WATERSHED ASSESSMENT MODEL (WAM) APPLICATIONS IN FLORIDA

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Abstract. The Watershed Assessment Model (WAM) is a GIS based model that simulates the complex hydrology and water quality responses within a catchment based on detailed watershed characterization data. WAM was first developed in the 1980's to take advantage of the spatial datasets that were just coming available. Today, WAM is a fully integrated ArcMap application where watershed characterization data can be easily imported, edited and simulation results easily review via the ArcMap interface. The conceptual design of WAM, its ArcMap interface and data structure, and recent applications in Florida will be presented. The presented model applications will focus on the recent use of the model and how useful it has been for assessing alternative abatement strategies for restoring the water quality entering Lake Okeechobee and the Florida Everglades. WAM has been used to simulate approximately one third of Florida for various water quality assessments including the establishment of several TMDLs.

Keywords. Watershed modelling, hydrology, water quality, GIS, nutrient sources and cycling, nitrogen, phosphorus, nutrient assimilation, land use, grid based

WATERSHED ASSESSMENT MODEL (WAM) DESCRIPTION

WAM is a deterministic hydrologic watershed model, geographical information system (GIS) based, that represents the complex water quantity and quality responses within the terrestrial portion of the hydrologic cycle based on detailed characterization data. WAM simulates the constituents important to eutrophication processes in water bodies (water, total suspended solids, biological oxygen demand, soluble and particulate nitrogen and phosphorus) within a watershed. The model was first developed in the 1980's to take advantage of the spatial datasets that were coming available. Today, WAM is a fully integrated ArcMap (ESRI, 2011) application where watershed characterization data can be easily imported and edited, and simulation results can be reviewed via the ArcMap interface. The conceptual design of WAM, its interface, and example applications are be presented here, but the reader is encouraged to review the User, Technical, Developer, and Tutorial Manuals for WAM at www.swet.com/WAM.htm for a more in-depth understanding of the model.

OVERVIEW OF THE MODELING CONCEPT

The sequence of physical processes modelled in WAM mirrors the earthbound part of the hydrologic cycle, which is represented by a spatially scalable grid of the watershed components. First the constituents that are generated on the land-based portion of the watershed are simulated; these are then transported via surface and subsurface flow to stream reaches and are subsequently routed through the reach network to the basin outfall. Figure 1 illustrates the main conceptual processes simulated in WAM in a holistic watershed picture.

Before the physical processes are simulated, the watershed is gridded into a rectangular array based on a user defined cell size (typically 1 hectare). The following is known for each cell in the grid: land use and soil classification; which "rainzone" it is within, and whether the cell is within a wastewater utility service area. The rainzones are created by placing Theissen polygons around the rainfall monitoring stations. It is assumed that rainfall within the Theissen polygon (rainzone) is uniform and representative of the entire spatial area to which it is attributed. Cells that have identical characteristics, e.g. the same soil, landuse, rainzone, and utility zone, are termed a unique cell type. Note that multiple cells can have the same unique cell type, which means the number of unique cell types can be much less than the total number of cells within a watershed. Since all cells with the same unique

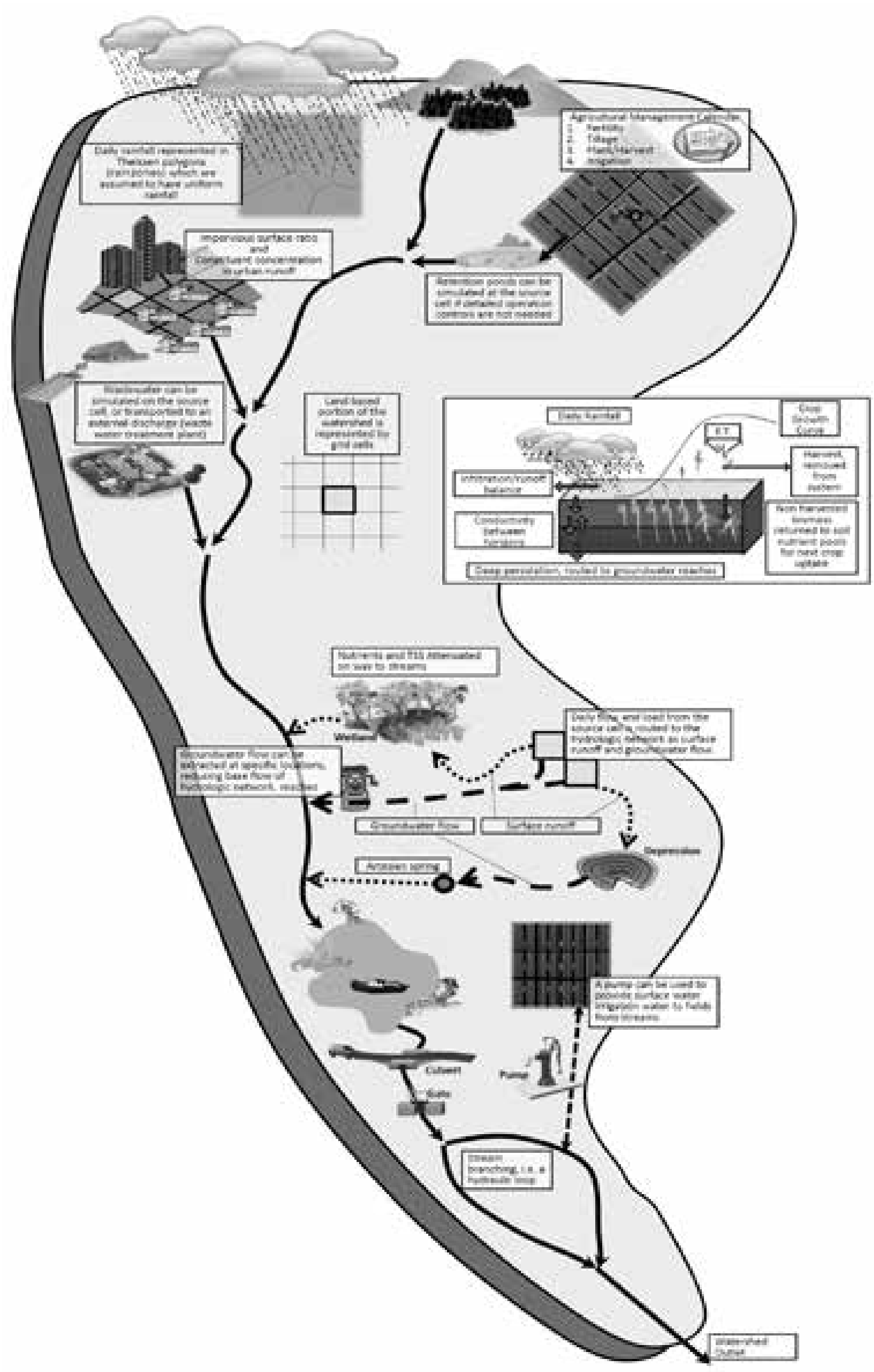

Figure 1: Conceptual View of Watershed Processes Simulated in WAM

cell type are identical from a simulation standpoint, they only have to be simulated once with their results then being applied back to each cell identified with that unique cell type. This concept greatly reduces the simulation time as the total number of cells in the watershed that are uniquely different is much less than the total number of cell in the watershed that must be routed to the nearest stream.

SOURCE CELL SIMULATION

For each unique cell within the watershed, the land use practices and soil characteristics are used together with daily rainfall by the Basin Unique Cell Shell program (BUCSHELL) to determine the simulated constituent (water, total suspended solids, biological oxygen demand, nitrogen and phosphorus) balance and release from each cell on a daily basis. BUCSHELL selects one of three field scale models that differ in their ability to represent the specific land use and soil relationship characteristics, allowing for a broad spectrum of conditions to be accurately simulated. Well drained soils are simulated by the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model, which was developed by Knisel (1993), and is a widely used and accepted model. Alternatively, high water table soils are simulated using the Everglades Agricultural Area Model (EAAMOD) which was developed specifically to simulate Histosols and other high water table soils (SWET, 2008a). EAAMOD was determined to be the best model to use for the Lake Okeechobee regulatory program (Zhang, 1999) and has been used extensively in south Florida. GLEAMS and EAAMOD are physically based models used to simulate soil and plant processes affecting water quality on an agricultural field scale. Due to the complex processes handled by these models, extensive parameterization of weather, land use, and soil characteristic data is required. A set of default parameters are available to assist users during initial model setup. If more detailed information is available the model default parameters can be edited easily through a user interface. The management of the landscape can be described using an event calendar that is used to schedule agricultural practices that manipulate the landscape on specific dates. These practices include planting, harvesting, fertilizer applications, irrigation and tillage. Also included in the event calendar is the evapotranspiration crop coefficient and nutrient uptake curves for the crop. Irrigation water can be sourced from groundwater or surface waters, which will directly impact the water balance of the watershed.

