Use of an Agricultural Non-Point Source pollution model to assess impacts of development and management practices [sic] in an urban watershed

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USE OF AN AGRICULTURAL NON-POINT SOURCE POLLUTION MODEL TO ASSESS IMPACTS OF DEVELOPMENT AND MANAGEMENT PRACTICES IN AN URBAN WATERSHED

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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requirements for the degree of
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in

The Department of Environmental Studies

by
John A. Cross
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List of Acronyms

AAO, AAOs..................................................Average Annual Outputs
AGNPS..................................................AGricultural Non-Point Source Pollution Model
AnnAGNPS........................................The continuous version of the AGNPS model
AOI........................................................Areas of Interest
BMP, BMPs.............................................Best Management Practices
BSW........................................................Bluebonnet Swamp Watershed
BSUW....................................................Bluebonnet Swamp Urban Wetland
CWA....................................................Clean Water Act of 1972
DEM........................................................Digital Elevation Model
EIA..........................................................Effective impervious Area
EBRP.....................................................East Baton Rouge Parish, Louisiana
LID, LIDs...............................................Low Impact Development
LDEQ...........................................Louisiana Department of Environmental Quality
LPDES........................................Louisiana Pollution Discharge Elimination System
NPDES........................................National Pollution Discharge Elimination System
NPS........................................................Non-Point Source
SSWM...................................................Surface and Storm Water Management
STATSGO............................................State Soils Geographic Database
SWMP...............................................Storm Water Management Plan
TIA..........................................................Total Impervious Area
TMDL, TMDLs.......................................Total Maximum Daily Load
TOPAZ...........................................TOpographic PArameteriZation model
WQA.....................................................Water Quality Act of 1987
Abstract

A Geographical Information System (GIS) linked to a Non-Point Source (NPS) model are being used to predict the effectiveness of storm water management strategies and examine the impact of proposed land use changes on Total Maximum Daily Load (TMDL) attainment. This study tests a methodology for analyzing land use changes and management using GIS analyses of impervious surfaces and Agricultural Non-Point Source (AGNPS) pollution modeling in an approximate 1100 acre urban watershed located in East Baton Rouge Parish (EBRP), Louisiana. The GIS analyses of Total Impervious Area (TIA) quantified increases in urbanization and provided land use data utilized in AGNPS modeling in a small urban watershed which also included a natural swamp park. AGNPS modeling was executed in several different scenarios to predict changes in NPS loadings associated with increases in TIA, its subsequent management and Digital Elevation Model (DEM) grid cell size. Data was processed and edited using ArcView (3.2) and GeoMedia (6) GIS systems. The test watershed underwent significant urbanization in the 8 years between 1996 and 2004, causing an increase in quantity and decrease in quality of subsequent runoff, and these created measurable impacts in the swamp park. Predictions of sediment, erosion and runoff were compared for each scenario year. Management practices were also simulated. TIA increased by 8.47 % from 1996 to 2004 and pavement counted for the greatest increase. Differences in Average Annual Outputs (AAOs) for 5m and 25m DEMs varied greatly with 5m simulations providing less in sediment erosion, load, yield, and runoff. The differences in simulations based on TIA assignment in 5m also varied from those based on TIA. Changes in AAOs based on the increase in TIA and the implementation of permeable
pavements resulted in a maximum reduction of 43%, 8%, 3% and a 1% reduction in erosion yield, runoff, load and erosion respectively. Urbanization of the BSW is still continuing today and now has even greater imperviousness. The proposed methodology might be adopted by planners and managers to forecast water quality and storm water management implications of proposed projects on downstream TMDL attainment.
1. Introduction

Urbanization changes the natural watershed, landscape and functioning through the addition of impervious surfaces, hydrologic alterations, and changes to natural vegetation and soils. It imposes requirements on planners and managers to manage storm water runoff because, as research shows, urbanization increases the quantity and decrease the quality of runoff entering receiving streams. These impacts are consequences of reducing infiltration and the ability of the landscapes to assimilate pollutants. This shift from a natural state to an urbanized one provides the basis for environmental degradation to habitat, rivers, lakes, streams and watersheds.

Conventional development increases impervious surfaces in the form of rooftops, roads, driveways, parking lots, and sidewalks. Construction activities usually focus on a ‘clear a fill’ approach which results the removal of native plants, soils and natural hydrologic functions of the landscape. Its footprint goes beyond these tangible changes to the natural landscape because it impacts downstream rivers lakes and habitat. Impervious surfaces have significant impacts on water quality and quantity by blocking infiltration and native soils’ function as a sink for minimal rainfall events. They also increase the speed at which runoff leaves the landscape and enters streams and rivers, lessoning opportunity for evapotranspiration. This results in larger peak flows and lessons the time for water levels to rise in localized urban streams (Walker 2002). The increased surface flow results in water quality problems by displacing and transporting sediments and other contaminants into adjacent water bodies (Dunne and Leopold 1978, Arnold and Gibbons 1996).
East Baton Rouge Parish (EBRP), Louisiana has undergone significant urbanization in the southern third of the parish which has impacted water quality in Bayou Manchac and the Amite River. These two waterbodies serve as boundaries for EBRP and the Louisiana Department of Environmental Quality (LDEQ) has found Bayou Manchac and portions of the Amite River to be impaired. They are listed on the Clean Water Act 303 (d) as requiring remediation. Excessive sediment and organic matter input are included in the types of pollutants and are known to increase biological oxygen demand in the receiving streams. This reduces their ability to support natural fish populations (LDEQ 2006). During the summer months, inputs of fertilizer nutrients such as nitrogen and phosphorous can intensify oxygen demand because the streams are at their lowest discharge rate. This stimulates the growth and decomposition of aquatic algae or eutrophification. Total Maximum Daily Load (TMDL) studies by the LDEQ in watersheds throughout the state of Louisiana have found that water quality goals cannot be attained until there is a decrease in NPS pollution already present. These studies have also found that the most effective target is storm water runoff.

The Louisiana Pollutant Discharge Elimination System (LPDES) Water Discharge Permit LAS000101 for the City/Parish of East Baton Rouge and others was approved by the LDEQ on November 19, 2004. It says that any permittee shall contribute to a comprehensive Storm Water Management Plan (SWMP). This includes pollution prevention measures, abatement and removal of pollutants, storm water monitoring, use of legal power, and other suitable proceedings to control the quality of runoff discharged from municipal storm water systems. As stated by the LDEQ (2004):

“The permittee must document in its SWMP how the Best Management Practices (BMPs) and other controls implemented in its
SWMP will control the discharge of any pollutant(s) of concern for discharges into a receiving water which has been listed on the Clean Water Act 303(d) list of impaired waters. If a TMDL has been approved for a waterbody, the permittee will be required to describe how its SWMP is consistent with any TMDL requirements applicable to MS4 discharges into basin subsegments where TMDLs have been established. If municipal runoff, municipal storm water, urban storm water runoff, or urban nonpoint discharges are listed as suspected causes of impairment to any basin subsegment number that receives storm water runoff from the regulated area, and that basin subsegment number is listed on the most recent EPA-approved 303(d) list, and a TMDL allocation has been assigned for pollutants from those sources, then the permittee will be required to modify its SWMP to implement the TMDL within six months of the TMDL’s approval, or as otherwise specified in the TMDL. If a TMDL has not yet been approved for basin subsegment numbers that are listed on the most recent EPA-approved 303(d) list, the permittee will be required to describe how the BMPs and other control(s) selected for its SWMP will minimize the discharge of all suspected causes of impairment” (LDEQ 2004, p. 1 of Part II).

Several other environmental laws call for the implementation and monitoring of BMPs in every state. Namely, the Clean Water Act (CWA) of 1972 which requires the establishment of effective BMPs to control non-point source pollution. The 1987 Water Quality Act (WQA) adds to the demands by requiring a National Pollutant Discharge Elimination System (NPDES) permit program and establishes TMDLs which quantify the assimilation capacity water bodies (EPA 2002). BMPs can be very diverse in their implementation and consist of both structural and non structural. A structural BMP is regarded as implementation of management technologies such as sediment fences or large vegetated open ditches, but they can also include non-structural practices such as good maintenance.

There has also been a significant trend in storm water management technologies such as Low Impact Development (LID) in mitigating Non-Point Source (NPS) pollution at its source. This type of development conflicts with conventional development because
LID focuses on mitigating and retaining runoff onsite by the utilization of water gardens, green roofs, rain storage, and other technologies. Most of these innovations center on retaining runoff within the landscape to mimic the behavior of natural hydrologic conditions. However, there is also a significant increase in state and local governments storing rainwater for flushing toilets, irrigation and the minimization of Total Impervious Area (TIA). TIA is the fraction of the watershed covered by constructed and non-pervious surfaces such as concrete, asphalt, houses and buildings (Booth and Jackson 1997).

LID has been implemented mainly in the Pacific Northwest and is responsible for some salmon population recoveries in Puget Sound. Although different in climatic and hydrologic conditions, it has a history of success and should be applied in south Louisiana. LID, in contrast to conventional development, protects native vegetation, soils, and minimizes storm water at the source (Puget Sound Action Team 2003). A main focus in LID implementation is that any new development occurs with minimal or no disturbance to runoff. LID uses landscapes and management strategies to treat runoff water at the source, rather than promoting efficient removal found in conventional development. Conventional development results in very little infiltration into the landscape and few conventional storm water management plans promote this infiltration (Arnold and Gibbons 1996).

The lack of infiltration accelerates erosion capabilities of storm water runoff, which destroys private property and impairs the ecological health of watersheds. Quantity and quality of storm water runoff also has a profound influence on downstream surface waters causing stream bank erosion, fish kills, backflow and flooding. These
impacts make TMDL attainment with new development impossible without first intensifying storm water management. There is great potential however for groundwater recharge through proper stormwater management. Water resource managers can use infiltration basins, vegetative management, runoff impediment, and/or lowering the groundwater level in the flood plain (Bouner 1987). Planning and management of watersheds uses LID and BMPs to minimize these impacts and others caused by urbanization (Puget Sound Action Team 2003) (EPA 2002).

Implementing management and development strategies is very costly, therefore planners and managers should utilize Geographical Information System (GIS) NPS linked modeling to predict impacts on TMDL attainment. Researching, analyzing, modeling urbanization characteristics and land use change will provide planners with better information in making decisions pertaining to protecting watersheds and TMDL attainment.

Development of suburban and urban areas within the Bluebonnet Swamp Watershed (BSW) located within East Baton Rouge Parish (EBRP), Louisiana between the years of 1996 and 2004 (figure 1) has resulted in an increase in impervious surfaces, soil modifications and alterations to natural hydrology of the landscape. The impacts to water quality and quantity in the BSW and the Bluebonnet Swamp Urban Wetland (BSUW) have resulted in morphological changes to the BSUW and contributions to the impairment Bayou Manchac and Amite River. Storm water management is a critical element at minimizing environmental problems caused by the increases in urbanization, but proper implementation and policy are difficult and expensive. Therefore, the AGNPS model was chosen because it offers opportunity to simulate management and land use
change’s influence on runoff, sediment loadings, sediment yield, and erosion at the field and watershed level. It also provides a tool to relate water quality with the landscape, its management and TMDL attainment.

This study evaluates how changes from 1996 through 2004 and a management practice impact storm water runoff quantity and quality in the BSW. It provides valuable information when assessing the impacts to TMDLs from urbanization or management. It develops a protocol for assessing these impacts and applies a potential management practice through modeling. This study also evaluates the AGricultural Non-Point Source (AGNPS) model’s sensitivity to Digital Elevation Model (DEM) grid size and how TIA is assigned within the model.

