This is not a peer-reviewed article.
Pp. 027-034 in Total Maximum Daily Load (TMDL) Environmental Regulations–II
Proceedings of the 8-12 November 2003 Conference (Albuquerque, New Mexico USA),
Publication Date 8 November 2003.
ASAE Publication Number 701P1503, ed. A. Saleh.

CHARACTERIZING FLOW AND NUTRIENT LOADS FOR TMDL DEVELOPMENT IN FLORIDA USING WAM

A. B. Bottcher, B. M. Jacobson, and J. G. Hiscock

ABSTRACT

The Watershed Assessment Model (WAM) has been used to simulate flow and water quality constituents for several Florida watersheds in support of Florida's TMDL program and other watershed restoration projects. WAM was set up and calibrated/validated for simulating both existing conditions and future watershed restoration strategies. WAM was used to simulate daily flows and constituents of interest, such as, nitrogen, phosphorus, total suspended solids, and BOD, for every watershed and each stream reach within the watersheds, as well as providing detailed spatial GIS maps of source loads throughout the watersheds. Florida watersheds for which WAM has been used include: Lower St. Johns River, Myakka River, North Lake Okeechobee, Suwannee River, Aucillia River, and Caloosahatchee River

The results of the WAM modeling program for TMDL development and other watershed restoration programs in Florida, as well as recent enhancements to the model, are described. The comparisons of measured and simulated values indicate that WAM has been reliably applied to new watersheds with little or no calibration. WAM's demonstrated ability to simulate the impacts of land use and management changes makes it a powerful tool in assisting planners and decision makers in the development of strategies to improve water quality.

KEYWORDS. WAM, Water Quality, Watershed, Modeling, GIS, Nutrients, BOD, TMDL.

INTRODUCTION

The Florida Department of Environmental Protection (FDEP) and the US Environmental Protection Agency (US-EPA) have the primary responsibility for the development of total maximum daily loads (TMDLs) for affected waterbodies in Florida. The process of setting TMDLs is underway and will continue over at least the next five years with the higher priority waterbodies being done first. The TMDL process first involves the determination and ranking of affected waterbodies by either physical observations of impaired conditions or through modeling. The second phase of a TMDL process is the development of remediation or abatement programs that will bring an impaired waterbody into compliance with the TMDL.

Both FDEP and US-EPA have selected the Watershed Assessment Model (WAM) to assist them in their TMDL programs in Florida. WAM has been used for phases I and II of the TMDL process, but is most suited for phase II (i.e., the evaluation of management alternatives for improving water quality). This paper will briefly describe the WAM model before discussing how WAM has been used in several watershed assessment projects in Florida.

DESCRIPTION OF WAM

The Watershed Assessment Model has a Geographic Information System (GIS) interface that controls process-based submodels that simulate surface and groundwater flow and water quality constituents (TSS, N, P, BOD) from land source grid cells to a stream network, and then hydro-dynamically routes these parameters, plus DO and chlorophyll-a, if the WASP (Water Quality

Assessment Simulation Program) link is used, through the entire stream network to the watershed outlet. Once set up, WAM allows water resource engineers and planners to interactively simulate and assess the environmental impacts of various land use changes and associated land use practices.

WAM was originally developed with an Arc/Info interface for the entire Suwannee River Water Management District (SRWMD) (SWET, 1998), but has since been converted to ArcView with numerous other enhancements added. The following is an abridged list of the WAM features (SWET, 2003):