The third field scale model is termed the Special Case, which is designed to simulate land uses that cannot be represented by typical crop models, such as mines, open water and wetlands. Special Case uses a simplified water balance method to calculate daily water volumes contributing to surface runoff and groundwater. The water balance calculates the change in water storage in terms of water depth (Sdepth) in the cell above the ground surface as the daily difference between rainfall as input and evapotranspiration, runoff and percolation to groundwater as outputs (Figure 2). Figure 2 illustrates the flow algorithm for water balance in a cell simulated by the Special Case field scale model. Runoff is generated when the Sdepth exceeds the maximum storage depth shown as “Depth” in the figure. A user defined nutrient concentration is applied to runoff when it occurs.

Once the field scale sub models (GLEAMS and EAAMOD) have simulated the daily flow and constituents for the vegetative portion of each unique cell, an additional post-processing algorithm may be applied to the sub models’ results to account for the presence of impervious surfaces, storm water retention systems, street sweeping, human wastewater generated within the source cell, a best management practice (BMP) adjustment factor, and a possible redistribution of nutrient speciation if needed. The resulting surface and ground water flow and constituent loads leaving the source cell after these post process adjustments are routed to the reach network.

TO REACH ROUTING

Once the daily constituents have been generated by the source cell models including the post processing algorithm within the BUCSHELL module, they are routed to the appropriate stream reach/segment before they are routed through the stream network. The source cell to stream and the stream routing are computed by the Basin Land Area to Stream Routing module (BLASRoute). Figure 3 includes a graphical depiction of the modeling process.

Before the constituents can be routed to the reach network, the individual flow paths from each source cell to the reaches must be determined, for both surface runoff and groundwater. Distances are not always Euclidean because they are the actual distance of the flow path following the surface topography from the source cell to the nearest down gradient feature. The flow paths can be redirected using overlain constraints of sub-basin and springshed boundaries. WAM tracks six unique distance types, listed in Figure 3. Figure 3 also illustrates each of the potential flow paths from four source cells. As can be seen, the model tracks the distance from the source cell to the reach

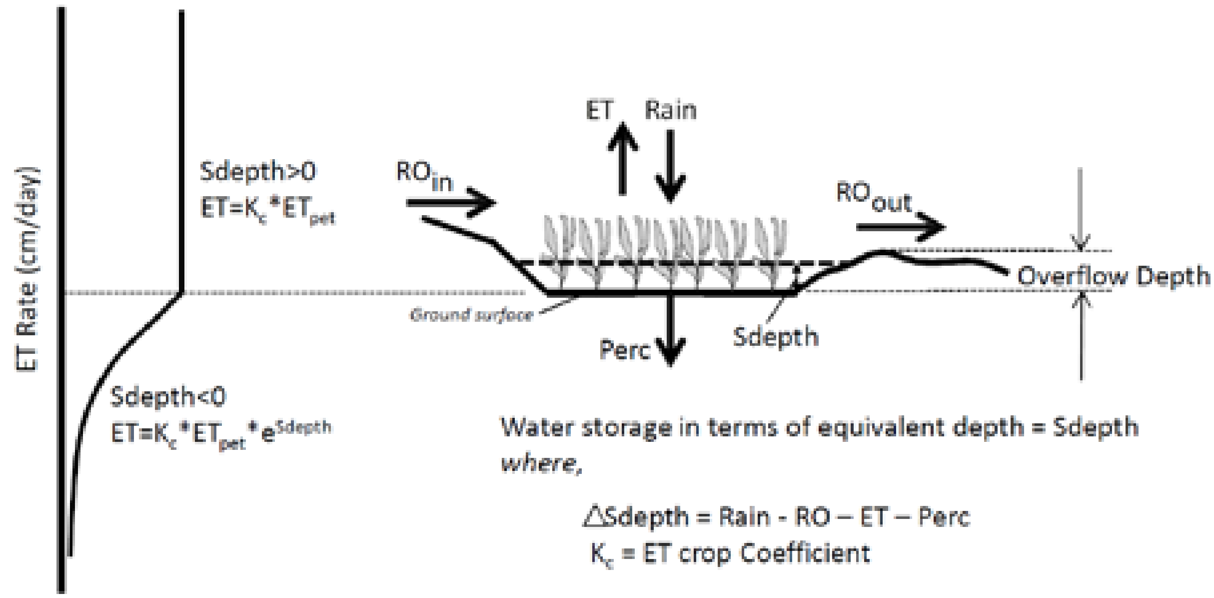

Figure 2: The Special Case Algorithm for Water Balance

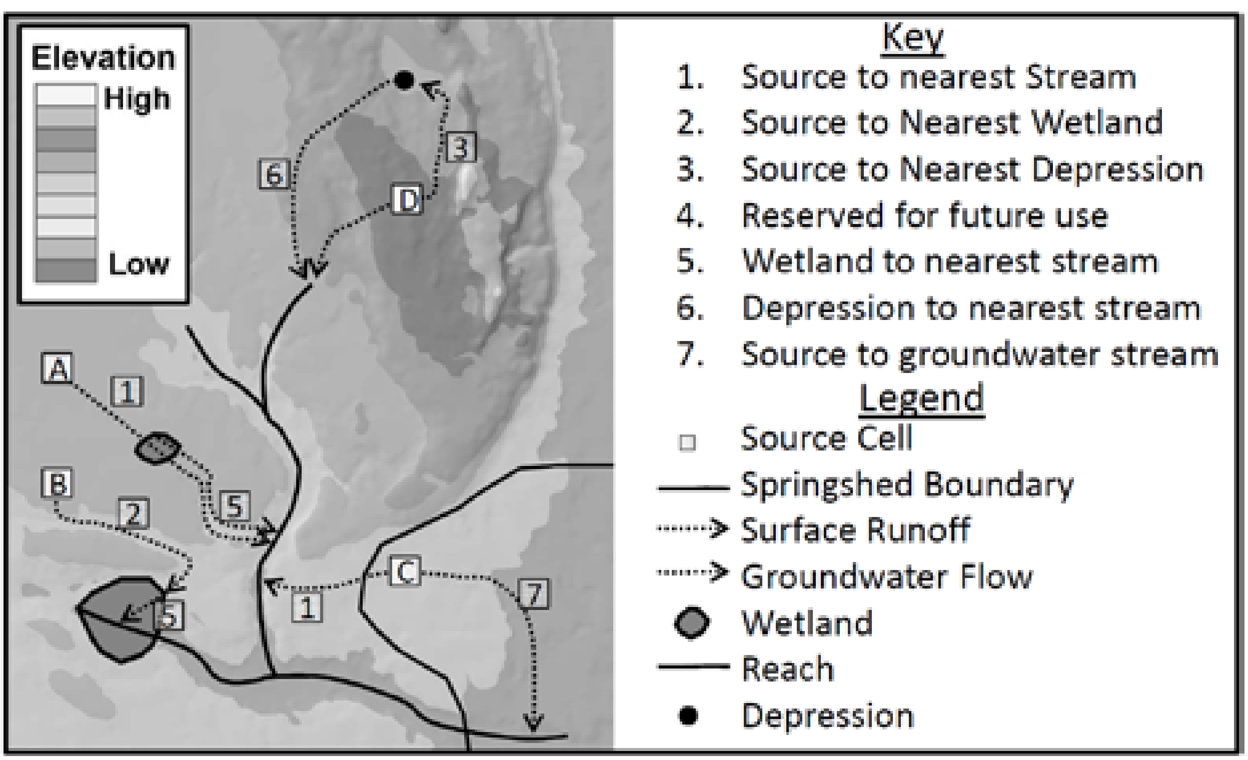

Figure 3: The Flow Directions Used to Route Source Cell Constituents to the Reaches

separately for surface runoff and groundwater flow. Additionally, if surface runoff does not directly enter a reach, the landscape feature it does flow into either reroutes it to groundwater in the case of a depression or assigns it as wetland flow for the remainder of its overland journey to the reach.

