An Ecosystem Approach to the Sustainability of Urbanizing Watersheds

AN ECOSYSTEM APPROACH TO THE

SUSTAINABILITY OF URBANIZING WATERSHEDS

A Thesis Presented

by

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DEDICATION

To those who love, who trust and who support.

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ABSTRACT

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Political boundaries make watershed planning difficult despite the influence of many state and federal programs. Broad, top-down, watershed initiatives fail to reach many municipalities due to human resources, time and legalities. Thus, a watershed ecosystem based approach to city planning should be utilized in order to integrate a holistic and scientific foundation for land use decisions. However, there is a need for research for developing and applying a watershed approach to urbanizing watersheds.

The goal of this study is to provide a series of science based transferable recommendations upon which municipalities can make land use planning decisions. These recommendations are informed by a watershed modeling and prioritization study conducted with the community of Northampton, Massachusetts. Analyses of water resource planning options were made concerning future development scenarios using an approach which links water quality and quantity, land use and government. A required component of the ecosystem approach, stakeholder participation, applied the Deliberative Attribute Prioritization Procedure (DAPP) for the first time in this context to assess the relative of different environmental concerns. The results of these stakeholder focus groups showed the importance of several key attributes including land use, water quality,

water quantity, and impacts to neighborhing communities that were utilized in the watershed models.

This thesis provides an integrated tool for water resource planning at the municipal level. However, without the effective transfer of these recommendations into existing policies like zoning, the results of the study have limited use. Therefore implementation of recommendations within municipal planning documents is an important component. This information will be utilized to evaluate priority water resource protection overlays by providing quantitative information and decision making within a community. A citywide watershed model and analysis used to guide policy-making and decision-making will assist in fulfilling the community of Northampton's continuing commitment to work toward economic, environmental, and equitable sustainability, as well as provide a model for other communities.

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CHAPTER 1

RESEARCH CONTEXT: LINKING WATERSHED SCIENCE AND LAND USE POLICY

Water transfers within and outside of a hydrologic boundaries often produce an imbalance in the natural water budget of a watershed (Reimold, 1998). Water withdrawals may be piped out of a subbasin for use as potable water or wastewater may be sent out of or into a subbasin for treatment. Surface discharges of wastewater, which may return effluent to a subbasin, can also disrupt the water balance by bypassing groundwater recharge through the release of effluent to a lake, river or stream. Water balances may be further impacted by impervious surfaces and the loss of stormwater recharge due to increased stormwater runoff and decreased infiltration to groundwater. These actions can result in a net loss or gain of water potentially resulting in unintended impacts to the hydrograph, leading to environmental degradation (Town of Lancaster, 2006).

All three water resources - potable water, wastewater and stormwater - are rarely cooperatively managed in the context of municipal land use planning and watershed sustainability. The disruptions to the daily and seasonal subbasin and watershed water budgets caused by inconsistent water losses and gains can adversely impact streams, sensitive wetland and riparian resource areas, water supplies and contribute to unusual runoff patterns. The changes caused by water imbalances impact attributes like biota, hydrology and flow, stream morphology, habitat, biodiversity, water supplies, water quality and overall watershed sustainability.

Rarer still, is water resource protection planning that thoroughly identifies and calculates costs and benefits including both environmental costs and the true costs of operating and maintaining water, wastewater and stormwater infrastructure and systems (Jingan et al, 2005). Environmental impacts have not traditionally been a significant factor in assessments and are challenging to quantify. Ultimately, the cost mechanisms of public works projects generally fail to allocate resources according to social benefits, requiring land use officials to factor in such priorities.

1.1 Watershed Planning. Land use impacts directly affect public health as well as environmental health and this factor is frequently omitted from land use planning. The effects of sprawling patterns of development can be seen in the many impacts to human mental and quality of life issues related to crowding and congestion, especially in urban environments. Other more physical impacts can be seen in reduced drinking water quantity and quality. Sources of drinking water, including groundwater, rivers, surface waters and reservoirs, are susceptible to contamination from non-point source pollution from land runoff or failing septic systems. Because groundwater is often left untreated, it poses the greatest risks of health effects.