These tasks are completed by a review of relevant literature, GIS analyses of TIA and AGNPS modeling to interpret urbanization and the hypothetical implementation of a management practice. The BSW study is a portion of Mitigating Non-Point Source Pollution in Urban Watersheds with Spatial Modeling, Best Management Practices for Wetlands and Community Outreach prepared for the East Baton Rouge City-Parish Planning Commission.

1.1 Description of Study Area

Within East Baton Rouge Parish, Louisiana, USA, the Bluebonnet Swamp acts as a localized best management practice (BMP) to mitigate storm water runoff. Increased development in this area and the storm water management associated with it may have an impact on the receiving urban wetland. The Bluebonnet Swamp Watershed (BSW) underwent significant urbanization in the 8 years between 1996 and 2004, causing an increase in quantity and decrease in quality of subsequent runoff, and these created
measurable impacts in the swamp park. The test watershed is an estimated 1100 acres and varies with different amounts to Total Impervious Area (TIA)

Figure 1. The Bluebonnet Swamp Watershed (BSW)

TIA in the BSW was divided into several categories. These included buildings, houses, driveways, parking lots, sidewalks, streets, and an ‘other’ category. The ‘other’ includes features such as basketball, tennis courts, and other categorically excluded features. It relates to a very small percentage of all TIA data.

Figure 1 contains the previously delineated BSW from Mitigating Non-Point Source Pollution in Urban Watersheds with Spatial Modeling, Best Management Practices for Wetlands and Community Outreach and the 1996 and 2004 BSW aerial photography. Image year served as the reference for assessing changes within the
watershed while the initial artificially delineated watershed served as a primary boundary to minimize extraneous data.

This information, site visitations and inspections provided a rationale of:

- The BSW is very unique because of the featured urban wetland and increases in development between 1996 and 2004.
- Increased levels of imperviousness and construction have had unfavorable impacts on runoff and sediment loadings entering the Bluebonnet Swamp.
- Questions arise about locating the critical sources of morphological change to the swamp and implementation of management strategies to minimize these impacts.

Figure 2. Feldspar samples in the Bluebonnet Swamp. Showing the accumulation of sediment accruing from increases in urbanization.
Urbanization in the BSW has had impacts on runoff and sediment loadings. Parts of the Bluebonnet Swamp have been filled and developed for residential and commercial uses and management for new developments has not been uniform. Urbanization present during and before 1996 has varied in storm water management practices and impervious surface quantities. Accumulation of sediment within the Bluebonnet Swamp is also evident in core samples (figure 2) taken in locations in the northern and southern portions of the swamp. It is also evident for the early stages of channel formation and presence of invasive grasses in the Bluebonnet Swamp (figure 4).

Figure 3. Recently filled and unstable channel through residential portions of eastern Bluebonnet Swamp Watershed (BSW).

Site visitations have also lead to discoveries of unstable surface water drainage, leading to sever erosion and subsequent high yield and high load in localized areas (figure 3 and 4). Observations of filled wetlands leading to higher elevations for residential and commercial development have directly changed the hydrological and
biological function of the Bluebonnet Swamp. This has resulted in a much faster time to rise within drainage networks as shown by Walker (2002) and relatively high flow rates though the swamp during storm duration (Kemp 2007).

Figure 4. Early stage channel formation in Bluebonnet Swamp. Showing sediments eroded from adjacent developments deposited to form low banks that are colonized by grasses along the main route of flow.

This test watershed provides significant opportunity for urban and environmental planners to understand how urbanization and management affect non-point source pollution. AGNPS NPS pollution modeling in the BSW can lead to better land use decisions by spatially illustrating impacts over time. It also isolates areas of concern which can be targeted by planners and managers with advanced management and policy to minimize impacts of suburban or urban development regarding TMDL attainment.

This study tests methodologies for assessing impacts which urbanization has on runoff characteristics by linking together a GIS analysis of TIA and Non-Point Source NPS modeling. The GIS analyses relate to the AGricultural Non-Point Source (AGNPS)
model in two unique ways. The analyses provide techniques to measure changes in land use and landscape feature data over time. BSW TIA also serves as reference for the editing of ‘fields’ data within AGNPS model.

Increases in sediment within the Bluebonnet Swamp can be directly linked to increases in urbanization and development in its watershed (figures 3 and 4). BSW TIA is utilized to decrease amounts of non permeable pavement and hypothetically replace such amounts with permeable systems. Booth & Leavitt 1999 provided a premise for the implementation of these systems (figure 5).

![Figure 5. Comparison of asphalt (impermeable) and Turfstone (pervious) runoff. Modified from Booth & Leavitt (1999)](image)

The authors’ conclude that the permeable pavement systems tested resulted in virtually no surface runoff and storm water became a majority subsurface concern (Booth & Leavitt 1999). Although based in the Pacific Northwest, the field evaluation does
provide a relevant basis for how these systems could perform in EBRP. Actual
performance of these systems in EBRP could be researched for further and more precise
implementation but performance data was not available for this study.

This study hypothesizes that implementation of permeable pavement systems in
new developments which occurred between 1996 and 2004 will lead to a decrease of
sediment, yield, load and erosion rates within the BSW. Given the four outputs of
sediment load, yield, erosion and runoff, successful implementation of permeable
pavement must show sensitivity in at least 1 total watershed Average Annual Output
(AAO) of AGNPS. Changing DEM grid cell size from a 25m to 5m will not result in
significant differences in predictions. Predicted outputs will be sensitive to TIA
calculation per sub-basin versus TIA assigned by majority rule from a digitized land use
map.
2. Literature Review

2.1 Hydrology in the Natural Landscape

Streams in the natural landscape are in a slow yet constant state of change and water managers try to control this state of change throughout the course of development. Understanding the principles and functions behind river and stream change can be understood by calculating flow regime (quantity minimum, maximum and mean). Mount (1995) explains that the Manning and Chezy equations, used to calculate flow, both rely on two forces. These forces are driving force, which is equal to the total weight of the water multiplied by the sine of the bed slope, and the resistance force, which is equal to the total bed area exposed to flow multiplied by the bed shear stress (Mount, 1995, p.20) or:

\[
V = \frac{1}{n} R^\frac{2}{n} \cdot S^\frac{1}{2}
\]

Where:
- \(V\) = mean velocity in fps
- \(R\) = hydrologic radius in feet
- \(S\) = the slope of the energy line
- \(N\) = coefficient of roughness

The benefits of channel maintenance flows or the appropriate natural flow for any river, stream or creek are that they provide clean drinking water, irrigation, and environmental benefits (Schmidt and Potyondy, 2004). These benefits include transporting water and erosion products without aggradation or degradation, temporarily storing flood flows on the floodplain, maintaining the energy dissipation of the stream, maintaining the ability to avoid flooding, sustaining aquatic ecosystems, providing sources of water, and providing recreational use. Healthy riparian areas are important to maintain because they provide stream bank support, reduce erosion, stabilize sediments,
recharge groundwater systems, sustain low flows, act as safety zones, provide pools and bars, and provide shade to aquatic life.

Mount (1995) points out that runoff characteristics are connected to precipitation, physiography, orientation, vegetation, soils, and geology of the particular watershed. Infiltration, in turn, is linked to soil saturation. When soils are saturated, additional rainfall will lead to a shortened “lag time” and an increased peak discharges. Downs and Priestnall (1999) suggest that the differences between hydrological and geomorphological approach, when studying the natural landscape, is that the hydrological approach is mainly focused on flow and the geomorphological approach is mainly focused on channel perimeter.

The sediment and contaminant loads’ behavior in a watershed can be explained through modeling techniques. Luzio, Srinivivasan, & Arnold (2004) note that models such as the Soil and Water Assessment Tool (SWAT) combined with ArcView or GIS systems can provide researchers with a vital understanding of contaminant loads and hydrologic processes. Sherif, Singh, and Al-Rashed (2003) explain that, when considering rainfall and storm duration periods, the Dynamic Watershed Simulation Model (DWSM) can be used to model water management options. Sediment and contaminant loads are potential discharges of the natural landscape. Research into discharges and the related hydrologic functions in the environment categorizes the “discharge profile” into three main parts. These parts are the surface runoff, the interflow and the groundwater component (Hellmann 1987). These processes are interrelated in the hydrological processes of a landscape.
Arnold and Gibbons (1996) note that conventional storm water management plans disrupt the natural hydrologic functions of ground water and stream flow. Their research focuses on the disconnect that conventional storm water management practices have with groundwater recharge and the exchange between surface water and groundwater. The potential for groundwater recharge through proper stormwater management is currently the predominant trend in water management. Bouner (1987) says that there are artificial means that water resource managers can use in enhancing groundwater recharge. These techniques include infiltration basins, vegetative management, runoff inducement, and/or lowering the groundwater level in the flood plain.

Groundwater recharge, the rate, and the quality of the water received are directly dependant on the soil properties of the site in question. The National Research Council (1994) considers that soils with irregular pore space are more efficient at removing contaminants from infiltrating water and soils with larger pore spaces are less efficient at contaminant removal.

2.2 Urban Hydrology

Runoff occurs when the infiltration rate of soils is exceeded by the rainfall rate. Increases in imperviousness from urbanization increases runoff quantity and lowers the infiltration rate. Runoff quantity is determined by subtracting infiltration and interception from the total amount of rainfall (Wolfe, 2001). Wolfe (2001) provides the formula for calculating runoff volume as:

\[ Q = \frac{(P-0.2S)^2}{P+0.8s} \]
“where $Q$ is the direct storm runoff volume (mm), $P$ is the storm rainfall depth (mm), and $S$ is the maximum potential difference between rainfall and runoff starting at the time the storm begins” (Wolfe, 2001, p. 7).

As noted by the United States Environmental Protection Agency (2003), storm water runoff from urban areas has two main components. These components are that the increased impervious surfaces from urbanization increase the quantity and velocity of the subsequent runoff. This velocity and quantity increase has a direct relationship with the quality of the runoff given its erosive nature. Arnold and Gibbons (1996) agree that the increases in impervious surfaces, which come with conventional urbanization, cause significant increases in runoff quantity and decreases in quality. They note that even a “slight twist” in parking lot design may result in increased water quality of the subsequent runoff and decreased quantities.

### 2.3 Urban Non-Point Source Pollution

Non-Point Source (NPS) pollution results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification (EPA 1993). It can be considered all land flow which is not a “point source”. Although the definition is not yet clear, its minimization should be the focus of any land use planning because it is such a pressing issue. Troeh, Hobbs, and Donahue (1999) explain that water pollutants belong to one of four categories, which include heavy metals, heat, organic pollutants, and sediment. Sediment is a rather worrisome pollutant because the amount contained in United States Rivers are 700 times that of the amount of sewage and sediment has several contaminants attached to it, such as microbes, pesticides, plant nutrients, and other polluting chemicals. The chemicals contained in sediment can linger for years, giving off
minute concentrations over time. Heat, on the other hand, is a worrisome pollutant because increases will have a positive correlation with oxygen content decline. Common heavy metals as water pollutants include: zinc, lead, manganese, cadmium, chromium, copper, mercury, selenium, silver, and arsenic. Organic pollutants are natural and biodegradable and include sewage, manure, and petroleum products. These nutrients can cause large outbreaks of algae blooms and the decomposition of the algal mass causes a decrease in available oxygen through a process called eutrophication (Troeh, Hobbs, and Donahue, 1999).

According to the USGS (2001), point sources of pollution are only responsible for an estimated 6% of nutrient inputs into the streams and rivers of the Lower Tennessee River Basin. The other 94% are attributed to non-point source pollution, which can largely be associated with improper watershed management. Water pollution is an ongoing problem, often resulting from urbanization.