Once the flow distances have been determined the constituents generated on the source cell are routed to the reaches. The conceptual basis for the source cell to reach routing is that the physical processes that occur between the source cell and the reach which result in a delay of flow due to travel time and peak flow dispersion based on the hydrograph shape (user inputted unit hydrograph) of the daily predicted source cell discharge. For runoff, the assumption is made that no significant losses of water from ET or transference of water to ground water occur along the flow between the source cell and the stream. Studies (Loague, 1994) have shown that such losses or transferences are typically minimal once flows become concentrated, i.e. overland sheet flow is no longer occurring.

An attenuation process (SWET, 2011a and 2011b) to account for the potential constituent assimilation capacity en route to the reaches is incorporated and is a function of the type of features encountered, such as wetlands or depressions. This attenuation process was patterned after work by Rutherford et al (1989). The assimilation/attenuation of constituents along the flow path is determined by the path which the flow takes. Surface flow is directly influenced by the landscape through which that flow passes, such as dryland or specific wetland types or both. If dryland and wetland conveyance types are encountered, then the attenuation algorithm is applied sequentially as the flow goes through the two flow sections. Similarly, if surface runoff is converted to groundwater flow by encountering a depression before reaching a stream, the attenuation and delay factors are proportioned accordingly.

IN-REACH ROUTING

Once flows and loads have been delivered to the stream reaches, they are routed through the network to the basin outfall, using a modified linear reservoir routing technique developed by SWET (2011a and 2011b) and Jacobson et al, 1998) for solving the equations of uniform channel flow using Manning's equation and a variable time step (10 min maximum) that is based on the stream velocity and model stability. Manning's equation is integrated over each time step to give the change in reach volume during the time step using a first-order approximation for the change in net flow with respect to volume. Using the derivative of Manning's equation with respect to volume was found to provide better estimates of average flow rate during a time step than more traditional approaches (e.g. Euler or Runge-Kutta), which can quickly become unstable for small hydraulic slopes (Jacobson et al, 1998). Using Manning's equation is appropriate because of the slowly varying and subcritical flow conditions expected in the streams. Manning's equation was chosen for its proven ability to predict uniform stream flow with minimal inputs. All of the inputs slope, roughness, cross-sectional area, and hydraulic radius can be easily measured or estimated (Jacobson et al, 1998).

Unlike traditional linear-reservoir routing methods, the relationship between flow and volume changes for each stream reach and time step. Because this approach does not account for momentum, it is not a fully hydrodynamic routing technique. It is best described as a numeric solution of the governing differential equations (Manning's flow and continuity) using a modified time-varying linear-reservoir routing technique within each time step. Considering the typical low hydraulic gradients within most basins and lack of detailed stream profile and climatic data, the approach is not expected to be the limiting factor for accurate flow prediction. In fact, its high computational speed allows very complex reach networks of greater than 1000 reaches, over 100 structures, and numerous hydraulic loops to be considered. This approach also allows for complex dynamic water control structures, point sources and complex branching and convergence to be handled. Weirs, culverts, gates, and pump structures are handled with user flexibility to set complex stage trigger controls. Channel splits or hydrodynamic looping, as often found in complex channelized drainage systems, is handled by the unique numeric solution technique (SWET, 2011).

The routing algorithms incorporate in-stream assimilative capacity or attenuation that can be individually set for separate reach types. The routines also accommodate complex water control structures such as gates, pumps, weirs and culverts. The operating protocols of the structures can be defined to dynamically match actual operating controls. Pumps and gates can be set to operate off the stage of any reach in the watershed, extending their ability to mimic water use management decisions ahead of critically high or low flow levels. Flow and stage boundary files can be used to input or extract water at specific locations, or control the rate of discharge from other locations by creating head differentials that restrict or direct the movement of water within the watershed. Tidal influences can be accounted for by a stage boundary file, as can point source discharges. Multiple flow paths, known as hydraulic loops, can also be simulated, which is particularly critical in flat topographical areas with interconnecting canal systems, such as the south Florida drainage system.

Model Output

The output of each of the sub-components of WAM can be reviewed and compared to each other, providing a complete and holistic picture of the sources and cycling of each constituent throughout the entire watershed. For example, maps can be created that show both the spatial distribution of each constituent leaving the source cell, as well as the amount that is delivered to the reaches after overland attenuation has been accounted for. The simulated reach output can be plotted on temporal scales that show the cycling of constituents in the reaches, which can also be visually compared to monitoring data. Tables can also be created to compare different landscape features or geographic regions to each other. The model interface provides output tools that assist in streamlining the analysis through several standardized formats of tables, graphs, and maps.

Graphical User Interface

The development of WAM and its user interface has closely mirrored the technological advances made in GIS software. The earliest version of WAM was started in 1984 when the US Army Corps of Engineers developed a spatial land use dataset for the Kissimmee River and requested that a watershed model be developed that could use this dataset. Most of the effort in the development of this model was in the creation of graphical display programs that would be able to review the spatial results because commercial GIS programs were not readily available at the time. With the development of the Environmental Systems Research Institutes (ESRI) GIS software, WAM was adapted to use their interface to review model inputs and outputs, first within ArcINFO and then in ArcView 3.x (Bottcher *et al*, 2002). In 2009 the WAM interface was modernized to function as an extension to the ESRI ArcGIS Platform. The data storage was also advanced to make use of a relational database management system, with user friendly tools to import watershed characterization data and review that data directly in the interface. The primary point of contact to the WAM extension is through a customized Toolbar within ArcMap, as shown in Figure 4. The Toolbar provides access to each of the specific tools that have been developed to allow a user to interactively characterize a watershed, complete a simulation and review the results, all from within ArcMap.

Figure 4: The WAM Toolbar

WAM makes use of a project and scenario concept for simulation organization. A "Scenario Manager" is used to create or copy scenarios in projects, as well as load the contents into ArcMAP. It provides an easy-to-use file management system that can track project development and removes the user from having intimate knowledge of the extensive file structure that comprise a project and scenario.

The interface provides a standardized format through which publicly available datasets can easily be imported and matched to default parameter sets that have been defined to represent the common features represented by the model. This makes the initial setup of a watershed straightforward and seamless by making use of existing classification and parameter characterization within the interface. The user is then provided with interactive tools to review and customize the classification and characterization of each of the model inputs to match local conditions. This parameterization is done through a property grid, which extracts data from the relational database management system and presents it in a user friendly format that allows the direct editing within ArcMap. Contextual help is provided to assist a user in the interpretation of the role a parameter plays in physical representation of watershed processes, as illustrated in Figure 5. The model is run directly from the Toolbar. Once completed the model output files are loaded into ArcMap and the specific output tools can be used to create standardized maps, charts and reports for each of the simulated constituents.