Many municipal planners do not have to consider the watershed outside of their political boundaries, leaving this aspect to broader-scoped organizations. Watershed initiatives directed by federal and state organizations fail to reach many municipalities due to human resources, time and legalities. The ultimate goal of this study is to provide a series of science based transferable recommendations upon which municipalities can make land use planning decisions. Without the effective transfer of these recommendations into existing policies like zoning, the results of the study have limited use. Therefore implementation of recommendations within municipal planning documents is an important component. This information will be utilized to evaluate priority water resource protection overlays by providing quantitative information and decision making within a community.

1.2 The Ecosystem Approach. Ecosystem approach is defined as "the interconnections within the environment among water, air, land, and wildlife, and the need to consider the broad impacts on the whole system before taking action" (MacKenzie 1996; p. 72). The ecosystem approach is a method for sustaining or restoring ecological systems and their functions and values. It recognizes that humans, with their cultural diversity and economic structures, are an integral component of ecosystems. The ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. Ecosystem approach requires a thorough understanding of structure and function of the ecosystem and is the typical point of view of environmentalists and research scientists. It is goal driven, and it is based on collaboratively developed vision of desired future conditions that integrates ecological, economic, and social factors. Often, the ecosystem approach is applied within a geographic framework defined by watershed boundaries.

Despite the interest in the ecosystem approach to resource management from researchers and state and federal agencies, one caveat to ecosystem approach is in implementation. Unless fundamental changes come about, land use planning will always be inconsistent with the ecosystem approach because of the challenges of integrating collaborative decision making.. This leads to questions regarding implementation where the integration of structural and functional webs of abiotic and biotic factors is of both conceptual and practical importance. If we understand that a healthy and stable environment is essential, why do we do such a poor job achieving it? Draheim (2008) insists that scientist must remain involved in all stages of a project from planning through implementation for monitoring and assessing project's success.

1.3 Thesis Focus and Applicability. This thesis will add to the existing literature in the field of planning by integrating a watershed-based approach that is necessary to study impacts at an ecosystem-level into municipal planning. It will also provide an analysis of water resource planning options concerning future development. A citywide watershed model and analysis used to guide policy-making and decision-making will assist in fulfilling the community of Northampton's continuing commitment to work toward economical, environmental, and equitable sustainability. The results of the analysis will also help guide policy regulations and decision making in the near future. Specifically, the environmental, economic, and social analysis will include a comparison of five development scenarios under changing criteria and assumptions regarding land use patterns, population density, lot size, and best management practices technologies. The scenarios require and initial calibration of the baseline model and additional adjustments to allow for innovative land use practices.

This analysis is valuable in considering mutual cooperation or conflict based on planning for the impacts of stormwater runoff. The analysis is a useful tool to assess efficiency of various conservation practices and uses GIS and scientific methods that may be transferable to other areas. The scenario-based analysis will include for the first time in planning literature, the Deliberative Attribute Prioritization Procedure (DAPP) (Shriver and Randhir 2006) that can quantify ecosystem benefits to alternative strategies. The project provides an opportunity to learn if the DAPP is an appropriate and feasible tool for resource planning. Community involvement is an important component to water resource planning but is often overlooked because it can be contentious and time consuming. One of the prime objectives is to show that the DAPP is an effective, efficient, and noteworthy procedure for use in water resource planning at the municipal level.

The effectiveness of the political process on the municipal level depends of the level of inclusiveness applied to the decision making. A spectrum of stakeholders represents a strong democracy, a transparent and open planning process and the engagement of the public. As in all democratic processes, citizens need to care and believe that their political participation will affect decisions. The DAPP process achieves this.

1.4 Goals and Objectives. The overarching thesis question is: What kind of transferable, prescriptive, and sustainable policies can be implemented using an ecosystem approach in land-use planning in the city of Northampton, MA? The objectives in answering this question range from broad to narrow in scope.

Goal 1 – To understand the historical and current state of land use planning and its relation to water resource management.

Objective 1.1: Identify development patterns.

Objective 1.2: Account for imperviousness of various land uses and assess stream quality.

Objective 1.3: Address issues of regionalism and planning within political boundaries, rather than hydrological ones.

Goal 2 – To complete a thorough environmental analysis that will provide a transferable example or method to help the city of Northampton with their sustainability planning and decision-making processes.

Objective 2.1 – Analyze hierarchies of various attributes contributing to sustainability of an urbanizing watershed.

Objective 2.2 – Utilize stakeholder values in determining value of water resource protection.