According to the EPA (1993), riparian buffer zones can be very effective at removing non-point source pollution from storm water, but if abused these systems can be destroyed. These areas may be effective at removing several containments and if these systems are damaged they should be restored to maintain their non-point source pollution assimilation capacity.

Walker (2002) found relationships between land use, land cover data and the time it takes for receiving drainage systems to rise as runoff occurs. A study within East Baton Rouge Parish found that the density of residential sites and the percentage of residential land uses both showed strong relationships with time to rise. It also showed strong relationships with commercial and residential development as increases in both
types of development will significantly decrease the time to rise in urban streams (Walker 2002).

2.4 Land Use Regulation

McCuen (2003) says that land use planning must begin at the micro watershed level and that planning such as this may reduce the need for pipes and stream ponds. Smart growth manages stormwater at the source not at the end of pipe. Smart growth, in this logic, is in agreement with LID because it focuses growth at the city center and results in more developable lots which prevents urban sprawl. These storm water management technologies to some degree also adhere to the same philosophy of treatment at the source not at the end of pipe (O’Brien and Company, 1999) and (The Puget Sound Action Team, 2003).

Berke, MacDonald, White, et al. (2003) demonstrate that “new urbanism” will decrease the environmental impacts that development has on its watershed through planning which requires less impervious surfaces. Planning alternatives like shortening the parking space length, as illustrated by Rushton (2001), can have significant improvements in environmental quality without sacrificing parking space. This is because the front end of automobiles can hang off the front of the parking space over grassy swales instead of more pavement. New urbanism reflects how urban planning can be modified from the conventional sense to improve the environment and water quality.

Berke, Macdonald, White, Holmes, et al. (2003) express through their research that the conventional approach to development usually comes with large increases in impervious surfaces and that new urbanism focuses on minimizing this with cluster developments. The authors illustrate that little research has gone into the relationship
between new urbanism and environmental protection, but they say that there is a relationship between impervious surfaces and runoff quality and quantity. They say that because of this established relationship, and the decreased impervious surface, which comes with new urbanism, cluster developments will result in better watershed protection.

2.5 Urbanization and Management

Booth and Jackson (1997) observe that urbanization has a profound effect on the preexisting watershed. The authors demonstrate that the removal of existing native vegetation and trees and replacement with shallow rooted grasses and other common non-native landscaping plants may promote channel erosion and not provide the ecological services that the native vegetation serves. Research demonstrates that with urbanization comes an increase in impervious surfaces in the form of rooftops, roads, driveways, sidewalks, and compacted surfaces from construction. The relationship of impervious surfaces to runoff quantity is a direct one. When there is an increase of 10-20% in the development of impervious surfaces in a watershed, there is a resulting two fold increase in the volume of runoff. A 35-50% increase leads to a three fold increase and 75-100% leads to more than five times the preexisting amount of subsequent runoff (Paul and Meyer, 2001). May et al. (1997) convey that if development occurs and the resulting impervious surface coverage is less than 10%, it will not have a significant impact on the environmental quality of the surrounding surface waters. The Center for Watershed Protection (2004) illustrates that as impervious surfaces increase, water quality in urban streams decreases. The report demonstrates that at a 10-25% impervious surface ratio
results in an obvious decrease in health of the streams and at 60% the streams channels are unstable, water quality is poor, and biodiversity is essentially destroyed.

Conventional development has mainly focused on the efficient removal and transport of runoff water. This results in very little infiltration into the landscape and few management plans that promote this infiltration. Gregory and Chin (2002) argue that the conventional urban watershed management of speedy removal of runoff from the landscape is being replaced with a more natural management option. The focus has shifted to channel restoration, which includes a more natural state for urban river and stream systems. Bledsoe (2002) Illustrates that as urban storm water management becomes more focused on the biological and physical aspects of water it is likely that a “multicriterion” approach of flood control, pollutant removal, and maintenance of key geomorphological processes will become more favored.

Booth, Hartley, and Jackson (2002) put across that maintaining environmental quality and protecting watersheds effectively through planning can be accomplished through following several elements. These elements are: protecting forest canopy with cluster developments, keeping the impervious surface percentage below 20%, using on-site detention that is targeted at flood duration, not just the peaks of storms; using riparian and wetland protection zones; and not building on steep slopes.

O’Brien and Company (1999) illustrate that keeping storm water runoff on-site can occur through the use of Best Management Practices. The plan that they submit is for maintaining sediment loss from the landscape, by keeping it “on-site” the development will not impair water quality from increased sediment loads. This management plan calls for implementation prior to construction, which is the most
effective time and way to implement BMPs. Kunz (2001) claims that BMPs have had “questionable success” and later explains this is because planners may not be implementing them at the time of development, but rather implementation is post development. Kunz (2001) also explains that BMPs are mainly effective at preventing the initial pollutant loads from development and post-development implementation will not have much success.

Research also demonstrates that BMPs are usually intended to alleviate the stress that sediments and excess nutrients have on receiving water bodies. These practices may not have an effective ability at treating chemical contaminants in the runoff water. Fiddolliott, Bojorquez-Tapia, and Hernandez-Narvaez (2001) reason that BMPs are known for activities such as agriculture, forestry, and construction, but that BMPs are not known for removing chemical contaminants. BMPs effectiveness is in sediment and nutrient removal, but they may also indirectly remove pollutants by stopping contaminants attached to sediments before they reach surface waters (Troeh, Hobbs, and Donahue, 1999).

The Puget Sound Action Team (2003) provides implementation information on this technology. They illustrate that Low Impact Development (LID) is a more natural way to develop land resources. This technology promotes infiltration rather than speedy removal of runoff and includes practices like soil amending with compost, permeable pavement, rainwater harvesting, and green roofs. Several on site case studies demonstrate that LID is an excellent way to save in construction costs over conventional stormwater management and improve environmental quality in the surrounding watershed.
When considering green roofs, there is little research on their effectiveness at reducing runoff quantity and increasing its quality, but there is some evidence that their implementation would have this effect. Sherman (2005) finds that increased compost used in soils has the potential to remove 55-75% of the subsequent runoff quantity and reduce peak flow by 50-80%, but it also resulted in an increase in the amount of nitrogen in the subsequent runoff water.

LIDs mainly focus on reducing the impervious surfaces and increasing the permeability of the site in question. As illustrated by Booth and Leavitt (1999) impervious surfaces can be decreased by using permeable pavement. Their analysis demonstrated that in rainfall duration the amount of runoff from conventional pavements can be as high as 1.2-1.4 mm/15min and that permeable pavements have a runoff rate, in the same scenario, of less than .1mm/15min.

When characterizing stream health, Scholz and Booth (2000) provide three main questions that must be asked. What are the trends in the stream condition, what is the current stream health, and how should planned stream restoration or rehabilitation be ranked? Phytoremediation can be very effective in absorbing contaminants in urban stream restoration efforts. Fritioff and Groger (2003) demonstrate through their research that phytoremediation captures a large amount of metals with a variety of plants. These plants mainly sequester these metals including Zn, Cu, Cd, and Pb in their root systems, but some direct uptake from shoots is also possible. Coppes (2002) illustrates that promoting infiltration with “smart subsurface systems” may be the answer to water quality issues surrounding urbanization and by increasing impervious surfaces with these systems, the developer still has room for landscaping and parking. There is evidence that
the use of riparian buffer zones and vegetative filter strips may reduce the strain that non-point pollution has on the receiving watershed. These vegetative buffers are used to diminish the impacts of human activity on the environment (May, 2000).

Water planning should be linked with social, environmental, and economic goals. According to the National Research Council (1999), “successful watershed management strives for a better balance between ecosystem and watershed integrity and provision of human social and economic goals.” (National Research Council, 1999, p.270)

Platt (2004) emphasizes that building ecological cities and moving towards “ecological citizenship” will be an opportunity for social interaction because it decreases the sense of “helplessness” in the community. Clifford (2002) illustrates that hydrology is interdisciplinary by nature and that as society manipulates the landscape through development, agriculture, and suburban and urban sprawl, the society’s welfare can benefit by more academic research into the field of hydrology. Man-made as well as natural rivers, lakes, and streams can provide enormous educational experiences for the youth in society.

2.6 Validation of an AGNPS Model in a Small Watershed

Suir (2002) found through the analysis of Mitchell et al. (1993) that predicted total annual runoff can vary 65 to 151%, and total annual sediment yield can vary 29 to 557% actual runoff and yield with the AnnAGNPS model. The AnnAGNPS model is the continuous version of AGNPS which replaced the single event version of AGNPS because its distribution was discontinued in the 1990s. The terms AGNPS and AnnAGNPS will be used interchangeably in this study, both referring to the continuous version of AGNPS. This basis though is contradicted by more recent work and
improvements however with Yaun et al. (2001) illustrating that the monthly and annual outputs predicted with AnnAGNPS are within 15% of sampled data without calibration.

Suir (2002) also found through Mitchell et al. (1993) that the model would be a great tool for watershed management, but it does require more work for it to become more accurate.

Suir’s AGNPS executions found sub-basin or cell average annual outputs varied greatly with the lowest documented cell erosion of 2.72 kg/year and the highest at 1065 kg/ha/year. Suir’s predictions of sediment yield were with the lowest .91 kg/yr and highest 334.12 kg/ha/yr. Sediment loading was lowest .91 kg/yr and highest 243.9 kg/ha/yr (Suir 2002). The findings of Suir (2002) were extremely low when compared to other AnnAGNPS executions and may be due to the implementation of an artificial levee within methodologies. An artificial levee would eliminate influence of relevant cells on outputs but it did maximize attention on possible changes to his area of interest.

Mohhamed et al. (2004) found that the overall model efficiency for surface water runoff to be .86 and peak runoff rate to be .65 and they were improved during calibration. The authors also found 0.88 overall model efficiency in sediment yield. Overall model efficiency is the sum of deviations from observations (Mohhamed et al. 2004). Changes in curve number of 10% can lead to a -80 to +220% and -85 to +170% changes in runoff peak and rates. It can also yield a -47 to +55% change in sediment yield (Mohhamed et al. 2004). Haregeweyn and Yohannes (2001) found that AGNPS predicted sediment yield to be very accurate with a coefficient of .97 in both 100 and 200m but runoff, with a coefficient of .59 and .58, to be not significantly accurate. They also found no significant difference in 100 and 200m executions. The Toledo Harbor AGNPS Project Team (2005) found their watershed total rate of erosion was 2.473 Mg/acre/year, sediment yield
to streams was .965 Mg/acre/year, sediment loading rate to watershed outlet to be .307 Mg/acre/year and the highest cell erosion to be 77.045 Mg/acre/year.
3. Materials and Methods

3.1 Methodology

This study tested a methodology for assessing impacts which urbanization has on runoff characteristics by linking together a GIS analysis of Total Impervious Area (TIA) and Non-Point Source (NPS) modeling. The Bluebonnet Swamp Watershed (BSW) is very unique because of the featured urban wetland and increases in development between 1996 and 2004. Most of the clearing and filling of wetlands for development in EBRP had occurred before the 1972 Clean Water Act, but according to Kemp (2007) there has been little effort to minimize the development of EBRP urban wetlands because section 404 permits have done little to curve this development and developers have complained that permitting is very time consuming and costly even though few have been denied (Kemp 2007).

The GIS analysis relates to the AGricultural Non-Point Source (AGNPS) model in two unique ways. It provides a technique to measure changes in land use and landscape feature data over time. It also serves as reference for the editing of ‘fields’ data and assigning runoff curve numbers within the AnnAGNPS model.

The GIS analysis quantified the increase in urbanization via impervious surfaces and corresponding decreases in permeable surfaces within the BSW. It also quantified the changes by land use area. These changes in urbanization and the present storm water management practices have direct impacts of the quantity and quality of subsequent runoff. Datasets provided by this analysis included impervious and pervious surfaces by category and change in their areas from 1996 to 2004. This information is fundamental
for the AGNPS model because it provides the information needed to calculate TIA percentages within land use areas.