WAM Applications in Florida

WAM has primarily been used in Florida as shown in Figure 6 where approximately 1/3 of the state has been simulated. The adaptability of WAM to the varying conditions around the state shows the model's versatility, plus it has been used successfully in New Zealand and northern states where snowfall is accounted for. In Florida WAM simulates the deep well drained sands of the Suwannee River basin where numerous springs exists causing

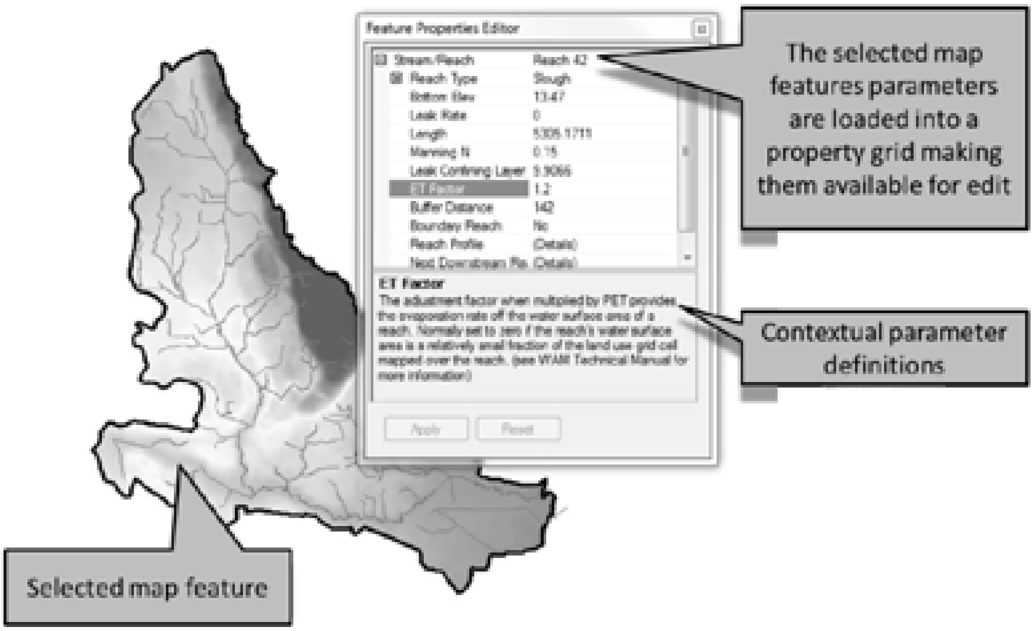

Figure 5: Features Selected within the Map are Loaded into the Property Editor for Editing

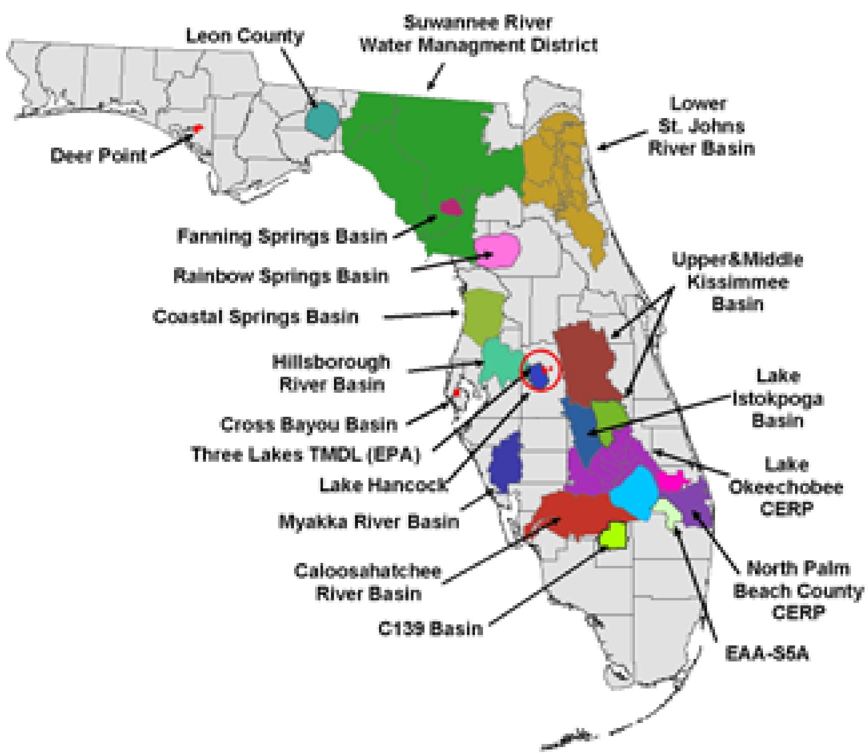

Figure 6: WAM Projects in Florida

concerns for groundwater nitrate movement, while also being able to simulate the flat coastal plains of south Florida where high water tables dominant and drainage is often through complex canal systems. Two example case studies for these two varying conditions will be presented.

CASE STUDY 1 – C139 BASIN IN SOUTH FLORIDA

The case study being presented for the WAM model is the 168,450 acre C-139 watershed that lies ten miles southwest of Lake Okeechobee in South Florida. The predominately agricultural watershed drains south into the Florida Everglades. This basin was chosen because it demonstrates WAM's ability to simulate hydraulically complex basins, where over 20 structures and multiple agricultural and urban land uses are present. The period of study was from 2002 through 2009. The calibration period was selected from 2002 through 2004 since its precipitation conditions were representative of the entire simulation period. This leaves the period from 2005 through 2009 for validation.

INITIAL BASIN SETUP

The physical characterization of the basin was based on land use, hydrography, soils, and topographic GIS feature classes provided by the South Florida Water Management District and the NRCS SURGO (NRCS, 2012) database. Climatic parameters, including rainfall, solar radiation, wind, and air temperatures, were obtained from the nearest weather stations. Significant effort was taken to verify the quality of these data through visual and statistical comparisons and where data gaps or errors were found, they were filled or corrected by using the nearest available data. A particular focus was placed on rainfall data because of its importance to the simulation process. In spite of these efforts, the limited number of rainfall stations will cause significant differences between actual rain amounts falling across the entire watershed versus at the rain station, particularly during the summer convective storm period.

Figure 7 shows the C-139 watershed layout including subbasins, hydrography, monitoring sites, and water control structures. Note that compliance monitoring stations are also located at simulated water control structures. The flow is generally to the east and then south in the L-2 and L-3 canals. The basin is located at a hydrologic divide where flow can exit the basin at seven locations to the northeast and south. Each of these basin discharges required stage boundary conditions for the proper flow estimation at the outlet water control structures. A detailed description of the C-139 WAM setup and calibration procedures are provided in the project report submitted by SWET (2011b) to the South Florida Water Management District.

HYDROLOGIC AND HYDRAULIC CALIBRATION

The first steps were to verify that the hydrologic and hydraulic (H&H) physical parameters are accurately represented (compared to measured data) or reasonable (when data were not available). This process starts by looking at the water generated at the source cells and then follows the flow from the source cell to the nearest stream and then through the water conveyance system to the basin outlets.

Source Cell Runoff and Percolation

Figure 8 illustrates the annual averages for runoff and percolation for each unique cell combination in the C-139 basin, plotted by land use. The scatter of the points for a given land use is due to soil variations. The flow data are mostly clustered together for individual land uses though there are a few outliers. When the input parameters of these outlier points were examined simulated results were found to be realistic. It was found that the ET estimates and associated runoff and percolation values for this basin were reasonable based on regional estimates by Jones et al (1984) and no changes were needed to the land use and soil parameterization. A similar approach was used to confirm that the soil influences were being represented reasonably by the model.

Basin Water Balance

Figure 9 illustrates the cumulative and daily discharge through one of the primary structures (G136) after calibration was completed. As can be seen a relatively good fit is observed for both accumulative and daily flows.