- Flow and Constituent Transport Modeling of Land Source Areas on a Spatial Scale/Grid of 1 ha or Less
- Unique Cell Recognition for Faster Run Times.
- Hydrodynamic Stream Routing with Daily and Hourly Outputted Time Series of Flow, N, P, and BOD, plus Dissolved Oxygen, Chlorophyll-A if WASP Linkage is used.
- Handling of Stream Network Looping and Tidal and other Time Series Inflow/Outflow Boundary Conditions
- Ground Water Flow Modeling with Well Withdrawals and Surface/Groundwater Interactions
- Allows Time Series of Point Source Inflows
- Linked to WASP6 for Simulation of In-stream Dissolved Oxygen, Chlorophyll A, N, P, and BOD.
- Wastewater Treatment Plant Service Area Coverage Used to Determine On-Site Septic Usage
- Uses NEXRAD Spatial Rainfall Data if Available
- Source Cell Mapping of Annual Average TSS, Nitrogen (N), Phosphorus (P), and BOD Loads and Associated Surface and Ground Water Flow.
- Overland and Wetland Load Attenuation Mapped Back to Source Cells
- Tabular Ranking of Land Uses by Constituent Contributions and by Subbasins.
- User Friendly Interface to Run and Edit Various Land Use and BMP Scenarios, plus Provide Tabular and Graphical Outputs

WAM is a process-based model, which requires little or no traditional model calibration. The land source submodels GLEAMS (Knisel, 1993) and EAAMOD (Pickering et al, 1998) use physically based parameters that are typically available for most areas. Therefore, it has been found that if WAM is not matching results then it is probably that the physical descriptions for the watershed are not correct. This process helps identify data problems and the additional watershed characterization work that is needed. All possible parameters, which can be physically measured, are used to ensure accurate model rendering of the watersheds. For example, locations of control structures, streams (including cross-sections), lakes, and wetlands were determined spatially to reflect the physical system as accurately as possible. Also, site visits and stage data are used to improve stream profile definitions. Measured stage, flow, and constituent concentration data are gathered and quality checked for use in model verification. Based on visual comparisons of simulated and measured data, the WAM results are typically within the measurement error of the observed data.

WAM APPLICATIONS

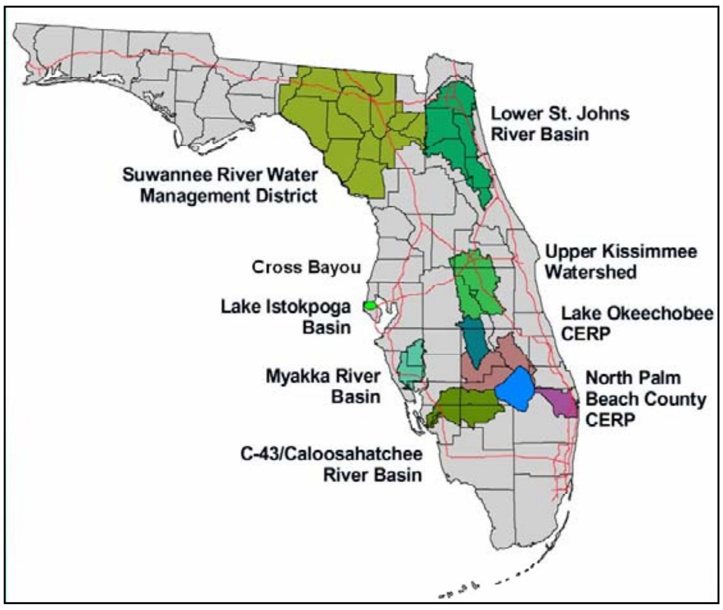

Figure 0. WAM Application Site in Florida

Figure 2. Suwannee Nitrate Images

WAM has been or is currently being used in nine separate watershed assessment projects in Florida (Figure 1). Two of these projects have been used for direct TMDL development while the others are associated with watershed remediation assessments to find the most appropriate best management practice (BMP) program to meet downstream TMDLs or to related water quality standards.