The AGNPS model is reliant upon land use data and management parameters associated with that land use. This model provided the opportunity to simulate management schemes and land uses within an artificially delineated watershed. It uses a Digital Elevation Model (DEM), soil, climate and land use or ‘field’ data. It also requires SCS (NRCS) runoff curve numbers (CN) to estimate runoff. Data collection, preparation and editing were very involved processes and required consultation and cooperation between the EBRP Planning Commission, Agricultural Research Service – United States Department of Agriculture (ARS-USDA), and Louisiana State University. The model was not calibrated and relied on other studies for its validation. Although not validating or calibrating the model with actual field data is a shortcoming and downside of this study, findings are relevant because the goals for executions focus on percent increase and relevant decreases. Isolation of Areas Of Interest (AOI) are also accomplished by targeting increases in model outputs of sediment yield, load, erosion, and storm water runoff or their corresponding decrease from the implementation of a management strategy on a per cell basis.

This procedure was used to assess the impacts of urbanization on the BSW and the BSUW, and whether or not these impacts could be mitigated through management practices and/or land use changes

3.2 Software

Geospatial data was processed with ArcView 3.3, ArcGIS 9 and GeoMedia 6. These geographical information systems offer a variety of data processing tools which
were used to edit, create and calculate BSW feature databases imperviousness. The AGNPS model was chosen because it is a tool for evaluating management decisions on a watershed basis. It can be downloaded from the ARS website: http://www.ars.usda.gov/Research/docs.htm?docid=5199. The available download also contains a wealth of application, technical documents, reference data and data development tools which.

3.3 Spatial Data Sources

Project data included both obtaining and digitizing. The Digital Elevation Model (DEM) was converted from LIDAR data available from atlas.lsu.edu and it was originally developed by U. S. Army Corps of Engineers, Saint Louis District in 2001. Louisiana STATSGO New General Soils Map was also downloaded on atlas.lsu.edu. It was originally developed by the U. S. Geological Survey, National Wetlands Research Center in 1998. 1996 and 2004 aerial photography were acquired through the EBRP planning commission. The 1996 BSW building database was also provided by the planning commission and the remainder of the imperious surfaces for 1996 and 2004 were digitized from aerial photography. AGNPS ‘fields’ or land use was digitized from aerial photography as well, but after artificially delineating and executing the model, land use was based per TIA% per AGNPS cell. This increased the number of simulations and land use layers.

3.4 Projection

All spatial data was placed in the same projection. All GIS analyses and AGNPS/ArcView interface executions were completed using UTM Zone 15, NAD 1983,
but some data was acquired in different projections. Projections were converted to NAD 1983 with projection utilities with ArcView.

3.5 Delineation

The original artificially delineated BSW (z59) was generated from the larger study, *Mitigating Non-Point Source Pollution in Urban Watersheds with Spatial Modeling, Best Management Practices for Wetlands and Community Outreach* (Kemp 2007) and it served as the base area layer for TIA calculations and an urbanization timeline, but delineation with AGNPS made it necessary for areas to be classified external to the original watershed.

Figure 6. TOPAZ Artificial Delineation at 25 m (left) and 5 m (right) resolution LiDAR DEMs. Showing differences in the number of AGNPS cells and locations of cell boundaries.
The delineations for AGNPS were accomplished within the ‘ArcView/AGNPS Interface’ which uses TOpographic PArameteriZation (TOPAZ). TOPAZ analyses landscape topography by utilizing a raster Digital Elevation Model (DEM). ARS (1999) illustrates the overall objective of TOPAZ to that of a comprehensive evaluation of the digital landscape topography. Figure 6 below displays all 3 artificially delineated watersheds which were used in BSW AGNPS executions. In this figure they are displayed on the 1996 aerial photographs only.

3.6 Changes in TIA% by BSW Area and Imagery Year

Excluding the initial building data provided by the EBRP Planning Commission, the remainder of TIA was digitized from aerial photographs with GeoMedia 6. This included streets, sidewalks, driveways, parking lots, and the minute category of other. These files were then exported as shapefiles because they offered easy access from the ‘ArcView/AGNPS Interface’. All surfaces which were present on the 1996 imagery were labeled as present during 1996 and each feature was labeled as to what it was. Area was calculated with scripts in ArcView 3.3. All database editing and calculation was accomplished within ArcView 3.3. The merging of all data into 1 database was also accomplished with spatial analysis tools in ArcView 3.3.

2004 aerial photography provided the basis for increases in TIA and TIA% in the same manner as the 1996 TIA was calculated except that the initial building database was not provided. It was digitized.

This dataset was the foundation of both the impervious surface analysis and the creation of the AGNPS fields. The TIA calculations by BSW area were used to place a percentage of imperviousness within the BSW as it existed in the 1996 and 2004
imagery. TIA was also used to quantify imperviousness in each spatially common land use area and finally, they were used to quantify impervious percentages within each AGNPS cell.

This portion quantified the increase in urbanization via impervious surfaces and provided the decreases in permeable surfaces within the BSW. Datasets provided by this analysis included changes in TIA and TIA% by BSW area. They can be summarized by feature or total. This information was fundamental for the AGNPS model because it provides variables needed to calculate TIA% by land use area, AGNPS cell area and it served as a reference in the assignment of runoff curve numbers.

3.7 Changes in TIA% by Land Use Area and Imagery Year

Two land use layers were digitized from the 2004 and 1996 aerial photographs by following the spatial features and distribution of urbanization throughout the BSW during those years. Each land use area was recalculated for imperviousness percentages with scripts in ArcView 3.3. This provided the basis for the assignment of runoff curve number data for 4 executions of AGNPS.

Figure 7 demonstrates how land use was interpreted and digitized from aerial photography. It also contains regions that may be outside the original watershed. The original BSW Z59 watershed served as the initial boundary for the land use map because data inside that watershed was primary. Areas outside of that boundary were more generalized and served primarily as an average land use because of the minimal amount of land use data needed for these regions.

Initial land use maps for use as ‘fields’ data were created by defining a common development on the aerial photography, calculating the area and assigning a unique
feature id to each cell. The amount of TIA in the same area was the intersected using spatial analysis tools within ArcView 3.3 and the new shapefile allowed for TIA calculation within each cell, but only after all features were merged into 1 to only represent only the TIA area within each land use area. TIA was then divided by the area of the particular land use area in which it resided using database management options within ArcView 3.3.

This was prepared with the 2004 imagery as a base layer and changing the TIA% to match 1996 TIA%. 1996 land use layer also included altering several of the land use areas to represent different features. This was done when there was an open space or forested area was cleared. Figure 8 below displays different spatially common land use areas and their corresponding TIA in 2004. The 2 layers were intersected in both cases to represent the TIA that is only contained in each area.

Figure 7. Digitized Land Use from 1996 (left) and 2004 (right) aerial photography. Based primarily on regions with common land use features.
Calculated TIA % by land use area will aid in more accurate predictions of runoff, erosion, sediment yield and loadings. It also isolated increases of development. This dataset provided changes in TIA% by land use area overtime. It did not provide changes per feature because TIA had to be merged into 1 feature so that it would provide a total area within each land use area and ease calculation methods. Isolation of land use feature’s changes is possible, but it was not needed in this study. This information was fundamental for the AGNPS model because it served as a reference in the assignment of runoff curve numbers.

3.8 Changes in TIA% by AGNPS Cell Area and Imagery Year

Six of ten executions of AGNPS in the BSW also depended on TIA percentages per AGNPS cell. The AGNPS cell’s area was calculated in TOPAGNPS portion of the ArcView/AGNPS Interface. As Stated by the TOPAGNPS Overview:
“One of several innovations in TOPAZ is the capability to generate a hydrographic segmentation and channel network with spatially varying characteristics; that is, the network structure, drainage density and subcatchments properties can be different in different parts of the watershed. This capability is used to account for spatial variation in hydrologic controls such as geology, soil type, vegetation and/or climate. TOPAZ can also prune very short, and likely spurious, exterior channel links from the generated channel network.” (ARS 1999. p. 9)

Subcatchments are the AGNPS cells. They contain all the hydrological geometry such as average slope and area. These cells are what all field or land use data is entered within the ArcView/AGNPS Interface.

This was completed in a similar manner as TIA% for land use, but the actual subcatchment area of each cell was used instead of land use area. TIA was intersected with the AGNPS Cell with spatial analysis tools within ArcView 3.3, but only after all features were merged into 1 to only represent the total TIA area within each AGNPS cell. Figure 9 below displays the spatial intersection of the AGNPS cell with the 2004 TIA. Total TIA was then divided by the area of the particular subcatchment in which it resided using database management options within ArcView 3.3.

This provided more precise information on the actual impervious percentages in each cell and it excluded the model from selecting the dominant feature of each cell. All were calculated using scripts with in ArcView 3.3

Calculating TIA% by AGNPS cell area will aid in more accurate predictions of runoff, erosion, sediment yield and loadings. It will also isolate increases of development by their corresponding localized drainage basin. This dataset provided changes in TIA area and TIA% overtime by AGNPS cell area. It did not provide changes per feature because TIA was merged into 1 feature so that it would provide a total area into each cell and ease calculation methods. Isolation of land use feature’s changes is possible, but
it was not needed in this study. This information was fundamental for the AGNPS model because it served as a reference in the assignment of runoff curve numbers.

Figure 9. 2004 TIA% Calculated by AGNPS Cell Acreage

3.9 Agricultural Non-Point Source (AGNPS) Pollution Model

The BSW AGNPS executions were limited to TIA% and undeveloped areas (open fields, small wooded areas, Bluebonnet Swamp) in regards to the specific land use, but the watershed does vary in spatial distribution. It also used ‘non-crop’ only to simplify use and because the predominant land use in the BSW is urbanized or undeveloped.

The later modeling used TIA% per AGNPS cell to limit the exclusion of certain areas within the BSW. Land uses or ‘fields’ are assigned within AGNPS as the dominant feature within each cell. An AGNPS cell may contain a large TIA%, but still have
adequate pervious surfaces or management practices which minimize impacts to runoff. This is why TIA% per cell is so functional in regards to run off curve numbers. Land uses within the BSW AGNPS executions were based primarily on TIA%. Problems associated with field assignments being majority rule are documented and Udoyara et al. (1995) found that small buffer areas between different generalized land use features may be lost in field assignment because AGNPS chooses the dominant land use in the sub-basin. Therefore, it is very difficult to implement riparian buffer zones within the model due to there small size when compared to land uses with a sub basin (Udoyara et al. 1995). In certain scenarios this was minimized due to the assignment of cell TIA%, but the true functions small scale riparian buffers and or management techniques are still very difficult to implement hypothetically.

This model provided the opportunity to simulate management schemes and land uses within an artificially delineated watershed. It uses a Digital Elevation Model (DEM), soil, climate and land use or ‘field’ data. It also requires Natural Resource Conservation Service (NRCS) runoff curve numbers (CN) to estimate runoff within each cell. As stated in the 1986 USDA Urban Hydrology for Small Watersheds TR-55 in figure 10.

\[
Q = \frac{(P - I_a)^2}{(P - I_a) + S}
\]

where

- \( Q \) = runoff (in)
- \( P \) = rainfall (in)
- \( S \) = potential maximum retention after runoff begins (in) and
- \( I_a \) = initial abstraction (in)

Figure 10. Runoff Curve Number formula. Modified from Urban Hydrology for Small Watersheds, TR55 Report. USDA, June 1980.

