwater model, and published evaporation rates in a mass balance approach. The average or typical year of rainfall was determined by reviewing the rainfall data recorded for the period of record during which both rainfall and flow data were recorded. The rainfall data review showed that 1992 most nearly represents a typical year for rainfall volume. September was selected as the calibration month within 1992. A summary of the rainfall volumes is presented in Table 5.1.

The last two weeks in 1991 were also used as a start-up period for the average year since this period was preceded by a dry period. The additional rainfall from this period raised the total for the average annual year simulation period to approximately 47.7 inches (1212 mm) at the Daytona Beach station. A dry antecedent period is desirable since input initial infiltration parameters must be set to dry conditions for a continuous simulation. The reason for this requirement is

Table 5.1 Calibration and simulation rainfall volumes.

Description	Daytona Beach Station (inches)	DeLand Station (inches)
Average Year	48.17	55.04
1992	45.39	54.26
Average September	6.83	6.53
September 1992	7.73	6.57

that the model can only regenerate infiltration parameters back to their original input values. This allows the model to simulate both wet and dry conditions.

5.4 Evapotranspiration

Evapotranspiration (ET) is a combination of evaporation from surfaces, (i.e. evaporation from surface waters), evaporation from subsurface sources (i.e. evaporation from the upper soil column), and transpiration also drawn from soil storage. The total ET term was handled both directly and indirectly. Losses from the soil column (subsurface evaporation and transpiration) were handled indirectly through use of the infiltration regeneration coefficient. The regeneration coefficient was adjusted such that the computed average annual infiltration was approximately equal to 16.5 inches (419 mm) (estimated by the SJRWMD for MODFLOW) in conjunction with the surface evaporation rates, overland flow characteristics, and infiltration parameters previously determined. The final regeneration coefficient used was approximately 0.001. This value is slightly lower than normal to account for reduction from the infiltration term by the recharge term that is sent to the surface. Based on MODFLOW results, computed transpiration and subsurface evaporation in the Tiger Bay study area collectively account for approximately 6.0 to 7.4 inches (152 to 188 mm) of the average annual water budget.

For the Tiger Bay study area, approximately 28.8 inches (732 mm) of rainfall are lost to surface evaporation during an average year, based on rainfall minus infiltration and direct surface runoff. Therefore, surface evaporation is an important term in the overall water budget. Surface evaporation rates were applied in both the RUNOFF and EXTRAN models to account for evaporation lost from overland flow and initial abstraction of surface storage after rainfall events and from ponded areas in the Primary Stormwater Management System (PSWMS), respectively. Surface evaporation in EXTRAN was modeled using

Table 5.2 Monthly surface evaporation.

Month	Monthly Evaporation (inches)
January	1.12
February	1.37
March	1.98
April	2.37
May	2.75
June	2.59
July	2.37
August	2.15
September	1.90
October	1.72
November	1.32
December	1.07
Total	22.71

Note: Evaporation volumes are the combined volumes from the RUNOFF and EXTRAN blocks.

monthly three-point stage-discharge (pump) curves in order to account for fluctuating amounts of inundated surface areas. The evaporation rates were based on pan evaporation values published by NOAA, multiplied by a constant of approximately 0.5, which was based on the calibration. The input monthly evaporation volumes used are listed in Table 5.2.

The total evapotranspiration used is the sum of the components, which are approximately 6.4 inches and 28.8 inches (163 and 732 mm), or 35.2 inches (894 mm). This value is within the expected range of values from this area, which ranges from approximately 25 inches to 40 inches (635 to 1,016 mm) (SJRWMD, personal communication, 1995).

5.5 Runoff

The RUNOFF block of SWMM was used to simulate direct surface runoff in hydrologic units for the Tiger Bay study area. RUNOFF uses a non-linear reservoir solution for overland flow routing of runoff (Manning’s equation). The Horton infiltration equation was used to simulate surface infiltration into the soil for shallow pervious area infiltration only. Based on statistics from the USGS

Tiger Bay stream gage from approximately 11 years of data (during which the average annual rainfall was approximately equal to the long-term average of 48 inches (1,219 mm)), total flow from baseflow and direct surface runoff averages approximately 6.3 inches (160 mm) per year. Of the 6.3 inches, 2.9 inches (74 mm) is estimated to be direct surface runoff and 3.4 inches (86 mm) is estimated to be baseflow. Direct surface runoff and baseflow were determined from the measured flow data using a simple hydrograph separation technique.