Suwannee River. The first application of WAM was for the entire Suwannee River Water Management District in northern Florida (SWET, 1998). The primary concern in the Suwannee River basin is the high nitrate level in the groundwater, which, through springs and other natural seepage features, has caused eutrophication concerns in the Suwannee River and its estuary in the Gulf of Mexico. Figure 2 shows WAM groundwater nitrate predictions as compared to observed data. The good match provided confidence that the land source predictions were reasonably accurate and therefore the model's ranking of nitrate sources by land use helped identify the abatement strategies for the basin. The Suwannee River basin was recently remodeled with the enhanced stream routing version of WAM. This rerun provided daily water and nutrient flows throughout the stream network. A primary advantage of the latest run was the association of specific land areas with spring flows to the river.

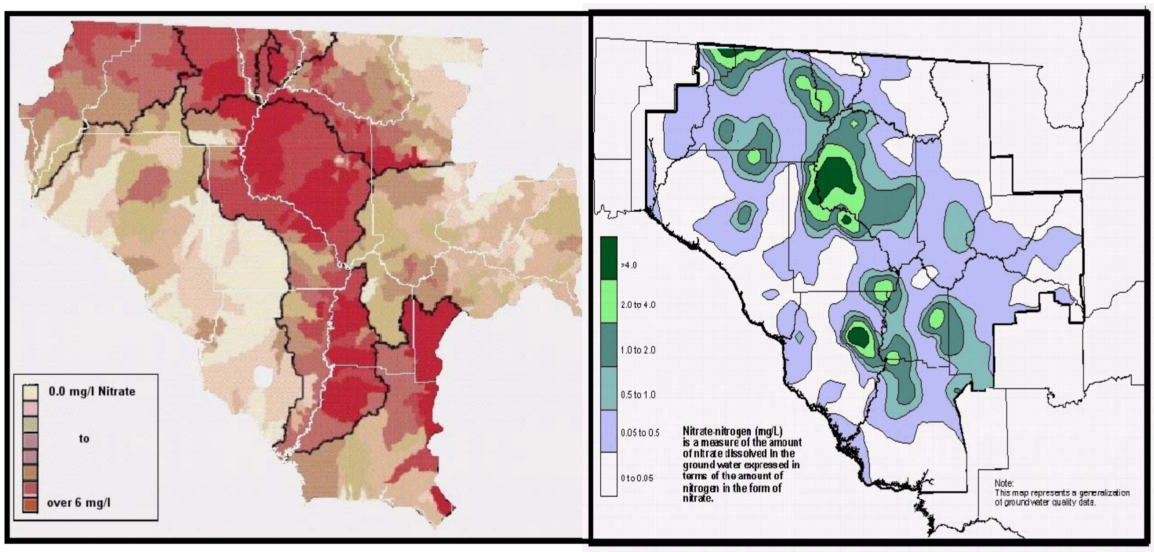

Figure 1: Observed (left) and Simulated (right) Groundwater Nitrate Levels in the Suwannee River Basin

Lower St. Johns River. The second application of WAM was for the lower section of the St. Johns River basin in northeast Florida (SWET, 2000). The primary purpose of this modeling exercise was to provide daily time-series of inflow of water, TSS, and nutrients to the lower St. Johns River in support of a major in-river modeling effort by the US Army Corps of Engineers (ACOE). The overall objective of the ACOE program is to set the Pollution Load Reduction Goals (PLRGs) for the river. A PLRG is very similar to a TMDL as defined by the St. Johns River Water Management District (SJRWMD). WAM successfully provided ten years of inflow information to the ACOE river model. In addition, the WAM model was also able to evaluate various management scenarios for reducing nutrient loads to the river. The focus of the nutrient reduction practices or BMPs was on the intensive vegetable farming in th e region. The land source submodel, EAAMOD, which specifically handles the high water table drainage and irrigation systems that are present on the vegetable farm, was incorporated into WAM to better represent this region. The physically based structure of WAM proved invaluable because of the number of ungauged basins in the area. WAM was shown to be able to represent these basins without calibration because it had been previously tested without calibration on two gauged watersheds and was found to match observed data very well. Figure 3 shows an example of the observed versus simulated soluble P results for an uncalibrated subbasin that was used to verify WAM's suitability to new basins. Most of the BMPs identified during the development of WAM are being implemented by the farmers in the region.