Executions depended on changes in CN to reflect changes in TIA%. The input editor offered the input of other information pertaining to annual root mass, annual cover
ratio, annual rainfall height and surface residue cover. This information was limited to
the defaults or was based on a relevant land use classification within the reference data
provided with the AGNPS download. This expresses limits in the execution but allowed
for the manipulation of 1 variable within AGNPS. This allowed changes in TIA% to be
directly related to CN. It also permitted for hypothetical application of permeable
pavement systems to be reflected in changes in CN.

Data collection, preparation and editing were very involved processes and
required consultation and cooperation between the EBRP Planning Commission,
Agricultural Research Service – United States Department of Agriculture (ARS-USDA),
and Louisiana State University. Please see figure 11 below regarding data used in the
BSW AGNPS execution.

Figure 11. BSW AGNPS Execution Data Summary
AGNPS has two different categories for field classification which are agricultural uses or ‘crop’ data and non-agricultural data or ‘non-crop’. BSW AGNPS execution contained only ‘non-crop’ data and was subdivided into ‘urban’ and undeveloped areas. This type of data was given specific runoff curve numbers to reflect the TIA% of the AGNPS cell. The *TR55 report* illustrated TIA percentages in relation to CN. The chart from the *TR55* report can be seen in figure 12 below.

![Figure 12. Connected Impervious Area %](image)

BSW AGNPS executions also used State Soils Geographic (STATSGO) databases developed by the NRCS and USDA. The initial Louisiana general soil data obtained from atlas.lsu.edu was intersected with the AGNPS cells and exported into the input editor from the ‘ArcView/AGNPS Interface’ as CSV files (figure 13). The BSW 3 soil types are Loring, Commerce and Oliver. The text file was used in the input editor to represent the BSW soil layers. These soil types were based on the Map Unit
Identification System (MUID) within the ‘general soils database obtained from atlas.lsu.edu. This database was developed by the U.S. Geological Society and the National Wetlands Research Center in 1998. Please refer to figure 13 regarding soil layer and data development for BSW AGNPS executions.

<table>
<thead>
<tr>
<th>MUID</th>
<th>ACRES</th>
<th>MUNAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA062</td>
<td>642.5330</td>
<td>OLIVIER-CALHOUN-LORING</td>
</tr>
<tr>
<td>LA069</td>
<td>30.7750</td>
<td>COMMERCE-CONVENT-SHARKEY</td>
</tr>
<tr>
<td>LA089</td>
<td>428.6350</td>
<td>MEMPHIS-LORING-OLIVIER</td>
</tr>
</tbody>
</table>

Figure 13. Soils in BSW AGNPS Executions

Climate data used in the BSW AGNPS executions was developed through tools offered in the original AGNPS download. The daily climate file required by AGNPS for execution was initially generated from a monthly climate file. These INP files are a series of text which represents dew point, sky cover % and wind speed. This information was available on a national level in an atlas document provided in the initial AGNPS download (see figure 14). The daily climate used for the BSW AGNPS execution was for 5 years of simulated climate. This file and the complete AnnAGNPS files were
created in the input editor and each execution had the same 5 year synthetic climate file. AnnAGNPS file. All input of other data of the execution of the AGNPS was performed within the input editor.

**Figure 14. BSW AGNPS Climate Data.** Modified from United States Department of Commerce (1968), *Climatic Data Atlas of the United States.*

Permeable pavement was simulated by changing the TIA% within each AGNPS cell only for the 2004 results. This was prepared only to represent changes in due to the implementation of hypothetical permeable pavement on previously impermeable driveways and parking lots present only during the 8 year timeline of development. This was because this study concentrated only on how implementing permeable pavement systems would affect the change in development’s impact on yield, load, erosion and runoff.
Figure 15. BSW 5m and 25m resolution DEMs

<table>
<thead>
<tr>
<th>Table 1. AGNPS Simulations in the BSW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>25m DEM</strong></td>
</tr>
<tr>
<td>1996</td>
</tr>
<tr>
<td>2004</td>
</tr>
<tr>
<td>Permeable Pavement</td>
</tr>
<tr>
<td>Total Simulations</td>
</tr>
</tbody>
</table>

Execution was completed by basing the permeable pavement’s effectiveness at decreasing runoff on the assumption that permeable pavement systems will have a profound impact on runoff. Booth and Leavitt 1999 found from the physical application
of test permeable pavements resulted in virtually no runoff as compared to standard pavement. 4 simulations of permeable pavement systems were based on their performance estimates. First a 25%, then a 50, 75 and 100% implementation of permeable pavement on 2004 parking lot and driveway increase from the TIA database. The 2004 TIA% per AGNPS cell simulation also represented the existence of 0% implementation of permeable pavement. Please review table 1 below for a list of simulations.

The percent increases in the implementation of permeable pavement were then plotted against the average annual outputs from the execution of AGNPS in the corresponding simulation. Any decrease at a rate greater than a 10% reduction in total output was considered significant. Isolated cells with significant reduction were also identified.

This procedure was used to predict impacts of urbanization on runoff, load, yield, and erosion totals in the BSW. It was also used to predict impacts of the cell outputs and if these impacts could be mitigated through management practices. Identifying contributing cells and predicting total output of the BSW will highlight key areas of concern and help interpret the effectiveness of a potential management strategy.
4. Results

4.1 TIA% by BSW Area

TIA increased by 8.47 % from 1996 to 2004 within the original Z59 BSW watershed (figure 16). In 2004 the watershed consisted of over 327 acres of impervious surfaces and reflected an increase of more than 93 acres from 1996. Urbanization of the BSW is still continuing today and now has even greater imperviousness. Although impervious surfaces can be related to the increased sediment loadings and runoff within the BSW, management in some cases may minimize those impacts. TIA for 2004 has increased beyond 30% today, which in some studies suggests a high level of watershed degradation and habitat loss. It can also impose greater instances of eutrophication and impairment of local waterways.

Figure 16. Total Impervious Surfaces and Percent
Although these changes do represent built or constructed surfaces, they do not represent the impacts to 'true imperviousness' or the Effective Impervious Area (EIA) as noted by Booth and Jackson (1997). It could be argued that the TIA of the BSW may reflect an even greater EIA because of the extreme landscape and land use changes over time. Certain areas which could be easily isolated by simple review of aerial photography of the BSW in 1996 and 2004 indicate these changes, but the true calculations of the EIA would be a very difficult number to accurately determine. Therefore, the TIA database will be utilized as a rough estimator of runoff curve numbers not the EIA.

**Changes in Total Impervious Area**

![Maps showing changes in impervious area from 1996 to 2004](image)

**Table:**

<table>
<thead>
<tr>
<th>Total Acre</th>
<th>1996</th>
<th>2004</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>234.0140</td>
<td>327.3240</td>
<td>93.3100</td>
</tr>
<tr>
<td>TIA%</td>
<td>21.24</td>
<td>29.70</td>
<td>8.47</td>
</tr>
</tbody>
</table>

Figure 17. BSW Total Impervious Area (TTA) from 1996 to 2004

Houses make up the largest percentage of the watershed (figure 16), but the largest increase in imperviousness can be found in parking surfaces. The BSW AGNPS
simulation that represents the implementation of a storm water management practice will address this greatest increase in imperviousness.

In the “increase” portion of figure 17, parking lots are the largest feature present. The highest parking additions are located in the northwest portions of the watershed, but driveways also have a significant footprint in the remainder of the watershed because of diversity of increases in urbanization. This large increase in pavements which are used much less when compared to streets and roads will provide the obvious choice in the implementation of a management strategy. The largest increase is among parking surfaces, so these surfaces will be our target in the hypothetical implementation of permeable pavement systems.

4.2 Changes TIA%/Land Use Area and TIA Tour

Although the TIA percentages were below 30% for the area of the BSW spatial variation is vast throughout in not only increases but land use patterns and common developments as well. Certain land use areas throughout the watershed are developed above 80% impervious (figures 18 and 20) but the actual impervious surface ratio may be higher because of the management of the landscape, compacted soils (fragipan), and poor infiltration capacity. Figure 18 displays the two years of urbanization. This provides insight into spatial change within the BSW. Two regions of major change are located on both sides of the Bluebonnet Swamp (figures 21 and 23) and they coincide with the “increase” depicted in figure 17, but provide us with a better illustration of regional changes.

In figure 18, the majority of developments are below 60% TIA within their respective land use areas in 1996, but in 2004 several regions exceed this 60% mark in
the NE BSW. In fact, in figure 21 there are a number of regions which show an extreme increase in imperviousness cover in 2004. This intensity of urbanization isolated in land use areas are assumed to have direct impacts to the intensity of runoff resulting in excessive erosion rates, sediment loadings and yield. One distinct characteristic shared in each of these areas is that they all contain retention areas which may slow runoff, but site inspections lead to the assumption that the intensity of urbanization in these areas may overwhelm management initiatives (figures 20 and 22).

Figure 18. 1996 and 2004 Total Impervious Area % (TIA). Calculated with common land use feature acreage.

These results provided a basis for runoff curve numbers in 4 initial simulations of AGNPS. Please refer to figure 11 for details of how TIA relates to the runoff curve numbers. This study focuses on imperviousness as a developed or manufactured surface.
These areas are based primarily on regions which have similar features within them. There is much irregularity in form and definition as aerial photography was its only basis, but it does provide a good representation of reality because it allows for variation of TIA percentages within the BSW. Calculating TIA% by land use area provided a way to base AGNPS simulations on TIA% variation in the watershed, but limits TIA% to relevant land use area rather than drainage basin as noted by Udoyara et al. (1995).

Figure 19. Residential Development within the NE Portion of the Bluebonnet Swamp Watershed (BSW). Displaying the affect of increased surface water runoff and erosion form increased development.

East Bluebonnet Swamp contains 60-80% (figure 21) impervious surfaces in some locations, but the surrounding green spaces do contain large amount of vegetation and there are several treatment ponds. The presence of these ponds does delay the speed of runoff, but such large amounts of impervious surfaces and rapid change within land use areas are predicted to have significant impacts to the quantity and quality of runoff.
Low Impervious Surface Ratio, Open Ditches and Swales. ~19-30% Impervious

Figure 20. Stabilized Residential Development with Vegetative Swales. Located in the Western edge of the Bluebonnet Swamp Watershed (BSW).

East Bluebonnet Swamp, 60-80% Impervious. Runoff Retention Ponds.

Figure 21. Light Commercial with 60 to 80% Total Impervious Area (TIA). Located adjacent to runoff treatment ponds in the eastern portion of the Bluebonnet Swamp Watershed (BSW).
Figure 22. Recent Residential Development in a Filled Wetland. Located just west of the Bluebonnet Swamp, but development on aerial photographs is limited to just a few structures.

Figure 23. Area of 40 to 50% Increases in Total Impervious Area (TIA). Located in a filled wetland just west of the Bluebonnet Swamp with unstable drainage networks.
The vegetative swales present in the NW BSW (figure 21) also provide a delay function with runoff. Areas such as this could be more productive and have the potential to be a Low Impact Development strategy with increases in native vegetation, soils and alternative management. By being so close to a large source of TIA (40-80%) it could provide even more mitigation with different land management.

The main difference in this method in relation to TIA% per drainage basin is that this method attempts to allow the model to select certain spatially significant but small riparian buffer zones and management areas for field assignment. In the next section these areas are averaged in as pervious amounts contained in each sub basin.

4.3 Changes in TIA% by BSW AGNPS Cell Area

Basing TIA % per cell area (figure 24) rather than land use area will provide more concise information in regards to runoff curve numbers within AGNPS. It also should provide more of a real world approach to estimating runoff as it gave us the % TIA per drainage basin. All results from this section are based on a TOPAZ delineation from a DEM with grid cell size 5m, not 25m. TIA% was only calculated from the 5m delineated watershed and its results are only applicable to AGNPS executions using TIA% per BSW AGNPS cell.