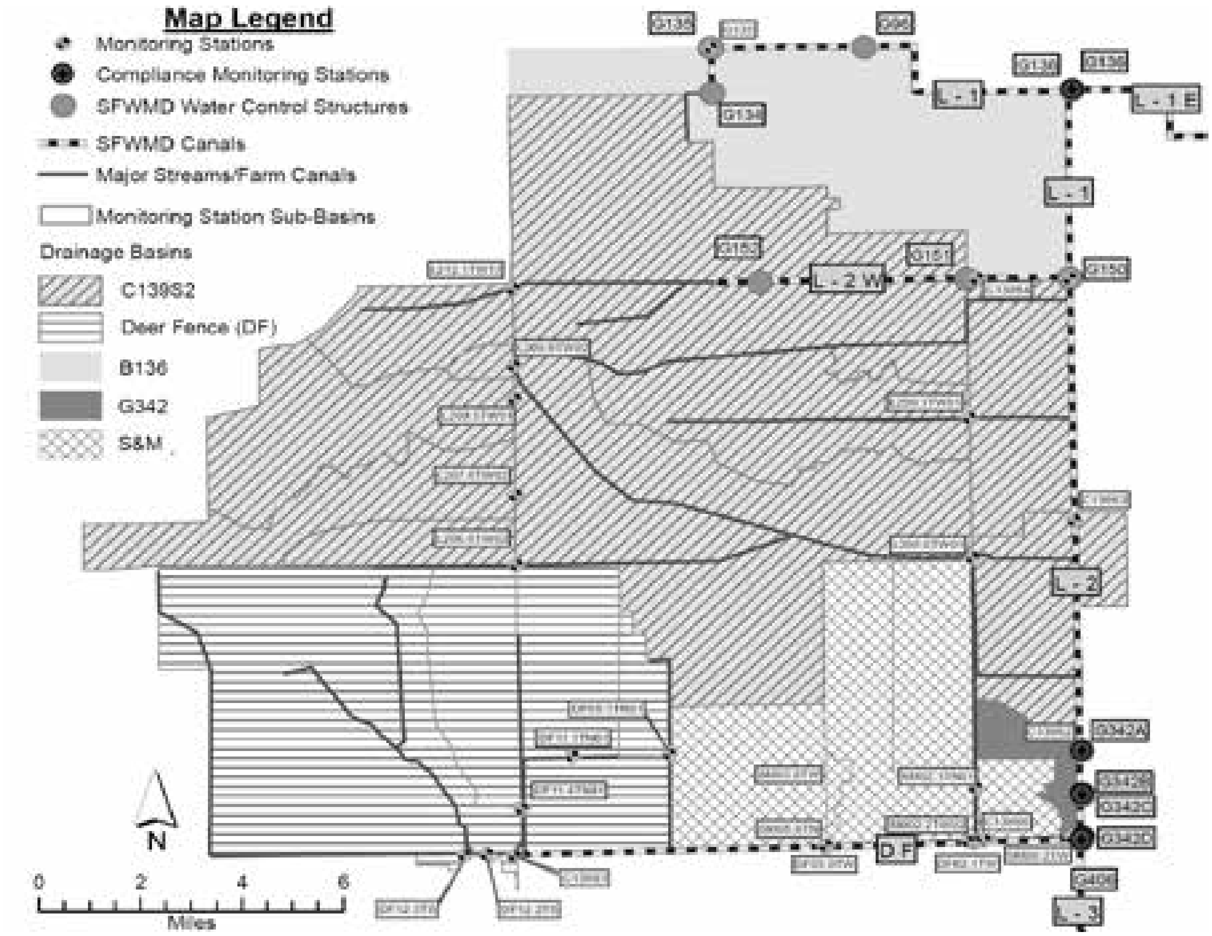

Figure 7: Reaches, Sub-Basins, Monitoring Stations, SFWMD Canals and Water Control Structures

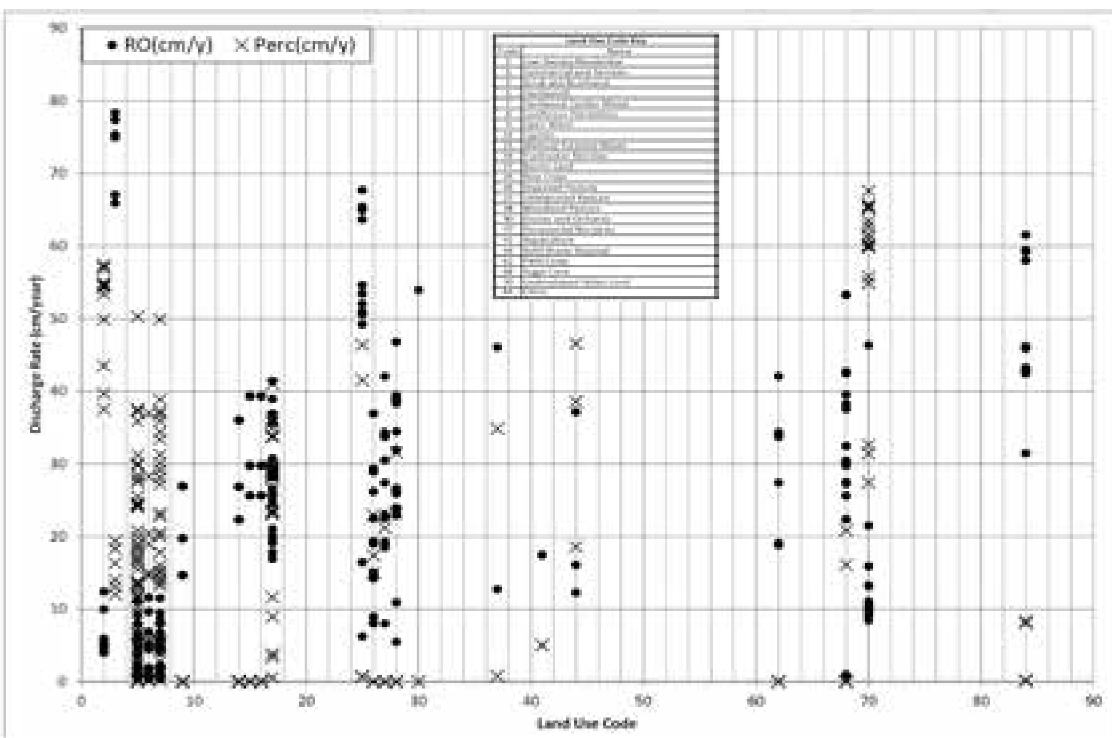

Figure 8: C-139 Annual Averages of Runoff and Percolation; Plotted by Land Use Type