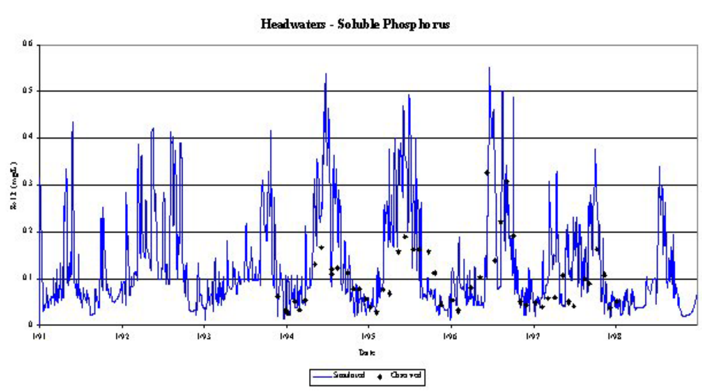

Figure 2: Observed and Simulated Soluble Phosphorous in Deep Creek

Myakka River. The WAM model was used to simulate the Myakka River basin located in southwest Florida for the US-EPA's TMDL development program (SWET, 1992). The Myakka River basin is characterized by row crops and phosphate mining in the north and cattle ranches, row crops and natural wetlands in its central region and urbanization in the south. The primary concerns are increased eutrophication and bacterial levels. WAM successfully modeled the overall basin response, but the row crops were being over predicted for nutrient losses. It was difficult to obtain details of the specific management practices that were being used by the row crop farmers in the region. After further investigation, however, it was determined that higher levels of on-farm stormwater retention and water reuse were taking place than were being represented in the model. Stormwater retention is a BMP handled in WAM and was adjusted to better represent the row crops. US-EPA used the modeling results to help set their TMDL for the listed reaches within the basin. The TMDL and modeling results are still under review and it is anticipated that additional WAM modeling, particularly for abatement management scenarios will be done based on the review comments.

North Lake Okeechobee Basins. Lake Okeechobee is the focus of the intensive Comprehensive Everglades Restoration Plan (CERP) program, which is headed by the ACOE and the South Florida Water Management District (SFWMD). However, numerous other private, state, and federal groups are involved. The overall objective of the CERP program is to meet the TMDL that has been set for Lake Okeechobee, which is 40 ppb of P. WAM is being used to assess current water and nutrient loading conditions for providing design inflow information for large regional treatment projects, that are intended to clean the runoff from the northern basins prior to discharging to Lake Okeechobee. WAM is also providing estimated P reductions that could be anticipated for a basin-wide BMP program. Figure 4 shows an example of the source area P loads as delivered to the nearest stream, i.e., with attenuation accounted for. WAM modeling has shown that at least a 25 % reduction can be achieved by BMPs only. This information is critical because it helps determine the sizing of the regional treatment facilities.

WAM was also used to assist FDEP in the development of an in-stream TMDL for the Taylor Creek/Nubbin Slough tributary. The concern in this reach is low dissolved oxygen (DO) levels. The recent inclusion of a linkage between WAM and the WASP model was used to simulate a two month period during 2002, in which hourly DO data were available. The linked model did a reasonable job of predicting observed DO levels as seen in the Figure 5. The DO modeling with WASP could not have been done without the previous WAM modeling work that was done for the entire basin because it provided the time series of inflows and nutrient loads

