EFFECTS OF LAND USE CHANGE IN URBANIZING COASTAL ECOSYSTEMS

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1 ABSTRACT

Population growth and development present a daunting challenge to land use planners and designers, particularly in coastal communities where urbanization dramatically impacts water quality, habitat, other natural resources, and the delicate balance of sensitive environments. This study investigates the effect of changing land use and land cover (LULC) on water quality, and suggests changes in development policy to mitigate impacts. The Fish River watershed, located in Baldwin County, Alabama, USA, is used as a case study to examine both spatial and temporal domains. This watershed is of critical importance to the health of Weeks Bay, a designated Outstanding National Resource Estuary located at the watershed outlet. Water quality data and the Soil Water Assessment Tool (SWAT) are used to understand the LULC dynamics. Spatial comparisons between sub-watersheds showed that sites with large increases in urbanized land uses had substantially higher Total Suspended Solids (TSS). Nitrate trends over time showed a general decrease, while Total Phosphorus (TP) increased significantly. This may have very important implications as analysis at the spatial domain showed that urbanization increases Nitrogen (N) loadings, therefore posing an increased threat of eutrophication. Land development policy was examined and Low Impact Development (LID) Best Management Practices (BMPs) were identified to mitigate TSS, TP, and N within urban catchments. Policy changes that have resulted due to this research include new development policy that supports reduced impervious surfaces, conservation of natural resources, natural drainage courses, and minimization of clearing and grading.

1.1 Keywords

Land use, water quality, development, policy

2 INTRODUCTION

Land use and land cover are watershed health indicators that are strongly tied to water quality. Urbanization and intense agriculture practices can be detrimental to water quality and watershed health due to runoff from impervious surfaces, leaking septic systems and fertilizer leaching from agricultural crops, golf courses and residential lawns. Population growth and development present a daunting challenge to land use planners, particularly in coastal communities where urbanization dramatically impacts water quality, habitat, other natural resources, and the delicate balance of sensitive environments. Coastal areas are highly desirable for human settlement and are almost three times as densely populated as the global average, with 1.2 billion people living within 100 km of the shoreline (Small and Nicholls 2003).

Nitrogen (N) and Phosphorus (P) are the two most important nutrients to track in coastal watersheds because excessive nutrient loading in coastal systems can result in algal blooms, lowering dissolved oxygen levels and ultimately causing eutrophication and decreased productivity. The Gulf of Mexico Dead Zone is an example of such nutrient loading from the Mississippi River. Assessing current N and P conditions and changing land use and land cover (LULC) trends over time is critical to future planning and development especially in sensitive coastal watersheds. Watershed modeling is a tool that can be used to assess the effect of changes in the LULC on water quality by programing the model with past and current data. Water quality models are good for predicting future water quality conditions and can inform future planning and development, however post validation of the model is not common due to lack of readily available current nutrient data.

This study investigates the effect of changing LULC on water quality in a coastal watershed, and suggests changes in development and conservation policy to mitigate impacts. The Fish River watershed, located in Baldwin County, Alabama (AL), USA, is used as a case study to examine both spatial and temporal domains (Figure 1). This watershed is of critical importance to the health of Weeks Bay, a designated outstanding national resource estuary located at the watershed outlet. Fish River contributes 75% of the freshwater source to Weeks Bay. There is no direct discharge from point watershed. Threats of increasing population, urban development (impervious surfaces) and LULC change from agriculture to sod farming, golf courses, and large subdivisions, has put this sensitive watershed at risk (Kalin et al. 2009). The objectives of this study are: 1) To explore temporal trends in water quality using N, P, Total Suspended Solids (TSS), and compare 1994 to 1998 LULC with LULC data with data collected from 2008 to 2010; 2) To determine spatial linkages between LULC and water quality at the sub-watershed scale; 3) To test whether the Soil Water Assessment Tool (SWAT) model can be used to predict effect of LULC changes on water quality within the watershed; and 4) To use results to suggest Best Management Practices (BMPs) for policy and design to mitigate water quantity, water quality and land use problems at the sub-watershed level.