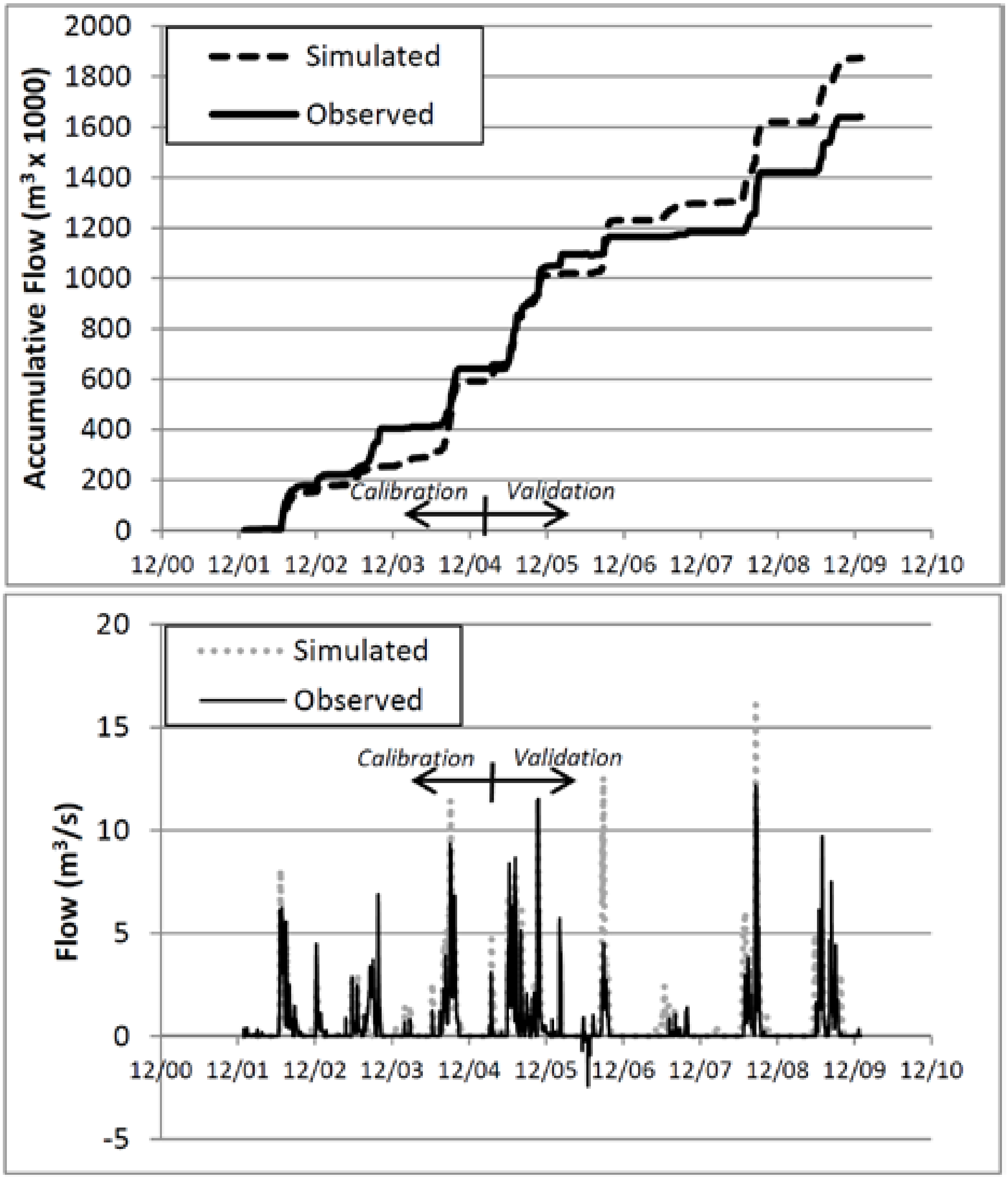

Figure 9. G136 Calibrated Daily and Accumulative Flow

Source Cell Runoff and Percolation

The DayFileToYear utility program was used to calculate the annual TP concentrations for each unique source cell type in the basin. These concentrations were visually reviewed and found to be within the previously observed concentrations for each of the unique cell land use and soil combinations (SWET, 2008b) and, therefore no changes for calibration were deemed necessary.

Reach TP Concentration

The simulated TP concentrations were visually compared to the observed data for each of the structures draining from the C-139 basin. Measured TP data at these structures were limited to weekly grab samples or weekly composited auto-samples. Each station had significant gaps in the data record. G135 had very limited data and therefore was not used for any comparison or analysis. Because much of the data were from grab samples, a few temporally isolated extremely high concentrations were recorded, which are most likely not representative of daily concentrations. As seen in the next section, this is why the daily average simulated TP concentrations are often less than the observed data.

The base condition (H & H calibrated scenario with no nutrient calibration – dotted lines in Figure 10) was found to have higher TP concentrations as compared to the observed data. Since the source cell TP concentrations were previously determined to be reasonable, this meant that the flow conveyance system must be assimilating TP. The observed rapid drop in TP concentrations to very low levels as flow rates decreased to zero or near to zero is a clear indication that biological uptake and deposition and/or adsorption processes on the high calcium sediments is removing TP from the water column during low flow conditions.

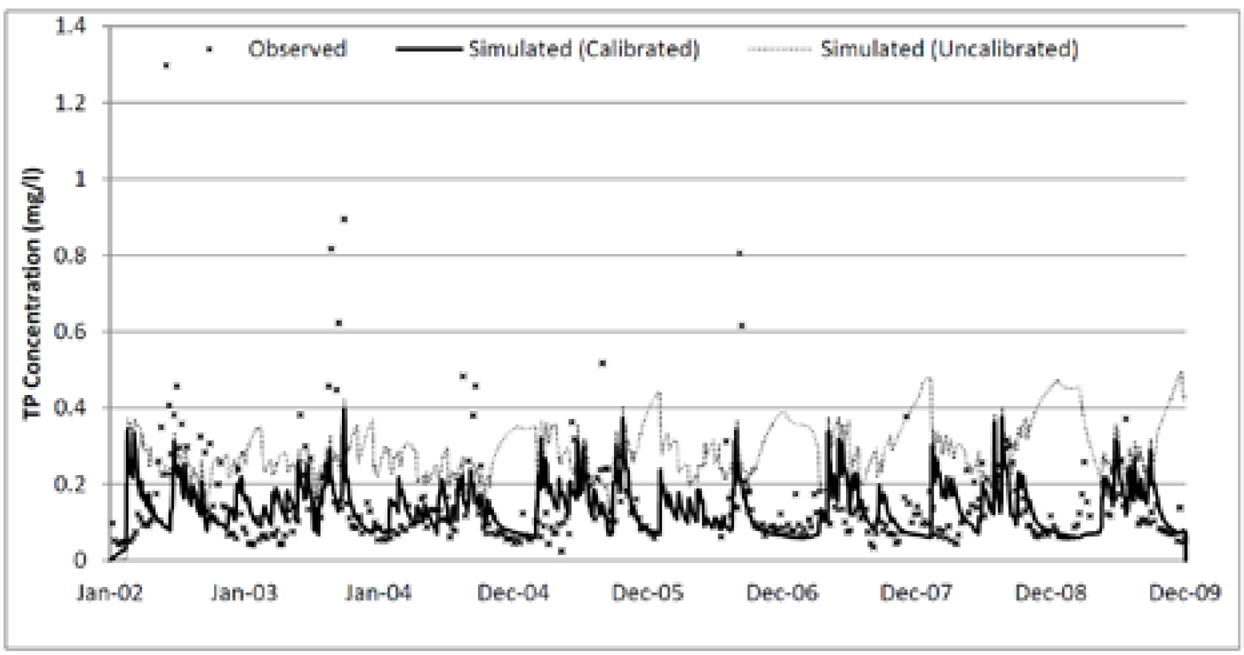

Figure 10. Simulated (un-calibrated & calibrated) and Measured TP Calibration at G342D

Reach TP Load

The total simulated TP load leaving the C-139 basin for each day was generated by summing the simulated loads from each of the structures that drain the basin, with G135 being excluded from this due to limited observed values. Figure 11 illustrates this daily load and compares it to the observed values. As discussed perviously, the observed TP concentrations at each of the structures were limited, with weekly flow composted values (at best) or grab samples only (at worst), while flow was recored daily. This presented a problem when generting the observed loads for each of the stations, and especially when combining these individual station loads to generate a total basin load dischage. This problem was overcome by calculating the mean monthly concentration for each station and using that mean daily average over each month. This daily value was multiplied by the observed flow for each day to generate the daily load for each station and these individual stations were summed to generate the collective basin discharge for a particular day. If a concentration mean could not be calculated for any one station for a particular month (due to no observations for that month), the total observed load could not be calculated and this is represented in Figure 11 as a -100 value. As can be seen from Figure 11, the simulated TP loads when compared visually flow