Goal 3 – To understand if Northampton's zoning trends encourage cooperation or encourage conflict amongst neighboring communities in dealing with water resource issues.

Objective 3.1 – To understand hydrology and landscape connectivity in Northampton.

Objective 3.2 – To create relationships between land use and hydrology.

Objective 3.3 – To generate common ground for mutual cooperation amongst neighboring communities.

1.5 Project Description. In this thesis, a watershed scale will be used to quantify components of the watershed. Subwatershed boundaries that flow throughout the City of Northampton will be derived from MassGIS data layers and will be used in spatially analyzing water quantity and quality of the Mill River subbasin. In addition to GIS, computerized watershed models will be used; specifically BasinSim. Data on annual precipitation, land use, and soils will be used to estimate runoff and infiltration rates.

Water quantity factors such as evapotranspiration, groundwater storage, runoff and streamflow, and water quality factors such as erosion, sediment, total nitrogen and total phosphorus will be simulated and assessed.

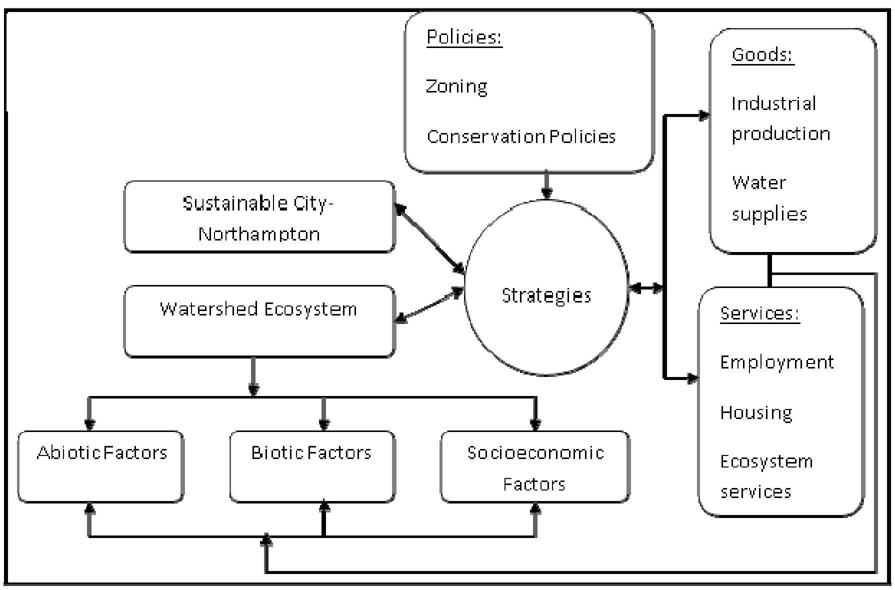
In 2003, the City of Northampton was awarded funds provided by the Commonwealth's Massachusetts Executive Order 418 program to develop an initial plan (Grow Smart Northampton) as part of the process for revising the Northampton Vision 2020 Comprehensive Plan. This plan provided a cursory water budget analysis for drinking water only. Furthermore, the DEP completed a Source Water Assessment Program (SWAP) Report. This report included a review of the watershed lands and aquifer protection zones. The largest threats to the water supply identified in the report were from residential fuel storage and large scale commercial uses (Northampton Open Space Plan, 2006).

The watershed model considers three factors: 1) precipitation and stormwater (stormwater runoff, recharge and evapotranspiration); 2) wastewater imports and exports; and 3) water withdrawals (Town of Lancaster 2006). This information must be obtained from sources such as the City of Northampton, United States Geological Survey and the National Oceanic and Atmospheric Administration in order to produce accurate results.

In order to perform the group valuation exercise, attributes of a sustainable city will be decided upon and prioritized by the project members. Weighted attributes for consideration include factors of a sustainable city such as land use, water quantity and water quality. Quantitative values for the attributes will be determined by the Deliberative Attribute Prioritization Procedure (DAPP) (Shriver and Randhir 2006, 2007). A focus group consisting of representative stakeholders in the city will determine the relative values of various attributes of the system. Stakeholders will be invited to the session and targeted representatives will be business owners, water officials, regional planners and city officials and constituents. This method has been used in local watersheds (Ware River watershed and Chicopee River watershed) with excellent results (Shriver and Randhir 2006). Relative importance of each attribute will be derived using an individual survey and a group consensus survey. Benefits for each scenario from the watershed model will be based on improvements to the city's land use regulations through corresponding value changes in the attributes.