3 LITERATURE REVIEW

LULC change has a history of being strongly tied to water quality (Trimble et al, 1987; Gash et al, 1996; DeMoraes et. al, 2006; Bruijnzeel, 2004; Bosch et al., 2007; Kalin et al. 2009). Urban developments have also been shown to increase heavy metals (Callender and Rice 2000), bacteria loadings (Gregory and Frick 2000, Schoonover et al. 2005), and stream temperatures (Brooker 1981, Krause et al. 2004).These studies indicate the necessity of critically evaluating the potential consequences of future development plans. Several researchers have also presented evidence that a 10 percent increase in impervious surface area could result in stream degradation (Schueler 1995, Booth and Jackson 1997, Bledsoe and Watson 2001). High proportions of impervious surface can lead to increased nutrient and sediment loading into streams (Harden 1992, Arnold and Gibbons 1996, Nelson and Booth 2002).

Water quality data was collected from the United States Geological Survey (USGS) Baldwin County permanent sampling sites from 1990 to date. The Geological Survey of Alabama (GSA, 2003) collected water quality data from the Fish River and Magnolia River between 1994 and 1998. GSA analyzed grab samples for Nitrates (NO3), Total Phosphorus (TP), Total Suspended Solids (TSS), ammonia and ammonium (NH3 plus NH4) and other chemical analysis.