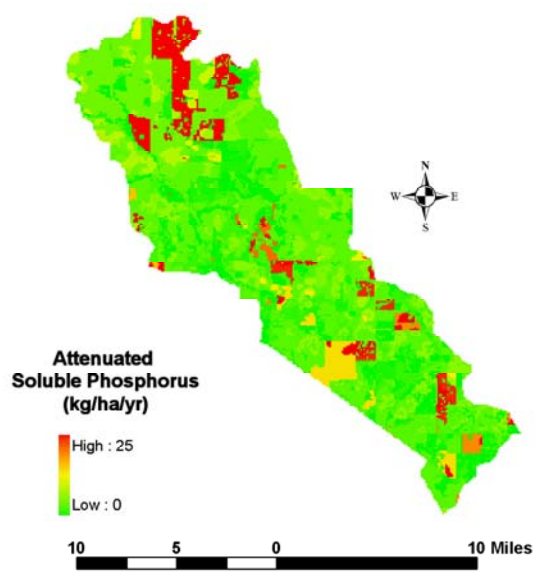

Figure 3: Simulated Attenuated Soluble P Source Loads in the S-191 Basin

for the WASP model. The good fit for the two months provided confidence that simulations could be done for longer periods of time. Therefore, the WAM/WASP model was run for ten years to obtain a better picture of year to year and seasonal variations. These

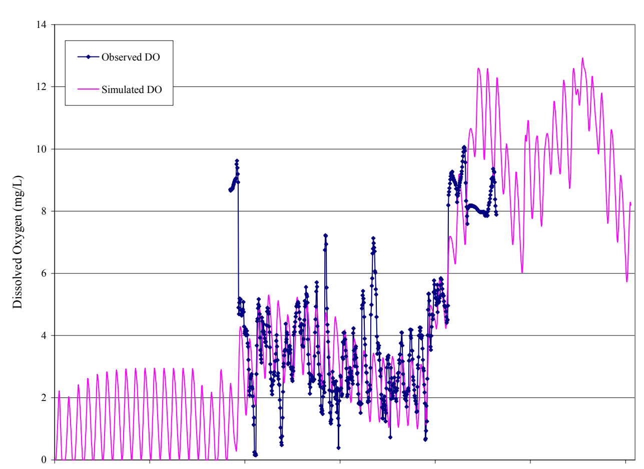

Figure 1: Observed and Simulated DO at S-191

results were used by FDEP to set a draft TMDL for the listing reach. The modeling exercise also pointed out that the DO field monitoring procedures must be carefully done because of depth sensitivity of sampling. Surface DO levels are quite different from depth averaged values or even more so from bottom values. WAM/WASP was adjusted for the sampling depth for the observed data.

Upper Kissimmee River and Lake Istokpoga Basins. The Upper Kissimmee River and Lake Istokpoga basins are large tributary basins to Lake Okeechobee, but only recently have they become part of the larger CERP program in South Florida (SWET, 2003b). WAM was used in these basins to assist in the budgeting of P sources. Because the WAM model uses the most current land use GIS coverages and land use management descriptions, its has the ability to estimate total P inputs to the basin from fertilizer and animal waste, but more importantly it could provide the estimated losses of P from the basins via runoff and groundwater flow. Though individual stream reaches were simulated well by WAM, the basin nutrient outflows were not well represented because of the influence of the numerous large lakes within the stream network. The in-lake nutrient dynamics dominate the outflow characteristics for many of the lakes. WAM currently uses an in-stream attenuation algorithm (SWET, 1999) that does not include wind mixing, macrophyte growth and die off, or algal growth relationships. During the CERP remodeling of these basins, it is anticipated that a lake model will be added to WAM.

Caloosahatchee River (C-43) Basin. The Caloosahatchee River, which has been canalized, is also referred to as the Canal-43 or C-43. This is a complex basin that receives regulated inflows through several structures along the west side of Lake Okeechobee. Flow from Lake Okeechobee combines with runoff generated within the basin. This combined flow passes through two additional large structures (S-78 and S-79) on C-43 before draining to the lower Charlotte Harbor and Estero Bay estuaries on the southwest coast of Florida. Besides the nutrient and eutrophication issues in the estuaries, salt levels are of critical concern. The operation of the structures on C-43 to maintain irrigation supplies and provide flood control has significantly altered the river's natural flow and has caused significant saltwater intrusion into the esturaries during dry periods. During wet periods, mandatory Lake Okeechobee releases with the high nutrient lake water is quickly passed through the C-43 canal, which has induced abnormal amounts of freshwater to the estuaries. The objective of the WAM modeling exercise was to determine the contributions of water and nutrients within the basin as compared to the lake releases. The results clearly showed that the structures' operation and resulting lake releases dominate the estuary flows at this time. The modeling also identified problems with some of the observed flow data, particularly releases from the lake that need to be rectified. The nutrients from runoff within the basin are important, but again are small compared to the lake releases of nutrients.