1.6 Research Methods

Figure 1 Conceptual Model Ecosystem Approach to the Sustainability of Urbanizing Watersheds



The conceptual theme underlying this thesis is the relationship between a watershed ecosystem based on hydrological boundaries and a sustainable city based upon political boundaries. The components of the watershed ecosystem include abiotic (nonliving chemical and physical factors in the environment), biotic (living organisms), and socioeconomic (relationship between economic activity and social life) factors for the city of Northampton, Massachusetts.

The sustainable city is dependent upon the successful implementation of various strategies. The strategies may be identified as policies or as goods and services. Policies, such as zoning (separation of uses) have been employed and exist, status quo, until more innovative land use techniques, such as conservation policies and best management practices are implemented in order to protect natural resources. Examples of goods are: industrial production, water supplies, and quality of life factors; while services can be defined by the supply of employment, housing, and ecosystem services.

Value judgments about water quality and quantity, as well as other attributes, are based on qualitative attribute rankings performed via the Deliberative Attribute Prioritization Procedure (DAPP). These attributes are produced from the watershed model, and are compared with the biotic, abiotic and socioeconomic factors.

The interconnectedness of these relationships highlights the importance of balancing watershed ecosystems and land use policies within political boundaries. The use of scientific modeling and attribute values provide for a better overall assessment of natural resources for a municipal planner.

1.7 Boundaries Analysis. The primary goal of objective one is to understand relationships between hydrology, zoning, land use patterns, and water quality and quantity. As a result, data will be produced that provides insight as to whether Northampton's zoning trends encourage mutual cooperation and creates conflict with respect to protecting water resources and ecosystems. A GIS based spreadsheet analysis will highlight the differences in land uses and stream quality. This objective will produce a basis for mutual cooperation concerning water quality amongst neighboring communities will be created. A review of existing planning and zoning documents for the city of Northampton as well as methodologies in implementing performance based zones in other areas will be performed. The case for emphasis on the regional ecosystem based approach will be explained based on relevant literature.

1.8 Deliberative Attribute Prioritization Process. In order to achieve the final objective, objective four, ecosystem approach attributes will be assessed and ranked by an expert panel using the DAPP method in order to recommend improvements to the city. The developers of the method, Dr. Timothy Randhir and Debbie Shriver (NRC watershed specialist) will assist in this exercise.

1.9 Watershed Modeling Simulation. A scenario analysis will be used to quantify various existing and proposed land use measures, best management practices (BMPs), and combination of these in order to achieve objective three. The advantages will be compared to the “Do nothing” scenario that will serve as a baseline. It is expected that the most time consuming task in running the scenario analysis will be calibrating the initial model using BasinSim watershed modeling software. The four scenarios are as follows:

1.9.1 Baseline (Current Zoning/Status Quo). Water quality and quantity analysis of the Mill River Subbasin will be determined based on present zoning and land use patterns. This scenario will form a reference point for quantifying effects of other scenarios. A separate scenario for various combinations of land use techniques will be performed.

1.9.1(a) Scenario 1: Aggressive New Land Use and Zoning Measures Scenario. In this scenario, new development will take place in the already densely populated downtown area and other densely settled areas in order to intensify impacts. This scenario will consider areas that increase open space and improve ecological benefits.

Considerations include lot size, zoning, land use, runoff, recharge, and soils. It is hypothesized that, despite development and the interruption of the natural hydrology of the land, it is possible to improve a site's water quality and quantity results with the inclusion of best management practices.

1.9.1(b) Scenario 2: New Development with BMPs. In this scenario, zoning will remain as is but new development will include best management practices (BMPs) in onsite wastewater, stormwater, and potable water facilities. BMPs are described by the Environment Protection Agency as "effective, practical, structural or nonstructural methods which prevent or reduce the movement of sediment, nutrients, pesticides and other pollutants from the land to surface or ground water." These practices are developed to achieve a balance between humans and resources within natural and economic limitations. It is hypothesized that the results will show slightly higher water quality and quantity results than the status quo produced.