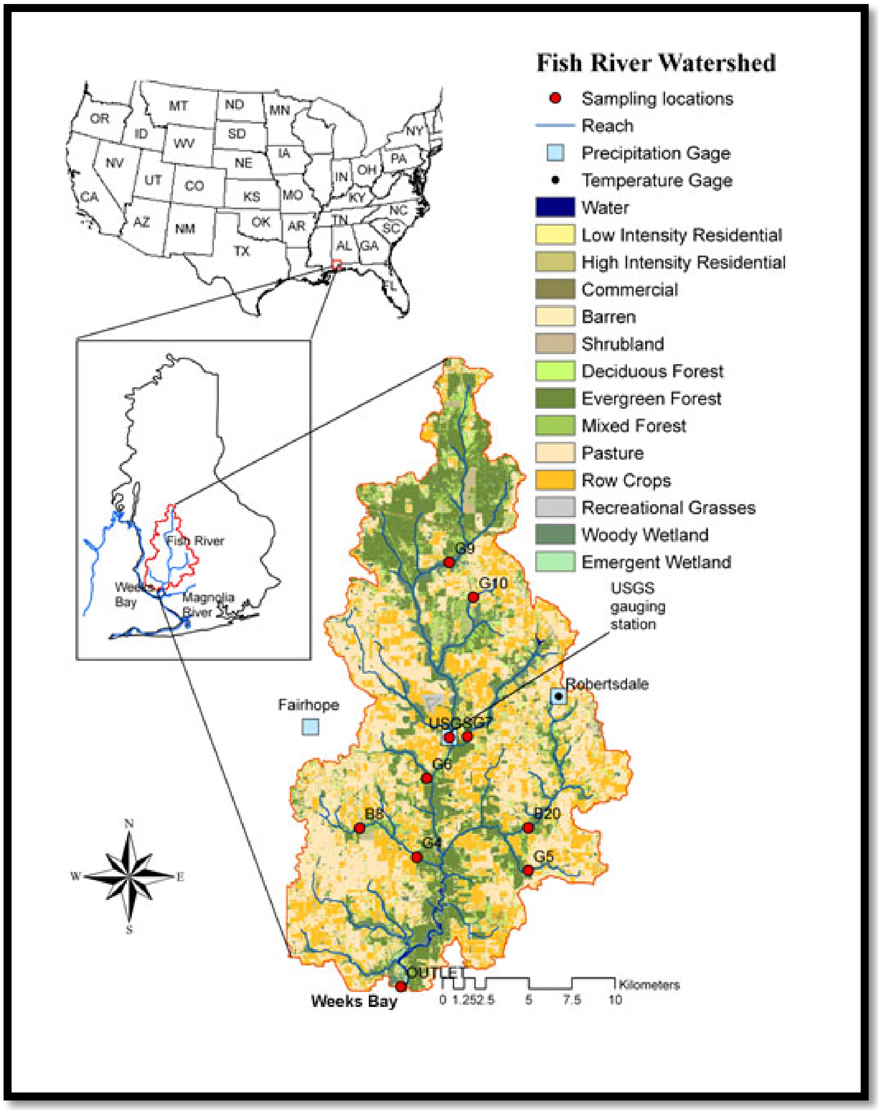

Figure 1. Location of the Fish River watershed with 1992 LULC distribution. Locations of precipitation and temperature gauges shown (Harsh Vardhan Singh).

Site locations were located throughout Fish River watershed and the adjacent Magnolia River watershed. Results showed that water quality is closely linked to physiographic and LULC characteristics. Prakash Basnyat (Basnyat, 1998) sampled the Fish River watershed from 1995 to 1996. NO_3 and TSS data were collected biweekly by grab sample. Basnyat was the first to observe that forested areas within the watershed acted as NO_3 sinks. He concluded that residential urban areas were responsible for majority of NO_3 and that agriculture areas were secondary contributors. Andrew Morrison (Morrison, 2011) conducted water quality sampling from 2008 to 2010. There was no specific sampling interval rather both grab and automatic sampling techniques were taken during stormflow and baseflow events. His data is used for model calibration in this study including post validation. Predictions by the model for 2008 and 2009 were compared with observed data.

The research of planning policy in Baldwin County shows a very traditional policy style including zoning, and large street subdivision regulations that promote infrastructure and impervious surfaces (Baldwin County, Alabama, 1996). No watershed information is given. Baldwin County is under the jurisdiction of water policy at the federal, state, county, and municipal levels. There are no watershed authorities. Urban land use policy is mandated at the county and municipal levels with municipalities have their own planning commissions. Small rural towns are under the jurisdiction of county planning commissions. All development must adhere to State of Alabama erosion and sediment control laws but due to tight economic conditions there are few enforcement officials. Land use and zoning policy show no incentives to promote sustainability. In 2010, Baldwin County initiated a new Comprehensive Plan (Baldwin County, Alabama, 2010) which promotes a more sustainable development but this plan does not support planning and development ordinances tied to designing BMPs to correspond to water quality analysis. An example of a BMP that removes pollutants is a rain garden or bioretention cell. LeBleu et al (2007) found significant removal of particulate phosphorus and total phosphorus elements were found under both conventional and internal water storage (IWS) rain garden types. Hydrologic effects measured included reduced outflow of hydrograph peaks and reduced total outflow volumes that would in turn reduce outflow pollutant load to receiving waters.

A model policy review revealed several examples of planning and development regulations in the United States support the selection of BMPs for development using water quality analysis and modeling. Permeable paving is often mentioned as such a BMP. A study conducted by Dougherty et al (2011) showed a 20 percent to 85 percent reduction in contaminants in leachate from rainwater and stormwater through pervious concrete compared to runoff from adjacent impervious concrete. The following model policies were selected for examination due to their BMP and water quality support: 1) The Cape Cod Commission, Cape Cod, Massachusetts (1999, 2000); 2) Model Stream Buffer Ordinance (Wenger and Fowler, 2000) and 3) Jordan Cove Urban Watershed Project in Waterford, Connecticut USA (Jordan Cove Urban Watershed Project, 2009).