5.6 Infiltration

The Horton equation uses an initial infiltration rate set to account for water already in the soil, a maximum infiltration rate, and an infiltration decay rate. In addition to the Horton infiltration equation, CDM has added another special feature to SWMM that establishes a maximum infiltration capacity (also called the total soil storage shut-off option). This special feature has been used and successfully calibrated and verified by CDM since 1986, and it will soon be available in the EPA release of SWMM. The maximum infiltration capacity is the same definition as the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) soil storage, S (measured in inches over the pervious area). The total soil storage limits the amount of rainfall that can be infiltrated in the given hydrologic units. This capacity is especially critical during periods of extended rainfall encountered during continuous simulations and larger design storms. Once the maximum infiltration volume or total soil storage is reached, the pervious areas effectively become 100% impervious. The Horton infiltration equation is as follows:

$$f_p = f_c(f_o - f_c)e^{-kt} \quad (5.1)$$

where:

- f_p = infiltration capacity into soil, feet/second
- f_c = minimum or ultimate value of f_p (WLMIN), feet/second
- f_o = maximum or initial value of f_p (WLMAX), feet/second
- t = time from beginning of storm, seconds
- k = decay coefficient (DECAY), second⁻¹
- e = natural log (base e)

Once rainfall has ended (dry hours), the infiltration capacity is recovered according to the following equation:

$$f_p = f_o - (f_o - f_c)e^{-k_d(t-t_w)} \quad (5.2)$$

where:

$$\begin{aligned} k_d &= \text{decay coefficient for the recovery curve, second}^{-1} \\ t_w &= \text{hypothetical projected time at which } f_p = f_c \text{ on the} \\ &\quad \text{recovery curve, second} \end{aligned}$$

The calibrated Horton infiltration parameters used for this evaluation ranged from 4.8 to 6.9 inches (122 to 175 mm) per hour (maximum rate) and from 0.10 to 1.1 inches (2.5 to 27.9 mm) per hour minimum rate. The maximum infiltration capacities (soil storage, S) ranged from 3.3 to 6.0 inches (84 to 152 mm), and the Horton decay coefficient was 2/hr.

Following a rainfall event, the maximum infiltration capacity recovery rate follows the same exponential recovery rate as the Horton infiltration recovery rate. Soil storage becomes an important term in stormwater runoff modeling. Previous calibrations in this watershed for single events have shown that some of the dual class hydrologic soils (e.g. A/D and B/D) tend to become saturated for storm events over 1 to 2 inches (25 to 50 mm). Figure 5.4 shows the USDA SCS soils classification for the study area.

For the Tiger Bay study area, the available soil storage was determined by using the calibrated parameters from the Tomoka River WMP and adjusting the values from AMC II to AMC I. As stated previously, the input soil values had to be adjusted to dry conditions in order to allow the model the possibility of regenerate back to those capacities. A time period of two weeks was simulated prior to the average year to establish equilibrium between model computed and actual soils parameters.

5.7 Groundwater Recharge and Baseflow

For groundwater recharge to the Floridan Aquifer, the EXTRAN block was used to compute equivalent groundwater stage versus discharge curves (simulated as three-point pump curves) and to evaluate the potential change in recharge due to control structure modifications. The stage-discharge curves used to compute groundwater recharge were constructed as follows. The SJRWMD MODFLOW results were used to establish the potentiometric surface for each major wetland area. Using a constant vertical hydraulic conductivity and constant Darcy flow length, the curves were constructed using Darcy's equation, with the driving head being the difference between the potentiometric surface (September, wet season) and the stage in the storage area, and the area equal to the inundated area for the given stage.

The input infiltration parameters (previously discussed) used in the RUN-OFF model were adjusted so that the computed annual infiltration volume was approximately the same as the annual infiltration volume used for the SJRWMD

Figure 5.4 The USDA SCS soils classification for the Tiger Bay study area.

MODFLOW evaluation i.e. 16.5 inches (419 mm). The USGS ZONEBUDGET program (part of MODFLOW package) was then used to compute the annual volume of groundwater infiltration that reaches the deep aquifer using the MODFLOW results provided by the SJRWMD. Of the 16.5 inches of annual infiltration volume input to MODFLOW, 6.7 inches (170 mm) were computed to reach the Floridan Aquifer. The remaining 9.8 inches (249 mm) of infiltration are recycled through baseflow and evapotranspiration. As stated above, average annual baseflow was calculated to be approximately 3.4 inches (86 mm), leaving approximately 6.4 inches (163 mm) as evapotranspiration. Using these data, the equivalent groundwater stage-discharge curves were refined in the EXTRAN block to convey 6.7 inches (170 mm) of infiltration into the Floridan Aquifer on an annual basis for existing conditions (no control structure modifications).