1996 imagery the cell average was just above 17.6%, but 2004 imagery average TIA% increased to 27.4% per cell. These results are very similar to increases found in the Z59 BSW watershed, but represent only the average. Results ranged from 0 to 65 % (figure 24) TIA % change per cell with cell 221 (figure 25 and table 2) experiencing the most changes from a 3.1 TIA % in 1996 to a 65.07 TIA % in 2004. This is the largest
increase in all cells but cells 213 and 92 also received very high changes in TIA \% in the 8 years between photographs.

Figure 24. Total Impervious Area \%. Calculated by AGNPS cell area for 1996 and 2004.
Table 2. Bluebonnet Swamp Watershed (BSW) AGNPS Cells with the Greatest Rates of Total Impervious Area (TIA) Increase

<table>
<thead>
<tr>
<th>CELL_ID</th>
<th>ACRES</th>
<th>04TIA%</th>
<th>04TIAACRE</th>
<th>96TIA%</th>
<th>96TIAACRE</th>
<th>TIA/Acre Change</th>
<th>TIA% CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>221</td>
<td>19.8213</td>
<td>65.07</td>
<td>12.8982</td>
<td>3.10</td>
<td>0.6140</td>
<td>12.2842</td>
<td>61.97</td>
</tr>
<tr>
<td>213</td>
<td>3.9628</td>
<td>60.09</td>
<td>2.3811</td>
<td>7.47</td>
<td>0.2960</td>
<td>2.0851</td>
<td>52.62</td>
</tr>
<tr>
<td>92</td>
<td>0.7398</td>
<td>58.84</td>
<td>0.4353</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.4353</td>
<td>58.84</td>
</tr>
<tr>
<td>233</td>
<td>28.3248</td>
<td>51.10</td>
<td>14.4743</td>
<td>44.81</td>
<td>12.6920</td>
<td>1.7823</td>
<td>6.29</td>
</tr>
<tr>
<td>231</td>
<td>25.4855</td>
<td>50.76</td>
<td>12.9355</td>
<td>34.89</td>
<td>8.8930</td>
<td>4.0425</td>
<td>15.87</td>
</tr>
<tr>
<td>223</td>
<td>5.1228</td>
<td>49.90</td>
<td>2.5564</td>
<td>49.29</td>
<td>2.5250</td>
<td>0.0314</td>
<td>0.61</td>
</tr>
<tr>
<td>243</td>
<td>45.3117</td>
<td>48.42</td>
<td>21.9411</td>
<td>37.88</td>
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<tr>
<td>222</td>
<td>37.1018</td>
<td>47.75</td>
<td>17.7153</td>
<td>12.45</td>
<td>4.6200</td>
<td>13.0953</td>
<td>35.30</td>
</tr>
</tbody>
</table>

The most dominant changes in TIA have occurred in 2 predominant spatial locations, although there are other regions within the BSW which have received changes, these two regions have received the most immediate development. Region 1 (figure 26) contains cells 221, 222, 232, and 212 and is located in the north east corner of the BSW. This area has incurred a large amount of urban and largely commercial land uses, but does contain some minimal retention areas. This region also contains the largest amount of TIA. Region 2 (figure 27) located just west of the Bluebonnet Swamp has also received the most drastic changes, but is a much different development and land use than Region 1. Historically this area may have been a portion of the Bluebonnet Swamp and had been built upon fill and other constructed soils. The 1996 aerial photographs display only a limited history of this area and contrasts distinctly with the DEM available in this region. In fact, just north of region 2 another portion of the Bluebonnet swamp has been filled for development, but in the 2004 aerial photographs there is little development located. These regions may indeed have a higher EIA than TIA, but since TIA consisted of only constructed surfaces such as streets and buildings, quantifying true runoff potential in this area is very difficult. Site visitations and imagery demonstrated the
profound affect that this development was having on the drainage system and localized erosion, but since the digitized constructed materials only consisted of about 30% and there is a clear contrast in the DEM and the imagery. Further investigations into these areas would be recommended.

Figure 25. Total Impervious Area % (TIA) Increase from 1996 to 2004

These 2 distinctly different regions provide a key insight into the in the average annual output files available with AGNPS. Isolating regions and implementing a modeling practice on the increase alone, we can predict if the implementation of a permeable pavement system will minimize the impacts to runoff, erosion, yield and load.

Figure 26. Region 1 Cells with Rates of Change
4.4 Execution of the AGNPS Model within the BSW

Differences in the total Average Annual Outputs (AAO) for 5m and 25m DEMs varied greatly with 5m simulations providing less in sediment erosion, load, yield, and runoff. Sediment outputs are in Mg (megagrams/year) or metric tons and runoff is in mm/year. Erosion is the amount average annual sediment displaced per cell, yield is the amount of average annual sediment erosion which leaves each cell, load is the amount of average annual sediment contained in runoff which leaves each cell and runoff is the amount of average annual water which leaves the cell. The soil database utilized in simulations contained a very high proportion of clay and this high clay content combined with such high runoff curve numbers and slope resulted in the yield of each cell equal to the amount of erosion.

Differences in simulations based on TIA% calculated from landscape feature area in 5m also varied from those calculated from BSW cell area (figure 28, tables 3 and 4). The largest outputs were found in simulations utilizing a DEM with a 25m grid cell size. Total AAO files decrease dramatically when the DEM grid cell size is changed to 5m, but differences between executions implemented with TIA% calculated by BSW AGNPS cell size and land use feature area are slight (table 4). For example, in the 1996 BSW
AGNPS executions with calculated TIA% from land use features’ average annual total erosion and yield were 1.28 Mg/acre/year, load was .27 Mg/acre/year, and runoff was 24.81 mm/acre/year, whereas the execution for 1996 with TIA% calculated with BSW AGNPS cell area predicted total erosion and yield to be 1.6Mg/acre/year, load .31Mg/acre/year, and runoff 17.62 mm/acre/year (figure 28, tables 3 and 4). When executions are based on a 25m grid, runoff, yield and load was 1.5 to just below 2 times higher than executions with a 5m grid. This shows that reducing grid size of the elevation model will significantly reduce predicted annual outputs.

Figure 28. Total Average Annual output (AAO) for 6 Scenarios

These significant differences follow the trend of TIA% in both land use and BSW AGNPS cell calculations in the previous sections. USGS (2003) suggest, DEM grid size plays a major role in predicting outputs with the model, but focusing on the change of
urbanization can isolate certain hotspots within the development timeframe. Therefore, it can be argued to some extent that the total TIA% change in the BSW within the 8 year timeframe has lead to a 30% increase in yield, but depending on DEM grid size and TIA% calculations for fields these changes fluctuate (tables 3 and 4). An 8.4% increase in TIA% leads to a 30% increase in yield and erosion predicted with a 5m DEM grid cell size and TIA% based on land use maps. This figure decreases to an 18.5% increase when grid cell size is increased to 25m. A more significant observation is that when TIA% is based on the BSW AGNPS cell area. This change reflects in yield increases of only a 3.23% (table 4).

This pattern is replicated with load as well because it increases more than 35.52% in the 5m TIA % by land use feature area, 20.36% in the 25m TIA% by land use feature area, and 5.81% in the 5m TIA% by BSW AGNPS cell area, but runoff differs greatly in that pattern. When TIA% is calculated by BSW AGNPS cell area and a 5m DEM grid cell size, runoff increases 19.54%, but when land use feature are used to calculate TIA% there is an 11.1% increase. The runoff changes which occur with 25m grid cell size and land use feature area as a base decrease to 10.25%.

DEM resolution has an significant effect that should not be overlooked when considering AAOs (USGS 2004), but the increase in TIA% in the BSW between 1996 and 2004, 93 acres or 8.47 percent (figure 16), results in more AAOs for the same climate inputs regardless of DEM resolution or TIA% calculations for runoff curve number estimations (Tables 3, 5 and figures 28 and 12). Runoff Increases associated with the 8.47% increase in TIA are from 10.2 to 19.5% and leads to the summation that the effect on runoff volume from increasing TIA% is magnified by a factor of 1.2 to 2.3. These
values are consistent with ranges documented by Paul and Meyer (2001) for TIA% 20 to 30.

Table 3. Effect on Predicted Mean Annual Runoff, Sediment Yield and Load in BSW of (1) Improving DEM Resolution from 25 to 5 meter, and (2) Increasing Total Impervious Area by 8.5%

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Map Year</td>
<td>5 m</td>
<td>25 m</td>
<td>Percent Difference</td>
</tr>
<tr>
<td>Predicted Sediment Yield (metric ton/acre/year)</td>
<td>1996</td>
<td>1.277</td>
<td>3.778</td>
<td>195.8</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>1.691</td>
<td>4.479</td>
<td>164.9</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
<td>32.4</td>
<td>18.6</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Map Year</td>
<td>5 m</td>
<td>25 m</td>
</tr>
<tr>
<td>Predicted Sediment Load (sediment/water concentration)</td>
<td>1996</td>
<td>0.273</td>
<td>0.768</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.370</td>
<td>0.924</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
<td>35.5</td>
<td>20.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Map Year</td>
<td>5 m</td>
<td>25 m</td>
</tr>
<tr>
<td>Predicted Runoff (mm/year)</td>
<td>1996</td>
<td>24.808</td>
<td>41.023</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>27.559</td>
<td>45.227</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
<td>11.1</td>
<td>10.2</td>
<td></td>
</tr>
</tbody>
</table>

Predicted increases in sediment yield were from 3.3 to 32.4 Mg/acre/year (Tables 3, 5 and figure 28) and the range scale is the affect of both DEM and land use map imagery resolution. A more significant finding is the change in imagery from 1996 to 2004 with a 5m grid and digitized TIA% has the highest change in runoff. This change reflects increases of a maximum 19.5%, but it maintains the lowest increase in erosion at 3.3% and load at 6.1% (table 4). As illustrated in figures the change was limited to just a few cells. These hotspots (figures 29-35) will be targeted for changes in AAOs, mainly yield, affected by the implementation of permeable pavement systems.

Cell AAOs created form a DEM with a 25m grid resulted in an 80 plus cells and results for this delineation were very high when compared to 5m, but watershed totals were agreeable with other studies while cell outputs were not. The rational behind these
extreme differences may have been the larger grid size and the lack of detailed information in regards to the watershed when compared to the 5m. The 25m averages out larger surface area and results in much higher error rates in the hydrologic geometry during delineation.

**Table 4. Effect on Predicted Mean Annual Runoff, Sediment Yield and Load in BSW of Improving Resolution of %TIA within AGNPS Cells**

<table>
<thead>
<tr>
<th>Predicted Sediment Yield (metric ton/acre/year)</th>
<th>5 m Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map Year</td>
<td>Majority Rule</td>
</tr>
<tr>
<td>1996</td>
<td>1.277</td>
</tr>
<tr>
<td>2004</td>
<td>1.691</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
<td>32.4</td>
</tr>
</tbody>
</table>

**Predicted Sediment Load (sediment/water concentration)**

<table>
<thead>
<tr>
<th>Map Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
</tr>
<tr>
<td>2004</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
</tr>
</tbody>
</table>

**Predicted Runoff (mm/year)**

<table>
<thead>
<tr>
<th>Map Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
</tr>
<tr>
<td>2004</td>
</tr>
<tr>
<td>Percent Change 1996-2004</td>
</tr>
</tbody>
</table>

In terms of scale, a DEM with a 25m grid generalized too much information for such a relatively small watershed in EBRP. A 25m DEM allowed for lower processing times but sacrificed the more accurate predictions smaller grid sized may offer. It is also important to note here that finding by Suir (2002) were derived by the implementation of and artificial levee system which isolated certain cells in relation to the entire watershed. This limits the impacts that connecting cells would have and shrinks watershed size. Findings in USGS (2003) and Haregeweyn and Yohannes (2001) were both based in Ethiopia which have overall relevance to predictions but differ greatly in environmental
conditions, whereas Suir (2002) was based in Cade, Louisiana. However, findings from the Toledo Harbor AGNPS Project Team (2005) are consistent with this study’s.