1.9.1(c) Scenario 3: New Development without BMPs. This scenario will compares current zoning without the incorporations BMPs. The combination will include land use in already developed and zoned areas along with regulation on developmental practices. Engineers and site designer have long used stormwater management practices such as retention and detention ponds and piped conveyances which drain into wetlands or water bodies and do little to infiltrate or reduce nutrients or pollutants from runoff. It is hypothesized that this scenario will not achieve premium water quality but may achieve adequate water quantity results.

1.9.1(d) Scenario 4: Combination 1. In this scenario, aggressive urban development occurs without aggressive use of best management practices. Intensified zoning is in place but infiltration and nutrient and pollution removal opportunities are at sta. It is hypothesized that this scenario may achieve adequate water quantity but may achieve adequate water quantity results.

1.9.1(e) Scenario 5: Combination 2. In this scenario, aggressive urban development occurs with the aggressive use of best management practices. Standards may exceed what exists in common practice to achieve the best method for sustaining or restoring water quality and quantity. It is hypothesized that this scenario will produce the highest and best water quality and quantity results.

1.10 Chapter Summary. The framework, goals and objectives of the thesis have been provided in this chapter. The author predicts, through a series of intense models and expert participation, a structure for the comprehensive management of water resources which promote conservation and sustainable land use. The following chapter details existing state of the literature in watershed science and policy.

CHAPTER 2
LITERATURE REVIEW

Municipal planners are often faced with the challenge of making sound water-resource zoning decisions within political boundaries while federal and state agencies, like the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP) promote programs utilizing inter-boundary, watershed-based decision-making skills (Goldfarb 1994). The watershed concept includes socioeconomic factors as well as ecological and hydrological ones. The following literature review contains an account of what has been published on the topic of environmental and land use planning on a watershed scale by accredited scholars and researchers. Various themes, methods and models for integrating empirical and scientific data are discussed with their implications for water resource protection by the municipal planner.

2.1 Planning Theory and the Environment. Alberti (1999) utilizes existing planning literature to measure the relationship between urban spatial patterns and environmental quality at the local, regional, and global scales. Four structural variables are presented to describe urban patterns (form, density, grain and connectivity) as well as four dimensions of environmental performance (sources, sinks, ecological support systems and impacts on human well-being) to summarize the research question. While the author aims to measure the effect of urbanization on ecological systems, framework is laid for future research. However, scientific measures at a more localized scale should be easier for a planner to evaluate.

A set of normative, or explanatory, planning criteria and processes for analyzing sustainable watershed management can and should be created. The emergence of widespread natural resource operational models for planners will occur through greater research, greater transfer of knowledge from the social science fields to the natural resource fields, the promotion of interdisciplinary collaboration, and, increased institutional changes required for decision making (Margerum 1997). This last method of integrating approaches to environmental planning and management dispels the current pattern of fragmentation in collaboration among stakeholders.

The results of the water balance highlight the importance of protecting streams and aquifers from the impacts of development. Planners should be able to make such decisions because technologies such as GIS and specialties such as environmental planning have further evolved (Rome 1994, White & Mayo 2004). Rome (1994) established a framework for the environmental history of residential development in American cities and suburbs from 1870-1990 where a pattern of development and neighborhood design that determines the severity of the hydrological disturbance is described. White & Mayo (2004) have created a model for predicting the trends in substantive environmental planning topics. The authors discuss the roots and foundations of the field of environmental planning and how programs can foster specializations while maintaining balance to promote sustainability.

2.2 Stakeholder Participation. Hedelin (2007) highlights the successful participation of stakeholders in the process of managing watersheds. It is important for the distinction to be made between participation and integration. The author uses a generic definition of participation to promote the idea of having a basic common interest with others to contribute to the process. Integration is a more holistic, interdisciplinary approach to management, adding commitment and legitimacy to the process. A set of decision-making strategies for planners and resource managers is created to utilize stakeholder opinion to value and promote rational discourse to water management issues. It is argued that the optimum way to reach sustainable development decisions is through a multi-dimensional approach.