4 METHODS

4.1 Water Sampling

Water quality and flow data were collected from October 2008 to March 2010 from ten sample sampling locations by Andrew Morrison, Auburn University Graduate Student. Each site had its own pressure transducer, and sampling visits were timed to capture both baseflow and stormflow events. Baseflow was measured during each site visit using a digital flow meter. Sampling consisted of grab samples and automated sampling. Grab samples were collected from all sites during each visit. Four sites were equipped with an automated water sampler that sampled up to 24 times over the duration of a storm to capture samples at the rising and falling of the storm event. Samples were analyzed separately and results combined to form one Event Mean Concentration (EMC). Samples were analyzed for NO_3, TP, TSS and NH_3 plus NH_4 by an outside lab in accordance to Standard Methods for the Examination of Water and Wastewater (1998).

4.2 SWAT Modeling

LULC data was collected from previous studies dating from 1990 to date. A SWAT analysis model was calibrated using 1992 LULC as a reference. The model was calibrated with water quality data from Basnyat and GSA to predict the following: 1) Flow from 1990 to 1998; 2) Sediment (TSS) for 1994 to 1998; and 3) Nutrients (NO3) and Organic Phosphorus (Org P) for 1994 to 1998. The model results were compared to the actual data collected by previous researchers. Post Validation of SWAT was used to predict water quality from October 2008 to January 2010 using 2008 LULC. Instantaneous observed data was converted into continuous monthly data using USGS's LOADEST software. Predictions by the model for 2008 and 2009 were compared with observed data.

4.3 Planning Policy

Current planning and design policy was investigated in Baldwin County, Alabama and three municipalities within the Fish River watershed: Daphne, AL (site 4), Fairhope, AL (site 4), and Foley, AL(site 6). Comprehensive Plans were reviewed with particular emphasis on zoning, Overlay Zoning, and Landscape Ordinance (Baldwin County, 1996). Policy was found to be basic and adequate with no emphasis on planning or designing for water quality. Developers and designers tend to choose BMPs that are traditional and typical, that is, BMPs they are familiar with. The majority of the stormwater and erosion laws in Alabama are mandated by the U.S. Environmental Protection Agency and enforced by state and local authorities (State of Alabama Soil and Water Conservation Committee, 2009). Enforcement is at the local level. County and municipalities agree that there is not enough manpower to consistently enforce the laws.

5 REFERENCES

5.1 Nitrate Trends

Nitrate trends over time showed a general decrease (Figure 2). Concentrations of NO_3 varied from site to site with the highest average and median concentrations at sites 7, B20, and 70 (USGS). These sites also discharged the highest amount of daily flow compared with other sites. NO_3 concentrations remained well below the minimum drinking water standards for human safety. Median concentration ranged between 0.3 to 1.2 mg per liter.