Figure 29. Average Annual Sediment Yield (metric tons/acre/year). Isolated cells are contributing most of the sediment and most of the change from 1996 to 2004 (Region 1 and 2), curve numbers estimated from TIA%/BSW AGNPS cell acreage.
The total average annual sediment yield in the delineated watershed was predicted to be 3.78 Mg/acre/year in 1996 with an increase of .70 Mg/acre/year by 2004. The 4.48 Mg/acre total by 2004 resulted in an average cell yield of 1.11 Mg/acre/year. This was more than a three fold increase in the average sediment yield per cell per year.

When looking AAOs per acre per cell in scenarios with a DEM with a 25m grid size and TIA% calculated land use feature area, we found major changes existing near or within regions receiving the most development, but certain cells contain relatively high readings when compared with Suir (2002) and the Toledo Harbor AGNPS Project Team (2005), but no per cell data was available in USGS (2003) and Haregeweyn and Yohannes (2001). Following closer scrutiny, it is concluded that these cells’ acres are extremely small (less than 1) and usually are the conjoining cell receiving major influence from adjacent cells, but scenarios with a watershed delineated from a 5m DEM also provided very high readings in isolated areas. These readings differed greatly from cell predictions made by Suir (2002), but analyzing there increases and the spatial display of areas of change isolates areas of concern which could be targeted for aggressive management and further modeling. It is also important to consider the differences per cell and per total watershed acreage. The total watershed AAOs are within ranges predicted by USGS (2003) and Haregeweyn and Yohannes (2001), but ranges per cell are in several cases much higher than Suir (2002) and the Toledo Harbor AGNPS Project Team (2005) predictions. The major changes noted in the TIA% are reinforced in predicted yield and erosion, runoff and sediment loadings per AGNPS cell. Upon closer inspection of the data large changes are observed in predictions that are limited to a minimal number of cells.
These hotspots of change reflect some of the overall trend of TIA increase, but differences arise when we focus on the increase. Region 2, as referred in the TIA%/AGNPS cell section, was also predicted to have large increases of sediment yield in the scenarios utilizing a DEM with a 5m grid and TIA% calculated from cell acres. All cells received relatively large increases in predicted sediment yield and erosion for the 8 year timeframe. In region 1 cell 122, (figure 30) from the 25m land use feature area execution received the greatest increase with 102.07Mg/acre/year. Cell 122 is also adjacent to a runoff treatment pond and recently modified natural drainage system.

Increases in average annual yield in region 1 on the east side of the Bluebonnet Swamp were located further south than the TIA increase and may be a result of lower runoff curve numbers associated with stabilizing development in 2004. The largest increases in TIA% were in the northeast section of the BSW, but the unstable condition
noted in the 1996 aerial photograph led to higher runoff curve numbers in 1996 simulations. Therefore, increases or hotspots of yield shifted south, away from the initial development.

Figure 31. Predicted Sediment Yield Increases for Region 1 Cells within 25m grid Executions with TIA% Calculated by Land Use Feature Acreage

Cells 323 and 382 (figure 31) on the western side of Bluebonnet Swamp are predicted to have the highest yield and erosion on the western portions of the Bluebonnet Swamp. The 25m DEM executions predicted an increase in cell 323 of over 96Mg/acre/year and in cell 382 of over 68Mg/acre/year. These relatively high increases in yield vary slightly in load and runoff within the 25m executions, but the excessive and out of range cells are present throughout. Therefore, subsequent simulations and predictions were generated from a DEM with a 5m grid. Executions with a smaller grid size should also lead to much more realistic predictions and locations of hotspots.
It is also important to note that the elevation, slope, and the stream networks of AGNPS cells change so that runoff and sediment travel towards the bluebonnet swamp then exit the watershed. This results in outputs from regional cells and affecting the outputs of lower and adjacent elevations. The 5m grid DEM has much less generalization and therefore smoother transitions in slope and elevation.

5m grid delineations have a similar trend in predicting changes in the two regions and region 1 does have similar predictions of hotspots in region1 and 2. Executions with TIA% calculated with cell area predicted much lower increases in yield for cells within region 2. Cells 72 and 73 in region 2 (figure 32) received the most increase of yield and erosion in that area. Cell 72 increased in yield and erosion by 5.96Mg/year/acre and cell 73 increased by 4.63 Mg/acre/year.

These predicted increases are much lower than the 90 to 103 Mg/year/acre predicted in the same region with 25m delineations (figure 30). When the increase in yield was based on calculations of TIA% by land use feature area (figure 33) predicted yields and erosion increases were very similar to TIA% by cell area, but cells 92 and 93 were predicted to also have vast increase in sediment yield and erosion in this region. These shifting hotspots illustrate the affects of different approaches to TIA% calculations and their utility within AGNPS. The same delineated watershed predicted an increase in cell 92 of 40.6 MG/year/acre and cell 93 of 29.8 Mg/year/acre (figure 35). Region 1, (figure 34) In the NE portion of the watershed, does mimic the same movement of change when compare to 25m delineations, but isolated cells of increased AAO are much lower. Infact, maximum yield results for 5m TIA% by land use are half as much as 25m simulations.
Figure 32. Predicted Sediment Yield Increases for Region 2 Cells within 25m grid Executions with TIA% Calculated by Land Use Feature Acreage

Figure 33. Predicted Sediment Yield Increases for Region 1 Cells within 5m grid Executions with TIA% Calculated by BSW AGNPS Cell Acreage
Figure 34. Predicted Sediment Yield Increases for Region 1 Cells within 5m Grid Executions with TIA% Calculated by Land Use Feature Acreage

Figure 35. Predicted Sediment Yield Increases for Region 2 Cells within 5m Grid Executions with TIA% Calculated by Land Use Feature Acreage
In executions with TIA% calculated by cell area, cell 213 had the largest overall increase in sediment yield and erosion in the entire watershed with 17.37 Mg/year/acre (figure 33). This cell is in the center of a light commercial area with new constructed management ponds and receives water through a vegetative swale. Such high levels of impervious surfaces (58% + when calculated by cell area) and its adjacency of high TIA% leave it susceptible to extremely high levels of AAOs (figure 33). When the TIA% are based on the land use feature areas (figure 34), this cell remains the hotspot but practically doubles in predicted yield and erosion increase with 33.5 Mg/year/acre. These dramatic shifts in the increases of AAO for the 8 year time span lead to the decision to use the TIA% calculated by BSW AGNPS cell area as the most accurate of all simulations and the ideal candidate for the hypothetical implementation of permeable pavement (figures 32 and 33).

Changes in AAO based just on the increase in TIA and the implementation of permeable pavements resulted in a maximum 8% reduction in runoff, 3% reduction in load, and a 1% reduction in erosion (figures 38-41). It also produced a maximum yield reduction of 43.9% (figure 41). Significant reductions in yield were only found in the implementation of 75 and 100% implementations of permeable pavement.

Booth and Leavitt (1999) concluded that well designed permeable pavement systems could reduce runoff to practically zero state by improving infiltration rates and converting runoff to subsurface flow (figure 5). Although the result is reliant upon infiltration rates and pore space of the urbanized soils, which after TIA tours was concluded to very low in the BSW. Although unrealistic, this study assumed that Turfstone would function in the same manner in EBRP because it allowed permeable
pavement runoff reduction rates to be directly related to TIA% and runoff curve numbers. The 47 acre increase in parking surfaces in the BSW from 1996 to 2004 was approximately half the total increase in TIA.

The AAOs associated with percent implementation of permeable pavement was then plotted against the percent implementation of permeable pavement. A 100% implementation of permeable pavement systems with the increase of development is predicted to decrease runoff by 8.1% (figure 40). Yield was by far the most affected by with a predicted maximum decrease of 43.9% (figure 41). This large decrease in yield may be an impact of improved permeability of pavement systems when compared to pre-existing soil types which are high in clay. This outcome may be somewhat inaccurate, but it does suggest a potential for effective management to decrease yield outputs to less than pre-development. In 1996 areas in the NW portion of the BSW actually contained much higher runoff curve numbers due to the presence of construction and recently graded and filled soils.

When we look at the direct impacts to runoff in a per cell basis we find that the implementation of permeable pavement systems will not only positively affect the areas of new development but, surrounding cells also see less overall output than 2004 AAOs. These findings are the result of permeable pavement having higher infiltration rates than previously undeveloped soils with high clay content. Reductions of annual output is noted throughout the watershed and in some cases, namely yield, reduction affects cells that have not received any new development. This leads to the conclusion that permeable pavements will reduce impacts to runoff quantity and quality throughout the cells. Maximum sediment yield per cell is noted in figures 36 and 37, which demonstrate a
7.35-12.24 Mg/year/acre. If intensive management were implemented in cells of change, it would influence watershed totals by minimizing excessive erosion and corresponding yield of itself and other spatially relevant cells. Although the implementation of most practical BMP’s such as hay bales and sediment fences, these practices’ focus is to reduce sediment yield and load, not runoff quantity, but they do decrease the speed and increase the travel time of runoff. This assumption is based on spatial distribution patterns of load. The amount of sediment contained within runoff travels through the watershed and the implementation of management techniques in key cells would minimize sediment traveling into and through the Bluebonnet Swamp.

found by Booth (1999), but by implementing management though runoff curve numbers most effective areas of interest can be isolated.

Figure 36. Predicted Maximum Sediment Yield Decreases from the Implementation of Permeable Pavement Systems for Region 1 cells within 5m Grid Executions with TIA% Calculated by BSW AGNPS Cell Acreage
These scenarios are a result of decreasing the impervious surface percentages for just the increase in urbanization. Therefore, it will lower runoff curve numbers to the appropriate level of impervious. Several conventional BMP’s may not function in this way as they might be implemented just to focus on load first rather than the precursor to runoff which creates erosion, yield and load. The changes in AAOs seen in the 8 year timeframe are isolated to regions 1 and 2 receive the most reduction in AAO/acre but total reduction does have wide spatial variation.