Stakeholders are increasingly seen as an intrinsic component in water resource management within watersheds. Shriver and Randhir (2006, 2007) discuss approaches that include applying quantitative measures in assigning "willingness to pay" values (not necessarily monetary) to biotic, abiotic, and socioeconomic components of the watershed. In their DAPP approach, participants are asked to answer a variety of ecosystem attribute questions in relation to each other to obtain the value. The attributes are derived from a watershed computer model and used in DAPP. This method could be of importance to a planner with time constraints because the focus group lasted a single afternoon while the process of deliberations and consensus building lasted approximately seven weeks. This approach allows for actual expert and citizen control rather than tokenism, or worse, nonparticipation (Arnstein 1969). Municipal planners can benefit from seeking the advice from experts and citizens in applying cost values to more accurately measure implications from zoning.

2.3 Science and Policy Assessment. It is important to use an integrated watershed approach order to create a comprehensive land use plan because increased urbanization and impervious surface water runoff contribute immensely to surface and groundwater contamination (Kaufman & Brant 2000, Margerum 1997, Perlman & Milder 2005). Kaufman & Brant (2000) examined the role of impervious cover as a watershed based zoning tool to protect water quality in the Christina River Basin of Delaware, Pennsylvania, and Maryland. They concluded that the measure of impervious cover should be considered an effective, scientifically defensible technique to protect water quality and promote sustainability. Margerum (1997) identifies an operational model to help guide planners through empirical investigations; transfer of knowledge from social sciences to natural resource fields; incorporations and collaborations; and, increased understanding of institutional changes required for integrated decision making. Perlman & Milder (2005) developed a planner's guide to ecological resources, particularly how land is used and developed and how land is transformed.

There is an apparent disconnection between scientist and policy-maker responses in dealing with water resource management (Wolosoff and Endreny 2002). Scientists undertake studies that can last for years, which is a luxury of time that many town planners do not have. Some municipalities have a rapid rate of suburbanization which has an impact on hydrology that cannot be generalized into water quality protection laws with great efficiency. Additional empirical research would serve to fill the temporal gap between science and policy, and promote a more holistic approach in planning. Transferable and scientific operational models for preparing natural resource protection overlays should be more available to the municipal planner for efficiency purposes.

2.4 Computer Modeling and Simulation Systems. Technological methodologies for incorporating preference benefit-cost analyses to environmental-economic decision-making have been documented by Shriver and Randhir (2006) and Tiwari (2000) using geographical information systems (GIS). A GIS based approach allows the planner to integrate the two types of information in the computation process. Many planners have, at least, introductory skills in GIS. The planner can measure implications of as-is zoning as well as a variety of scenarios for water resource protection.

GIS can and should be the primary technical tool that the municipal planner uses in making water resource zoning decisions. There are several studies and pilot programs which document methodologies in determining watershed health (Kaufman and Brandt 2000, Town of Lancaster, MA 2006). A watershed inventory should be done to identify biotic and abiotic factors prior to starting the analysis. GIS data layers, like zoning, aquifers, land uses, soils, geology, and others including precipitation and evapotranspiration, should be collected (Fennessey and Vogel 1996). Precipitation and evapotranspiration represent input and output features (along with runoff) in a simple mass balance equation or water budget. It is important for a planner to consider the interconnectedness of water, wastewater, stormwater and water balances (surface and groundwater) in zoning for water resource protection.

Much of the literature available to planners emphasizes impervious surfaces as the key indicator of water quality (EPA 2007, DEP 2007, Brabec et al 2002, Tripathi et al 2006). Impervious surface has been identified by the EPA as the most prolific source of non-point source pollution in stormwater runoff. Assumptions must often be made at the municipal level about methodologies used to calculate runoff which may skew data resulting in incorrect evaluations. It is suggested that older, non-technical approaches from the 1970's, which many planners use to determine imperviousness, are inefficient and often inaccurate. These inaccuracies are based on three factors: considerable variation in imperviousness within each land use based on land cover types; density patterns, lot and parcel sizes within each land use classes skews imperviousness; and, base studies from which the impervious surface percentages were based on have changed (Brabec et al 2002). This information is important to consider, but planners in Massachusetts have more updated geographical data than many other states, as the land use classes were updated most recently in 2002. It would also be irresponsible not to complete the next step to determine total impervious surfaces and soil runoff values in a watershed. One must take into consideration those variations in densities and land covers to calculate effective imperviousness, based on 'effective' impervious coefficients (Aqua Terre Co. 2004). This important step allows a planner to have not only a more accurate value to determine stream quality, but provides threshold measure for imperviousness in a particular zone.