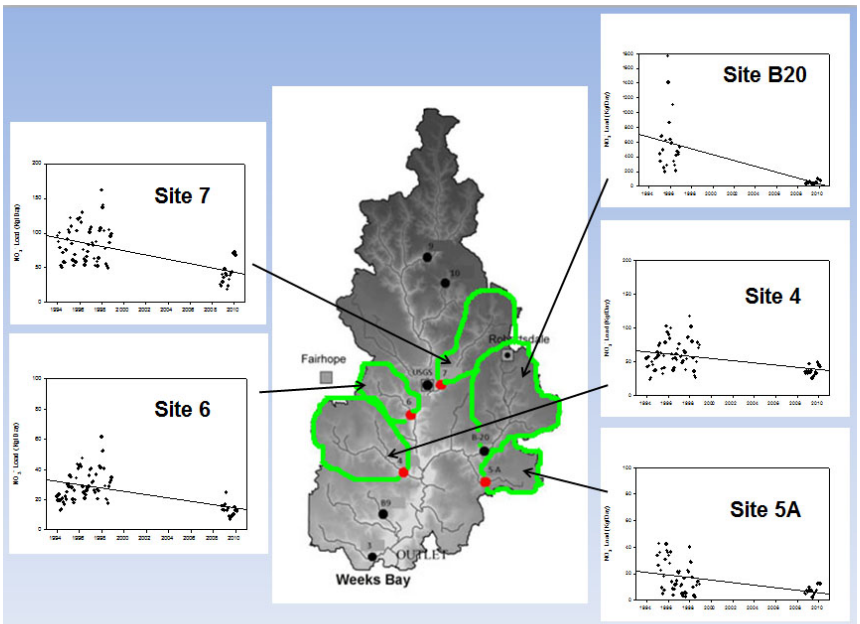

Figure 2. Nitrate (NH_3^-) trends over time showed a general decrease (Kalin et al. 2009).

5.2 Ammonia and Ammonium Trends

The average and median concentrations for NH3 plus NH4 remained relatively low for all sites (less than 0.1 mg per liter). High concentrations did occur at site 7 and 6. Both these samples were collected during separate storm events. Other samples during the same storms showed highly variable concentrations of NH3 and NH4. It was observed that conditions during storm events can be highly variable with occasional pockets of high concentrations within the water column.

5.3 Total Suspended Solids Trends

Spatial comparisons between sub-watersheds showed that sites with large increases in urbanized land uses have substantially higher TSS (Figure 3). However, concentrations of TSS were relatively low for most of our sites, with the exception of site 4. Median concentrations at site 4 equaled 66 to 122 mg per liter respectively with other sites typically less than 15 mg per liter. Site 4 sub-watershed has highest urbanized area of all sites (36 percent).

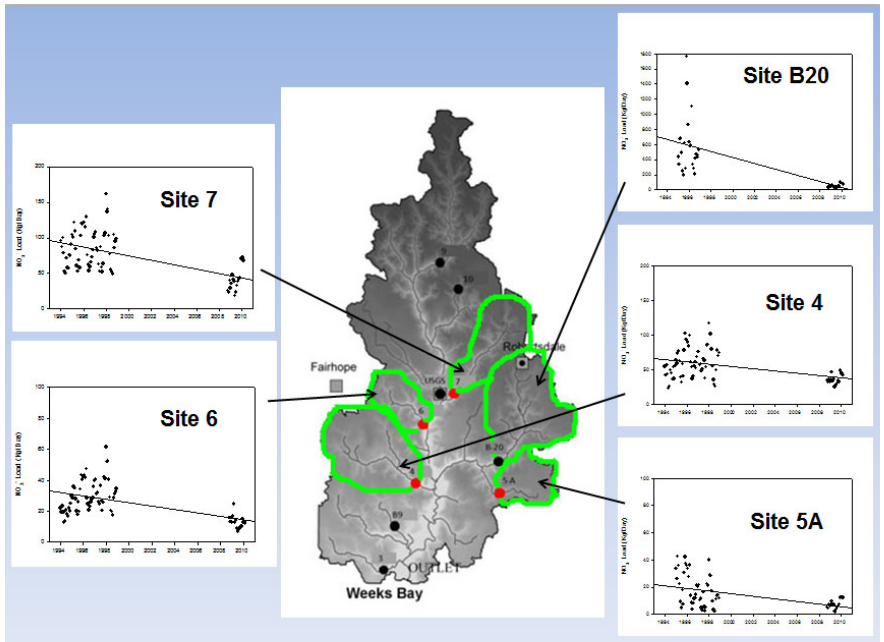

Figure 3. TSS loading results show mostly decreasing trends with the exception of site 4 which has a significant increase in load over time due to urbanization (Kalin et al. 2009).

5.4 Total Phosphorus Trends

Total Phosphorus (TP) increased significantly (Figure 4). Concentrations of TP were found to be relatively similar throughout the watershed and were typically higher than nitrate levels. Median concentrations ranged between 0.5 to 1.0 mg per liter for all sites. Highest TP values were found at sites 10 and 5A. Maximum concentrations of over 3 mg per liter were found at site 5A and are likely due to high amounts of agricultural land upstream.