Baseflow was modeled as a constant inflow from each hydrologic unit. Evaporation of baseflow from the surface had to be accounted for in order to obtain the net baseflow that was measured at the Tiger Bay stream gage.

5.8 Direct Surface Runoff

Once the infiltration parameters were calibrated and the equivalent groundwater recharge stage-discharge curves were sized, EXTRAN was used to route surface water flows through the Tiger Bay Canal PSWMS which is part of the larger Tomoka River Watershed PSWMS. EXTRAN was used to compute surface water flows, velocities, and stages in the PSWMS as well as surface water volumes transported past points of interest (e.g. out of the system for the mass balance). Figure 5.5 shows the RUNOFF and EXTRAN model schematic to scale.

The month of September 1992 was used to calibrate flows at the USGS Tiger Bay Canal gage. With no adjustments to parameters other than those discussed previously (e.g. adjustment of infiltration parameters to AMC I conditions), the computed flow for the month of September was within 7% of the measured flow. The measured annual flow volume at the Tiger Bay Canal gage was 1,920 ac-ft ($2.36 \times 10^6 \text{ m}^3$), and the computed annual flow volume was 2,150 ac-ft ($2.64 \times 10^6 \text{ m}^3$).

5.9 Mass Balance

Using data from SJRWMD's MODFLOW model, the Daytona Beach rain station, and the USGS Tiger Bay Canal stream gage, a mass balance or water budget for the average annual year was constructed. A simplified version of the mass balance is shown in Figure 5.6.

Figure 5.5 RUNOFF and EXTRAN schematic.

5.10 Control Structure Considerations

Hypothetical control structures were strategically sited at four locations within the Tiger Bay Canal PSWMS. The intent of the variable control structures was to estimate the potential impact on aquifer recharge volumes using the calibrated groundwater stage-discharge curves and the potential impact of

Figure 5.6 Simplified mass balance for the average year.

Figure 5.7 Conceptual cross-section view of a weir constructed in a drainage ditch.

increased water surface elevations on adjacent property owners by raising the control structure elevation in the Tiger Bay Canal by 3 feet (0.92 m) and then 5 feet (1.52 m), respectively.

5.11 Results

The results of this feasibility study using the continuous SWMM methodology indicate that there may be potential to increase recharge of the Floridan Aquifer by increasing surface water stages in the Tiger Bay area using variable water level control structures. However, there needs to be a balance between aquifer recharge, water conservation and flood control. The use of variable control structures will allow internal system control of surface water stages, aquifer recharge, and wetland vegetation. Additionally, a variable control system will allow impacts from the increased water levels to be monitored, and system adjustments made. This would also allow for planned maintenance drawdowns. Figure 5.7 shows a conceptual cross-section of a weir constructed in a drainage ditch.

In summary, the application of continuous simulations using the SWMM (as modified by CDM) to consider water conservation appears to work well. It appears that the feasibility of increasing recharge by increasing storage depth and duration can be determined; however, quantifying the benefits from the additional recharge requires additional data and study, as do potential negative impacts from higher groundwater tables and increased durations of inundation of wetland vegetation and private land.

Future enhancements to SWMM are planned to allow more direct interaction between groundwater and surface water. This may include direct evaporation off EXTRAN surface waterbodies and standard interfaces to public domain groundwater models such as MODFLOW.

References

- Camp Dresser & McKee Inc., 1989. City of Daytona Beach Stormwater Master Plan, for the City of Daytona Beach, Florida.
- Camp Dresser & McKee Inc., 1995. Tomoka River Watershed Management Plan, for Volusia County, Florida.
- McDonald, M.G. and A.W. Harbaugh, 1988. A Modular Three-Dimensional Finite-Difference Groundwater-Flow Model. U.S. Geological Survey, Techniques of Water Resources Investigations Book A3.
- National Oceanic and Atmospheric Administration., 1982. Technical Report NWS 34.
- United States Environmental Protection Agency, 1994. Stormwater Management Model (SWMM) Users Manual.
- United States Geological Survey. Potential for Groundwater Development in Central Volusia County, Florida; Water-Resources Investigations Report 90-4010.
- St. Johns River Water Management District, 1995. Potentiometric Surface of the Upper Florida Aquifer in the SJRWMD and Vicinity.