Isolating areas and their impacts allow planners to maximize the efficiency of management implementation and by the implementation of management there will be some reduction in the runoff curve number. Implementing management in this agricultural model was accomplished by decreasing runoff curve numbers by
implementing approaches that decrease the impervious surface ratio. Performance of permeable pavement systems in the BSW is not going to function identically to results

Figure 38. AGNPS Prediction of Sediment Erosion by Replacing Impermeable Driveway and Parking Lot Areas Added (4.2% of TIA) from 1996 to 2004 with 25, 50, 75 and 100% Permeable Pavement

Figure 39. AGNPS Prediction of Sediment Load by Replacing Impermeable Driveway and Parking Lot Areas Added (4.2% of TIA) from 1996 to 2004 with 25, 50, 75 and 100% Permeable Pavement
Figure 40. AGNPS Prediction of Runoff by Replacing Impermeable Driveway and Parking Lot Areas Added (4.2 % of TIA) from 1996 to 2004 with 25, 50, 75 and 100% Permeable Pavement

Figure 41. AGNPS Prediction of Sediment Yield by Replacing Impermeable Driveway and Parking Lot Areas Added (4.2 % of TIA) from 1996 to 2004 with 25, 50, 75 and 100% Permeable Pavement
5. Conclusion

Documentation and calculation of TIA was completed using the 3 different methods of per total watershed, digitized land use and AGNPS sub basin area. These calculations were used in 6 different scenarios with AGNPS to represent the BSW in 1996 and 2004 aerial photography and 4 scenarios on the implementation of permeable pavement systems on 2004 parking surfaces increases only. The BSW AGNPS AAO watershed totals decrease from decreases in DEM grid size and this demonstrates the need for lower grid size, but depending on the project goals, AGNPS is very useful in isolating hotspots for maximizing the effectiveness of management initiatives. Total outputs of the BSW are similar to levels found in the Toledo Harbor AGNPS Project Team (2005), USGS (2003) and Haregeweyn and Yohannes (2001), but there are high and unrealistic readings per cell in every scenario which conflict with Suir (2002). However, cells with minimal readings are closer to Suir (2002) findings. Suir (2002) findings are the most relevant to this study because simulations were based in Cade, Louisiana, which is approximately 100 miles from the BSW. However Suir (2002) results are based on a watershed with an artificial levee which limits the influence of adjacent and surrounding cells. Predicted decreases in AAOs through the implementation of permeable pavement systems and AGNPS majority rule in field assignment make the assignment of runoff curve numbers more subjective and implementing management through changing this number with more accurate calculations would be much more realistic. Certain areas of the BSW contain management which is spatially minute when compared to residential and commercial areas. The spatial insignificance of management areas such as vegetative swales and retention/detention ponds and leads to great difficulty
in demonstrating function within the model as Udoyara et al. (1995) implies it would, but LID and BMPs would significantly decrease runoff curve numbers. This would lead to lower predicted AAOs. Utilization of AGNPS in an urban watershed would be much more effective with better information especially in regards to detail in soils and elevation. In its present state AGNPS is an excellent tool for watershed management because it isolates Areas of Interest (AOI) which can be targeted for aggressive management in the BSW and EBRP. The obvious contrast in DEM elevations and aerial photography illustrate the need for more accurate elevation models. More accurate DEMs, which reflect changes in elevation from portions of low lying area being filled for development, would result in more accurate predictions of AAOs and delineations of watersheds and delineation of sub basins. The aerial photographs displayed several extreme examples of elevation change and site visits also express the need for more soil data which better represents foreign soils used in fill for development. The diverse management techniques throughout the swamp may offer different runoff curve numbers that illustrated by the Tr55 report, but the realistic performance are unknown. Elevation, soil and management databases should be maintained by planners, managers and developers to insure accuracy in modeling to assess TMDL attainment. Tours of the BSW provided evidence of unstable drainage networks and severe localized erosion (figures 1, 2, 3, 4, 18, 20, 21, and 22).

Intentional detention and retention could be calculated and reflected in runoff curve numbers for future areas of development with potential management. This information could assist planners and managers in allowing only those increases in development and management that would not result in increases AAOs. If emphasis
would be on retrofitting management techniques on already present areas, assumptions could be made from the investigations of present available technologies and performance to estimate a functional runoff curve number. The goal of these calculations is to quantify how a particular type of management would decrease the runoff curve numbers. It is unlikely that the implementation of permeable pavement would reduce increases of runoff quantity and impairment from increases in urbanization, but a combination of slight changes in management techniques and retrofitting LID in the BSW and EBRP could lead to vast increases in water quality and habitat growth. The reintroduction of native plants and minimal hydrologic alterations of vegetative swales and undeveloped areas within the watershed would only benefit habitat and the community within the BSW and EBRP. Reducing peak flow and increasing time to rise within natural drainage systems with localized management initiatives by local government, developers, land owners and citizens will have positive impacts on water quality for TMDL attainment. Further investigation on ideal management and impacts to runoff curve numbers would greatly benefit planners and managers in EBRP, Louisiana and nationally because urban NPS modeling will maximize effectiveness without the trial and error of field implementation in regards to TMDL attainment. The results of BSW AGNPS executions provide outcomes which isolate spatially significant cells that would be prime candidates for increases in NPS management. It also quantified impacts to sediment yield, load, erosion and runoff in from increases in urbanization and hypothetical management on the entire BSW.

The timeline of development resulted in an 8.47% increase of TIA. Pavement increases of driveways and parking lots counted for the greatest increase. Differences in
Average Annual Outputs (AAOs) for 5m and 25m DEMs varied greatly with 5m simulations providing less in sediment erosion, load, yield, and runoff. The differences in simulations based on landscape features in 5m also varied from those based on TIA. Changes in AAOs based on the increase in TIA and the implementation of permeable pavements resulted in a 43% reduction of yield, 8% reduction in runoff, 3% reduction in load, and a 1% reduction in erosion. Varying results of reduction in AAOs demonstrate the need for further simulation of added management. The results provided from ten BSW AGNPS executions demonstrate the need for validation and calibration when modeling for TMDL attainment.
## 6. Recommendations

### Table 5. NPS Management Costs and Benefits

<table>
<thead>
<tr>
<th>Practice</th>
<th>Utilization of GIS &amp; AnnAGNPS Modeling for Land Use Change &amp; Management Implementation Regarding TMDL Attainment</th>
<th>Structural &amp; Non-Structural BMPs Prior and Through Construction</th>
<th>Structural &amp; Non-Structural BMPs Post Construction</th>
<th>LIDs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Costs</strong></td>
<td>Model can be downloaded for free. Requires validation and calibration for policy implementation. Requires accurate and site specific DEMs, soil layers, land use and management data, and accurate CN calculation or approximation. Larger DEM grid cell size significantly impacts predicted outputs. A finer resolution DEM requires more processing, but is more accurate. Accurate predictions require accurate databases.</td>
<td>Cost of implementation and maintenance. Non-Structural costs are associated with programs, policy, enforcement and community outreach. Structural are more expensive, focus of land management and the implementation of technology for mitigation. High short-term costs of structural BMP implementation.</td>
<td>Structural have high short term costs, but low long term maintenance and management costs. Once stabilized, most grassy swales and other structural BMPs require little to no real maintenance and/or management. Non-Structural costs are associated with programs, policy, enforcement and community outreach.</td>
<td>Costs are relatively equal to conventional development and in some cases LIDs may be less expensive but require long term management. However, long term management may still cost less than conventional development.</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td>Isolates areas of concern, allowing planners and managers to effectively test management. Provides numerous ways to simulate the implementation of management and increased development by the adjustment of parameters, namely CN. Divides the watershed into sub-basins and predicts outputs on a per sub-basin output. Allows variation in sub-basin size and data resolution. A sub-basin output is an excellent representation of how management or land use changes impact water quality at the field level. Provides the spatial definition of impacts to water quality/quantity and erosion influenced by model parameters. Can be used to predict influences that development and/or management has on TMDL attainment.</td>
<td>Helps relieve the increased strains that construction has on runoff quality. Helps minimize sheet, rill and gully erosion. During periods of construction, there is little stabilization of soils and they are prone to erosion. Mitigation during this time period will lead to much less downstream degradation by treating storm water onsite. Implementing BMPs can significantly remediate the impacts construction has on storm water and pollutant loading on adjacent water bodies by retaining sediment with structure implementation.</td>
<td>Helps relieve the increased strains that imperviousness has on storm water quantity and quality. Stabilized landscapes require less mitigation and little long term maintenance. Implementing structural BMPs can mitigate impacts that urbanized areas have on storm water and pollutant loadings with lower costs than treatment facilities. Non-structural BMPs can also reduce these impacts through community outreach, education and public programs in land and landscape management programs; and promoting on-site use of rainwater.</td>
<td>Helps maintain natural hydrology, stream flows and water levels in wetlands and it protects streams, fish and wildlife habitat from peak storm flows. Reduces pollution in storm water, protects water bodies from bacterial contamination, preserves and restores trees and other vegetation (PSAT, 2006). LID is the design solution to water quality problems caused by conventional development. Provides new choices for site design, storm water facilities and recreation. Helps lower construction costs for storm water treatment. Helps make more aesthetically pleasing neighborhoods with higher property and resale value. Provides more available lots for development and less for runoff treatment ponds. May reduce storm water utility fees (PSAT, 2006). Can help eliminate flooding, protect streams and wildlife, maintain drinking water supplies, and lower the costs of streets, curbs and other infrastructure. Can be retrofitted to urban areas. Reduces contamination by sediments and mitigation costs from cleanup (PSAT, 2006).</td>
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</table>

Site visitations and inspections demonstrate the need for the BSW and EBRP to continue mitigating NPS at its source by implementing management through policy.
which is comparable to that of LID (table 5). With minor alterations in storm water management, landscapes and use reduction of runoff and water quality improvements would be possible in present developments, but it is imperative that any additional development not increase runoff. Technologies and management which promote onsite detention/retention will lead to a less overall strain on drainage systems and lesson the time to rise so well documented by Walker (2002). There are many ways this overall goal can be accomplished, but LIDs and BMPs offer the most cost effective and efficient ways for state and local government to increase the time to rise in local drainage networks while maintaining proper drainage. Creating just a 15 minute delay in surface water runoff will lead to huge reductions in erosion, pollution loads, and lesson the strain on natural systems.

LID was developed in the Pacific Northwest and although different in climate and elevations their yearly rainfalls are similar to EBRP. Management in the BSW, EBRP and Louisiana should continue to change its focus of efficient removal of storm water found in conventional development. The use of native hydrophilic plants and soils in vegetative swales could be very similar to that of LID and could be implemented at a minimal cost (table 5). However, the development of ideal implementation would be the subject of more research and testing in the environment of south Louisiana.

Utilization of the AGNPS model in urban watersheds would be more accurate with more accurate information. Local government and developers should collaborate to update elevation and soil data with any modification made from urbanization. The DEM is the basis of AGNPS and serves as the development of drainage basins and watershed. DEMs should be updated with any and all fill activities from development and soil
additions should be as well. Maintaining these databases at an extremely detailed scale and at the local level will help EBRP in predicting the impacts new developments will have on AAOs. The development of runoff curve numbers associated with ideal management for the parish would also be particularly useful for hypothetical management implementations. This database could also be applied to present development to target the most cost effective areas for management initiatives which would maximize efficiency. The AGNPS model and the methodologies set forth in this document are excellent tools for environmental planners and managers to estimate changes to runoff quality and quantity caused by increases in urbanization, land use change and management in regards to TMDLs.

Implementing LIDs, BMPs and evolving conventional development and management to become more watershed-friendly will lead to vast environmental, social and economic benefits by improving the aesthetic and ecological health of all watersheds (table 5). As our population grows and we develop more of our natural lands watershed health should be a top priority not only for the sake of the environment, but for future generations to enjoy the natural resources they are entitled to. If we do not take steps to repair and prevent further degradation of water resources and ecological health of watersheds, they may become beyond the point of repair. It is paramount in this regard that environmental planners and managers utilize the innovations found in LIDs, BMPs and any other appropriate technologies to minimize impacts from existing or new development. The reluctance to implement LID in EBRP and throughout the state is an image of the stronghold conventional development has in our society. This can be overcome by implementing policy which economically rewards landowners and
developers for runoff reduction. Subsidizing for runoff reduction through applications such as LID would decrease the burden on state and local government in reducing runoff and pollutant loads for TMDL attainment. Instead of implementing command and control policies which do not relate management to the economy, subsidizing effective management would create an economic incentive to reduce runoff and pollutant loads. Therefore, landowners and developers would embrace technological innovations such as LID.

GIS and modeling techniques such as AGNPS will also allow environmental planners and managers to better assess the impacts of development and the implementation of management (table 5). It is strongly suggested that utilization be a part of land use planning decisions in any state or local government and if used effectively, would maximize effectiveness in TMDL attainment. However the model should be calibrated and validated to ensure accuracy.
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Vita

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