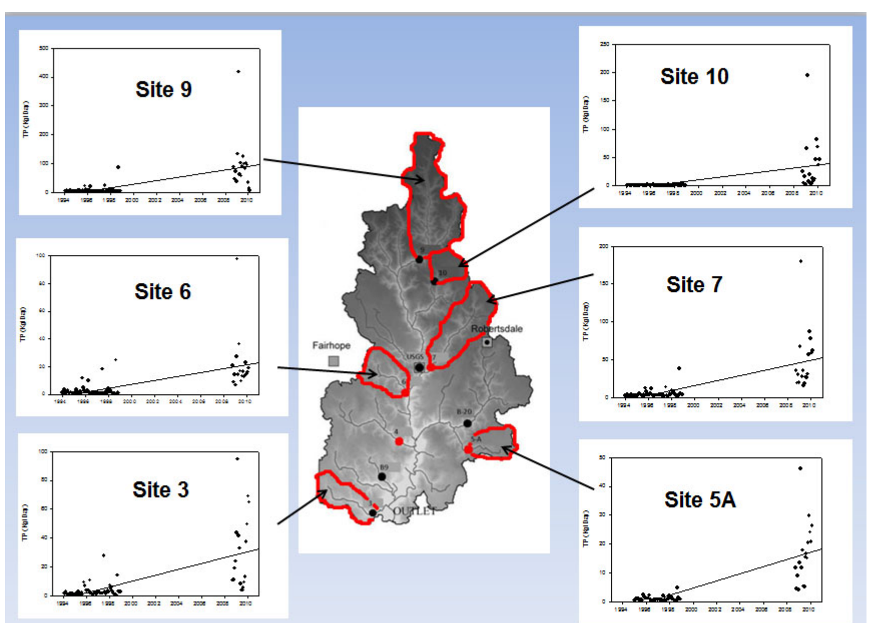

Figure 4. Total Phosphorus (TP) increased significantly (Kalin et al. 2009).

5.5 Land Use/ Land Cover Change from 1992 to 2008

Landscape analysis revealed significant urbanization between 1992 and 2008 (Figure 5). Water quality data and LULC data from Basnyat (Basnyat, 1998) and GSA (GSA, 2003) were used to calibrate the SWAT model for: 1) Flow Calibration verses Flow Validation; 2) Sediment calibration verses Sediment validation; 3) Nitrate calibration verses Nitrate validation; and 4) Organic P calibration verses Organic P validation. Post-Validation of the SWAT model from 2008 to 2009 was performed by calibrating parameters using 1992 LULC and transferring it to the model with 2008 LULC. Instantaneous observed data was converted into continuous monthly data using United States Geological Survey LOADEST software (USGS, 2011). Water quality data collected from October 2008 to January 2010 was compared with model simulations.