As indicated, irrigation withdrawals are made from the C-43, which during low flows can dominate the flows in the C-43. WAM was specifically modified for this application to allow the irrigation demand that is generated by the source cell submodels to be withdrawn from either the groundwater or streams/canals. With this enhancement, WAM quickly identified additional data problems, in that the structure placements and canal depths as previously defined were insufficient to supply the necessary irrigation water. It was clear that structure operational levels and perhaps even missing pump stations have to be better delineated before more accurate simulations can be done.

North Palm Beach and Cross-Bayou Basins. Both of these projects are just getting underway, so no results can be reported. However, these basins are important because hydrodynamic looping is being added to WAM to handle the interconnectivity of the stream network in these basins. The North Palm Beach basin has canals that branch and come back together which give flow multiple paths to the basin's outlets. The looping feature of WAM will be completed by the fall of 2003.

CONCLUSIONS

The WAM model has been successfully applied to multiple basins within Florida for assisting in the development of TDMLs and for the assessment of management alternatives for meeting the flow and water quality goals of impaired waterbodies. As WAM has been applied to new watersheds, additional enhancements have been incorporated in WAM, such as surface and groundwater withdrawals, spatial groundwater modeling, hydrodynamic looping, and irrigation withdrawals. The modular structure WAM allows for ready adaptation to new and unique conditions of a watershed.

REFERENCES

1. Bottcher, A.B, J. Hiscock, N.B. Pickering, and R.T. Hilburn. 1998a. WAM-Watershed Assessment Model. Proceedings of Watershed Management: Moving from Theory to Implementation. Water Environment Federation, Alexandria, VA
2. Bottcher, A.B, N.B. Pickering, and A.B. Cooper. 1998b. EAAMOD-FIELD: A Flow and Phosphorous Model for High Water Tables. Proceedings of the 7th Annual Drainage Symposium. American Society of Agricultural Engineers, St. Joseph, MI.
3. Knisel, W. G. 1993. GLEAMS: Groundwater Loading Effects of Agricultural Management Systems. UGA-CPES-BAED Publication no. 5.
4. Mock, Roos & Associates, Inc. 2003. Phosphorus Budget for Lake Istokpoga and Upper Kissimmee Basins – Modeling SubReport. Submitted to the South Florida Water Management District. West Palm Beach, FL.
5. SWET. 1998. GIS Watershed Assessment. Final Report to the Suwannee River Water Management District. Live Oak, FL.
6. SWET. 1999. Development of a Phosphorus Assimilation Algorithm for Lake Okeechobee Tributaries. Final Report to the South Florida Water Management District. West Palm Beach, FL.
7. SWET. 2000. Development of Grid GIS Based Simulation Models for Lower St. Johns River Basin (LSJRB) Hydrologic/Water Quality Assessment. Phase 2 Final Report to the St. Johns River Water Management District. Palatka, FL. Report includes a User Manual.
8. SWET. 2001. WAM Modeling of the Myakka River Watershed. Final Report to the US Environmental Protection Agency, Region IV. Atlanta, GA.
9. SWET. 2003a. WAMView Modifications. Final Report to the Florida Department of Environmental Protection. Tallahassee, FL.
10. SWET. 2003b. Hydrologic / water quality characterization of the watershed – watershed assessment report. Central and Southern Florida project -- Comprehensive Everglades Restoration Plan. South Florida Water Management District.