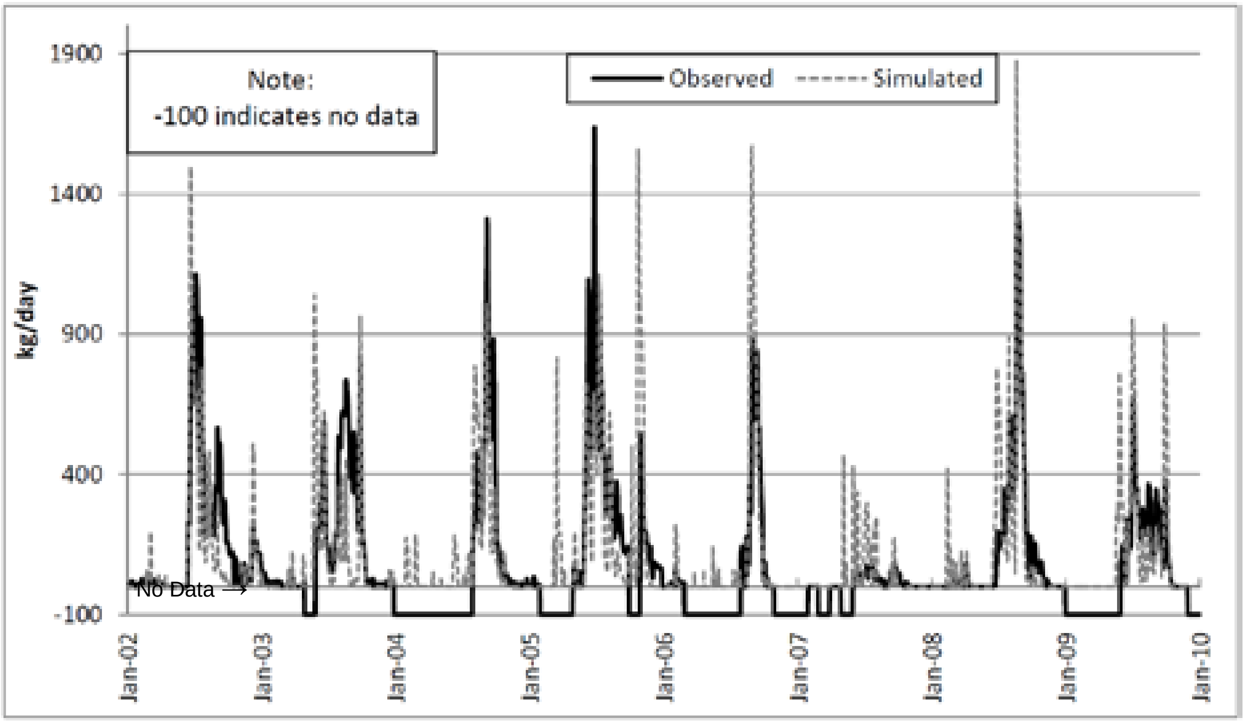

Figure 11. Daily TP Load Discharged from C-139

the general trend of the observed flow with a few notable exceptions. The mismatches are caused by a combination of modeling and observed data errors, mostly associated with flow predictions. As previously noted, inconsistent structure controls and unrepresented variable rainfall across the basin created unknown errors in the model inputs. In spite of these shortcomings, the model did represent the general trends observed in the measured data.

CASE STUDY 2 – RAINBOW SPRINGS IN NORTH FLORIDA

The purpose of this project was to simulate water and nitrogen discharges from Rainbow Springs located in western Marion County, Florida. Rainbow Springs is one of the largest spring systems in the state, and is the dominant source of water in the Rainbow River, which flows into the Withlacoochee River near Dunnellon, Fl. The study area represents the primary recharge basin or springshed for Rainbow Springs, which is about 475 square miles in size and is located in portions of Marion and Levy Counties (Figure 12).

Land use within the study area varies from urban to rural and agricultural, where the dominant land use category is rural/agriculture followed by native areas. The dominant agricultural land use is pastureland followed by row crops. Residential and undeveloped residential areas make up about 23% of the study area, while urban and industrial represent only about 5.5% of the area. The Marion County portion of the study area is slightly more developed as seen as by the lower amount of agriculture and higher percentages of residential and urban land uses.

There were three land use scenarios that were developed and run using WAM. The first is the “base” or “existing condition” run that is based on the 2006 land use coverage. The next two scenarios are the “2025” and “2055” future land use coverages. The future land use scenarios also required that a future condition utility zone coverage be developed. The results of each scenario and comparisons between them will be provided in a later section.

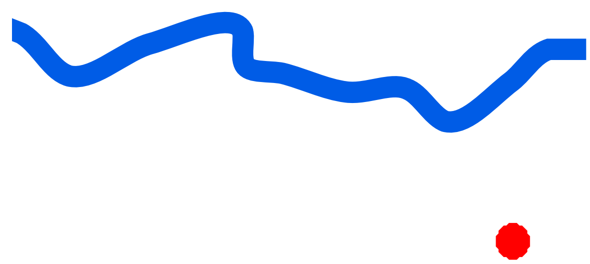

Figure 12: Rainbow Springs watershed Location

MODEL RUNS AND VERIFICATION FOR BASE RUN

This section provides the results and verification of the WAM simulations for Rainbow Springs. Figure 13 shows the simulated (modeled) flow vs. observed flow for Rainbow Springs. The two notable features in Figure 13 are that the simulated flows are on average about 30% higher than measured flows and that simulated flow patterns are shifted and not as peaky. The higher predicted flows are likely due to the fact that the delineated study area is actually larger than the actual springshed, plus the fact that natural fluctuations in the springshed boundary are not represented in the model. The model is fairly robust in it evapotranspiration estimates and therefore predictions will most likely only miss the actual spring flow if the aerial extent of the springshed is not representative.

The temporal dynamics of the simulated flow is offset from actual flows because of the need to bring the simulation to equilibrium more quickly than would actually occur in the basin. This was done so that the influence of land use across the entire springshed can be simulated in a reasonable time period. It is estimated that some areas of the springshed could take 20 to 30 years or more to reach the springs, which would make simulation periods unrealistic and creates the secondary problem of having to initialize the starting groundwater to some unknown constant level. Bringing the simulation to equilibrium more quickly than reality is actually more beneficial for assessing what future nitrate levels might be expected under current land use practices, and especially when evaluating potential spring responses to future development and various preservation and abatement strategies.

Both graphical and tabular simulation outputs are generated and displayed using the WAM GUI. Figure 14 shows the simulated results for soluble nitrogen loads (grams/ha/year) in surface runoff that will flow to the nearest stream after all attenuation/assimilation processes have occurred. Surface runoff within the study area will either flow out of the springshed to a boundary reach (denoted by areas outside of the yellow boundary shown in Figure 15), flow directly into Rainbow River (dark red areas near the river), or will flow to local depressions where it will percolate to groundwater and subsequently reappear at Rainbow Springs (denoted by areas inside the yellow boundary). The runoff that enters groundwater via depressions has higher attenuation rates for nitrogen than runoff flowing directly to streams, as shown by the lighter colors that represent lower nitrogen loads in the figure. Figure 15 shows the simulated nitrogen loads (grams/ha/year) that result from direct groundwater recharge in each source cell. Although the color intensities appear similar between Figures 14 and 15, the scale clearly shows that significantly more groundwater and nitrate recharge is occurring from direct percolation than from surface runoff flowing to depressions.