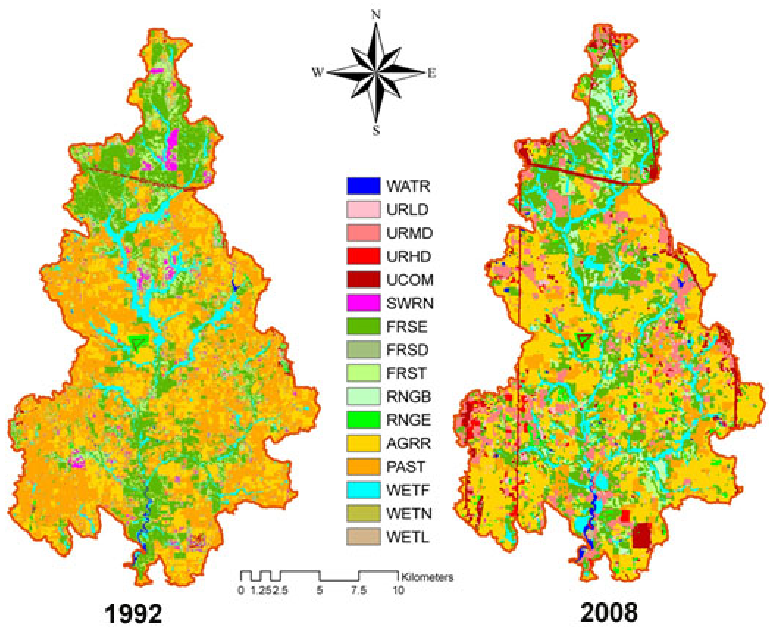

Figure 5. Land use change 1992 to 2008 (Kalin et al. 2009).

5.6 Planning Workshop

A planning and development workshop was held to educate Baldwin County planners, engineers and other professionals and government officials on the benefits of using water quality analysis and SWAT watershed modeling in long-range planning initiatives within the Fish River Watershed. The workshop also showed how SWAT could be used to inform Low Impact Development (LID) as a development method to increase water quality. The workshop was held in September 2010 in Fairhope, Alabama. Thirty Landscape Architects, Planners, Arborists, Civil Engineers, and Forest Hydrologists attended.

The transdisciplinary workshop included presentations on: 1) the state of the Fish River Watershed, water quality data and SWATS watershed modeling; 2) an overview on model planning policy (The Cape Cod Commission) and 3) LID model policy and design, and economic benefits of protecting trees during development (Model Stream Buffer Ordinance and Jordan Cove Urban Watershed Project in Waterford, Connecticut USA). A hands-on LID planning and design charrette followed. The charrette focused on a site in Baldwin County and emphasized the current ordinance constraints of using LID techniques in Baldwin County and the need for policy change. Design time was also used to show how LID Best Management Practices, especially permeable paving, might offer improvement to specific water quality problems. Examples of model policies that support LID and the selection of design BMPs based on water quality analysis at the site scale were discussed.

Survey results from the workshop and charrette concluded that the event was a success. Thirty percent of the attending group was from the Fish River Watershed area including Baldwin County Planners, City of Daphne Planners (site 6), City of Foley Planners (site 4) and City of Fairhope Planners (site 4). Several comments identified how important it was to not only learn about the watershed modeling information, but also learn how to communicate the information to developers and stakeholders.

6 MODEL PLANNING POLICY REVIEW

6.1 The Cape Cod Commission, Cape Cod, Massachusetts (1999, 2000)

The purpose of the Cape Cod Commission is to protect ground water and surface water; identify allowable uses in sensitive areas, comply with and compliment state and federal regulations; and protect sensitive resources. Strategies that have made this a model plan include: use regulations; performance standards; overlay districts; and LID subdivision design with Best Management Practices. Use restrictions cited within the document include: certain industrial uses; transportation infrastructure (airports, bus stations, etc.); outlets for floor drains; removal of native soil; activities that withdraw large volumes of water; disposal of waste and construction material, and some special use restrictions including large subdivisions with large impervious surface build outs.

6.2 Model Stream Buffer Ordinance (Wenger and Fowler, 2000)

The Model Stream Buffer Ordinance was written with the intent to reduce erosion and sediment; trap and remove P, N, and other contaminants; and protect wildlife habitat. The ordinance supports vegetative buffers along streams, rivers and other water bodies that reduce stream side erosion and support wildlife habitat. The width, extent and density of buffer are determined by the adjacent land use. Buffers along streams adjacent to residential properties are less dense than those along commercial properties. Each land use also list a set of prohibited activities such as fencing out cattle in agricultural use. Tools that give regulatory protection include overlay zones, freestanding ordinances, and floodplain ordinances. Non-regulatory protection includes transferable development rights, density transfers, conservation easements and acquisition. Clear communication of restrictions is vital to the success of ordinance.

6.3 Jordan Cove Urban Watershed Project in Waterford, Connecticut USA (Jordan Cove Urban Watershed Project, 2009)

The Jordan Cove community project in the Glen Brook subdivision of Storrs, CT is funded in part by the Connecticut Department of Environmental Protection (CT DEP) under the United States Environmental Protection Agency (US EPA) Section 319 Clean Water Act grant program. This model subdivision supports a ten year monitoring project that is a paired watershed study with part of the Glen Brook subdivision being developed using a traditional lot style and typical construction practices, while the other part was developed using a LID approach. BMP design practices included shared pervious driveways and a reduced width access road. The permeable driveways and roads in this unique subdivision contribute to the watershed's water quality objectives by reducing nitrogen, bacteria and phosphorus export from the site, maintaining the predevelopment peak runoff rate and volume, and maintaining predevelopment suspended sediment loads.

7 DISSCUSSION

This study supports the hypothesis that LULC is linked to water quality. Linkages were determined using multi-linear regressions between LULC and water quality data. Concentrations of NO3 for baseflow periods showed significant positive relationship to moderate density and high density residential areas. Forest areas continue to act as a nitrate sink as previously reported by Basnyat, 1998. Concentrations of NH3 plus NH4 were positively linked to pasture and grassland areas during stormflow. Results for TSS stormflow showed positive relationships for agriculture, pasture and grassland, forest, and high density residential areas. Baseflow TP results showed a positive relationship between agriculture and moderate density residential areas and a negative relationship to forested wetlands. Stormflow TP concentrations showed positive relationships to agriculture, pasture and grassland, forest, and high density landscapes.

The SWAT model performed well for water quality during calibration validation (1994 to 1998) and prediction periods (2008 to 2009) at most sampling sites. Model performance was best for flow and weakest for NO3. Model simulations systematically underestimated TSS loadings at various sites during extreme events.

8 CONCLUSION

Automated sampling over time during storm events can provide a better water quality snapshot than occasional grab samples. However, automated sampling does produce an increased cost and workload. Changes in urban LULC have dramatically increased since 1995 and urbanization can be linked to increases in TSS and NO3 particularly due to the loss of grasslands and wetlands. Sub-watersheds with mixed LULCs require use of multilinear regression analysis to determine interactions. Flow was not statistically different between study periods for most sites. Nitrate loads typically decreased between study periods. The load of TP increased dramatically between study periods. A shift in the N to P relationship over time is thought to have come from the introduction of peanuts as a new crop to the watershed. Nitrate concentrations are highest in watershed with a large percentage of agriculture and urban LULC. Forest areas continue to act as a nitrate sinks, but development is encroaching on this natural resource. Concentrations of TP were typically higher than nitrate levels at most sites, and the highest concentrations of TP found in sub-watersheds with high agricultural land use. Also, the seasonality of water quality and flow can play an important role in selection and awareness of BMPs sizing and can help mitigate and reduce runoff during large storms in urban areas.

The SWAT model performed poorer with the 1992 LULC data in simulation water quality than with 2009 as expected. These findings underline the importance of using the most accurate and up to date LULC data in modeling. This study raises the credibility of the SWAT model as a dependable watershed tool for predicting the changes in water quantity and quality due to LULC changes. Water quality monitoring and modeling are effective tools to inform policy and design in sensitive watersheds. Modeling can be used as a support and validation tool for future watershed scenarios.

Support is need for land use and development policy change especially in sensitive coastal watersheds. Planners, designers and government officials participating in this study have begun to embrace model planning policies that support the selection of BMPs that correlate with water quality analysis resulting in new ordinances that support the use of BMP's that addresses the needed pollutant removal efficiencies. Civic leaders, developers, engineers, planners, and architects, all need to be educated about water quality analysis, BMP pollutant removal properties, and the use of SWAT as a watershed planning tool.

8.1 Further Study

The results from this modeling study will be used to develope a template of design scenarios to be used as examples on how to use the SWAT model results to implement water quality senesitve design in the Fish River watershed.

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