Figure 13. Measured and Simulated Flows in Rainbow River

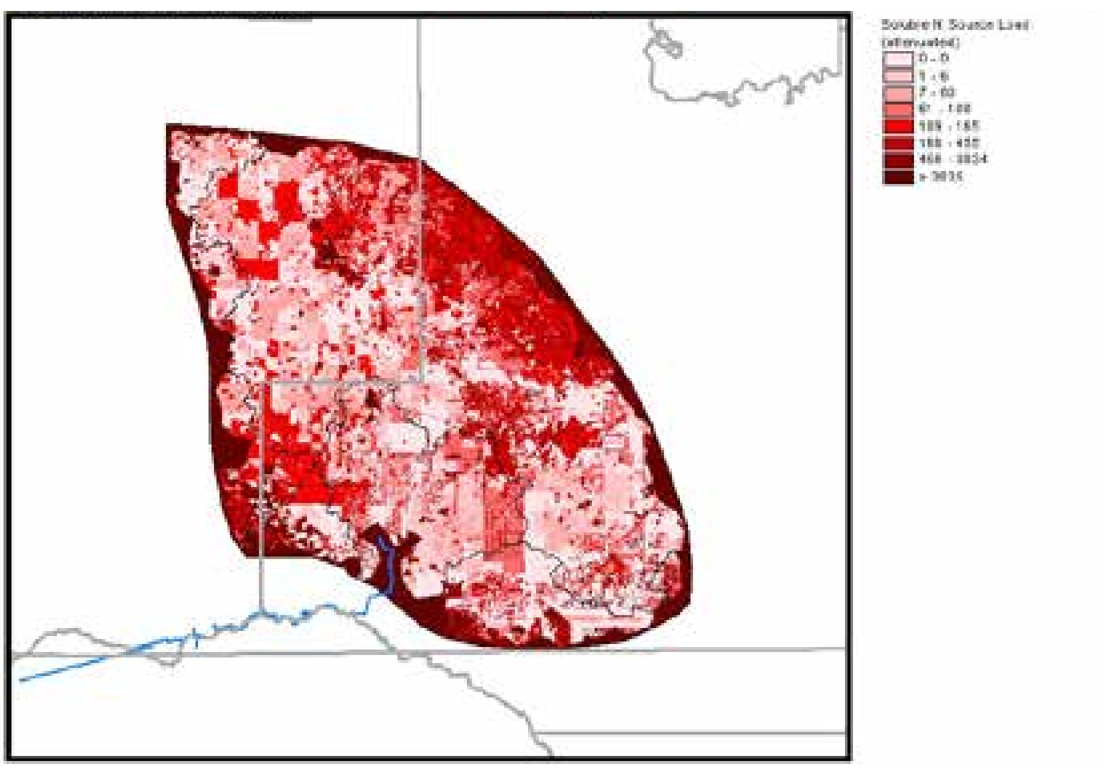

Figure 14. Measured and Simulated Surface Nitrogen Flows in Rainbow River Basin

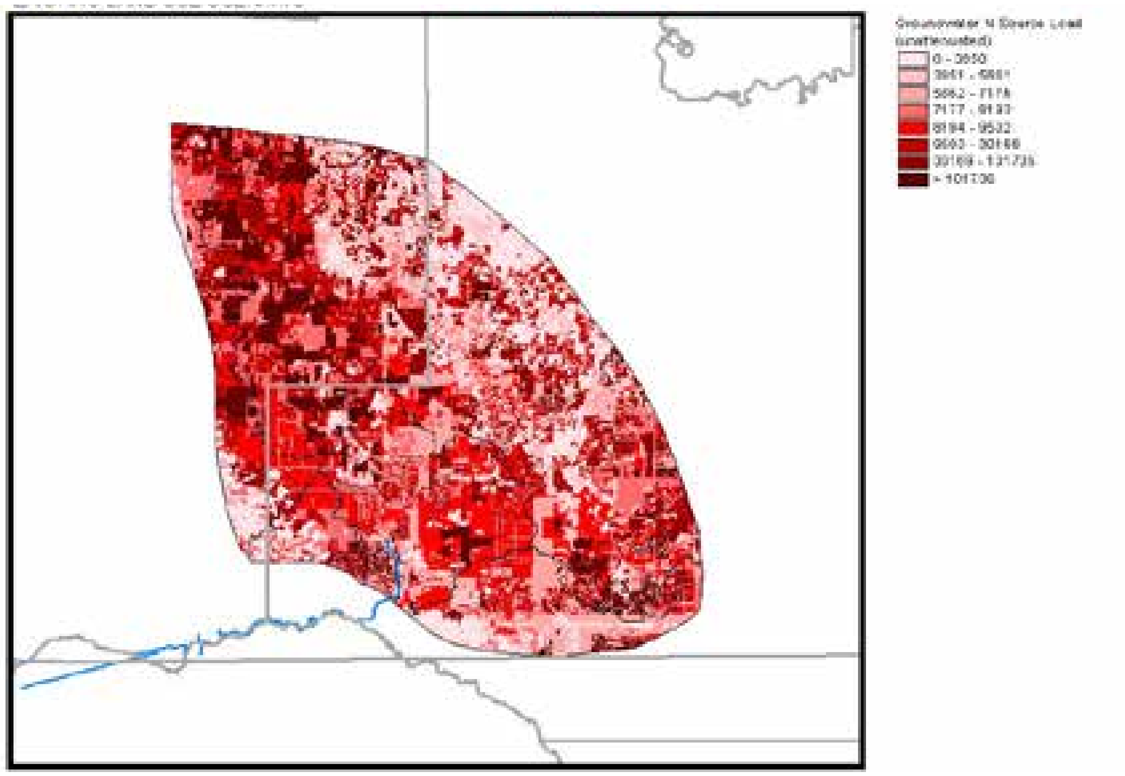

Figure 15. Measured and Simulated Groundwater Recharge of Nitrogen in Rainbow River Basin

MODEL SCENARIO RUNS FOR THE 2025 and 2055 FUTURE CONDITONS

This section provides the results of the 2025 and 2055 future scenario runs using WAM. The future land use conditions were provided by Marion County. Figure 16 provides the predicted trends that are anticipated to occur as the springshed develops. The first trend line shows what would happen if we could limit development to 2007 conditions while the second trend line shows the anticipated nitrogen increases in the spring based on predicted development trends. As can be seen the nitrogen levels in the spring are likely to reach about 4 to 5 ppm by 2055, which compares to about 1.7 ppm currently seen in the springs.

FUTURE DEVELOPMENTS

WAM has evolved over the past 25 years and now includes the recent release of the ArcMap 10 Graphical User Interface (GUI) and updated interactive User, Technical, Developer, and Tutorial Manuals. The SWET staff is also working on a new best management practice (BMP) optimization tool within the WAM GUI that will allow users to more easily develop and evaluate BMP abatement strategies for watersheds. The release date for the BMP optimization tool is anticipated to be fall of 2012.

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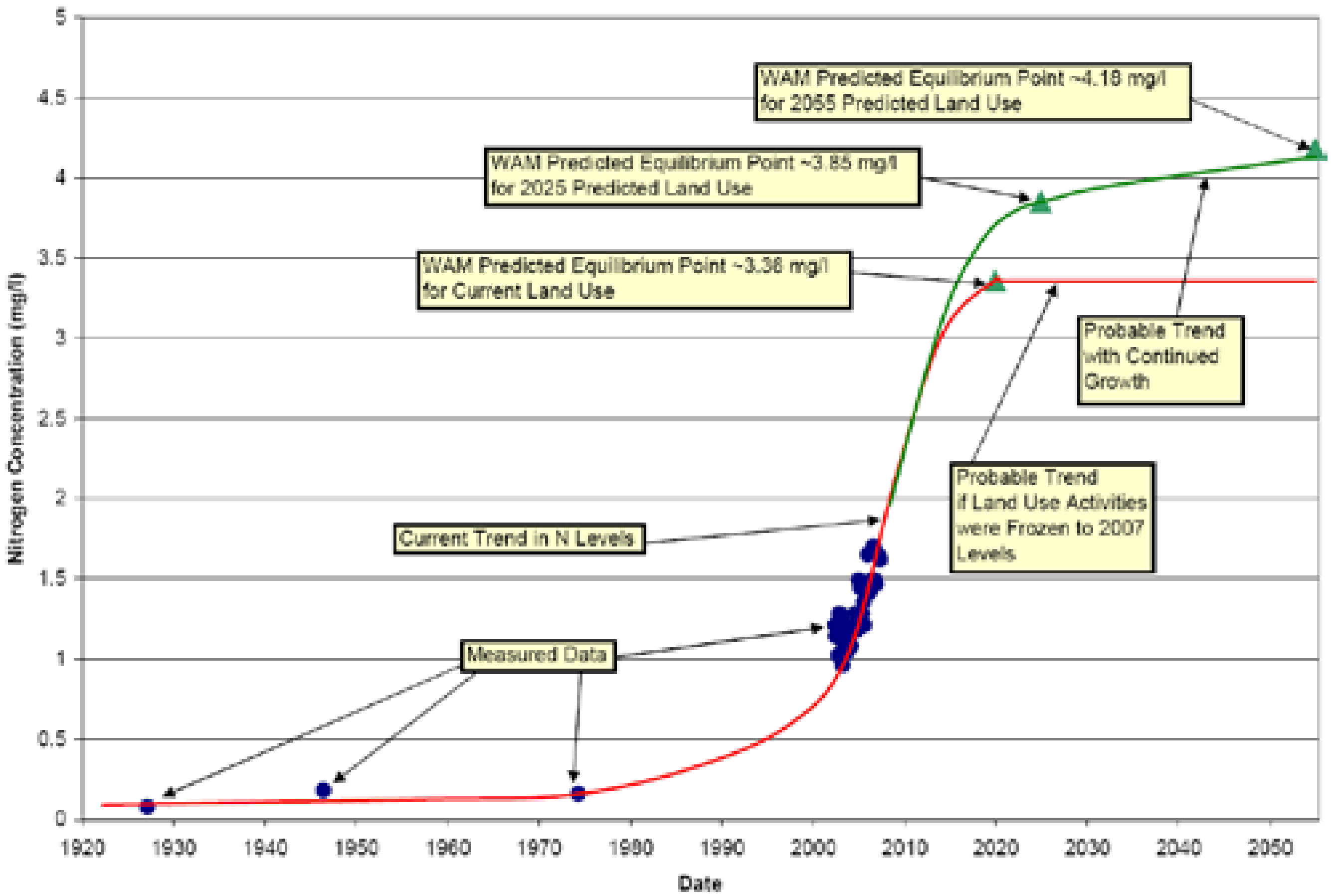

Figure 16. Estimated nitrogen trends in Rainbow Springs for Past, current, and future conditions.

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