There are additional technological models to assess watershed health and water quality like STELLA, BasinSim and the Soil and Water Assessment Tool (SWAT). These models are excellent tools which may be downloaded without a fee; however, a local planner may not have the resources to sufficiently learn each one. Erosion, nutrient and sediment yields are used in the BasinSim model and the interconnectedness of water is highlighted using the STELLA model. Tripathi et al (2006) used the SWAT model to simulate the hydrologic cycle as based on the water budget equation. Since the model maintains a continuous water balance, complex basins were subdivided to reflect differences in evapotranspiration (ET) for various soil types. The runoff was predicted separately for each sub-area and the total runoff is obtained for the entire basin. The Soil Conservations Service's (SCS) curve number technique is utilized in the SWAT model. The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall in a particular area. The curve number is based on the area's hydrologic soil group, land use, and hydrologic condition.

A causal factor in the disconnection between environmental degradation and water resource protection is that the impact is most often an aggregate of development components. Asphalt, roofs and other impervious surfaces are often recognized as the worst offenders while lawns can be almost as disastrous in contributing to non-point source pollution. Thompson (2004) argues even well-intended citizens fail to adopt pro-environmental behaviors and more education and outreach is necessary for water resource protection. Education, outreach and action should be part of the municipal planner's implementation toolkit.

2.5 Chapter Summary. Future research in water resource protection and sustainable development practices is also necessary in evaluating zoning within municipal boundaries. Jepson (2004) aims to analyze the responses from a 2001 survey that was intended to provide answers to three questions regarding: the nature and extent of sustainable development practices in the US, the barriers to policies to implement such practices, and, the role of planners in the enactment of policy. Jepson first had to create a framework to define sustainable. He used various literatures that promoted the 3 E's of sustainability – Economy, Environment and social Equity. Communities of all sizes and in various parts of the country participate in some form of sustainable development and the role of planners may be further enhanced to promote a more holistic discipline in planning, rather than specialization.

Water resource protection zoning should be based on scientific information that many planners simply do not have time or resources to prepare properly. It is prudent to provide a transferable methodology for planners to follow that would give proper balance to human impact on natural resources. Subbasin focused analysis may actually provide better watershed health measures because it focuses on a smaller, more efficient scale. This could put a positive spin on working within (or close to) political boundaries. A more powerful argument for planners to consider implementing integrated water budget approaches to municipal planning can be developed.

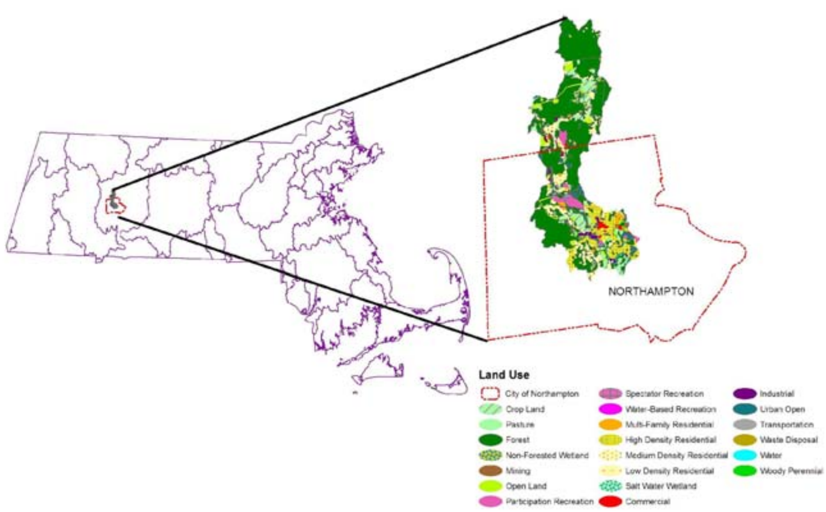
CHAPTER 3

METHODS OF ANALYSIS

This chapter describes the study area and data, as well as the rational and details, for the three methods created to identify recommendations upon which municipalities can make land use planning decisions. In order to analyze land use impacts on water quality and quantity in Northampton a watershed inventory must be performed to assess the problem as biotic, abiotic and socioeconomic factors are explored in an ecosystem-based approach in order to ensure the healthy ecosystem which humans and economies depend on.

3.1 Study Area. The study area is Northampton, Massachusetts. According to the United States Census 2000 Demographic Profile, there were 28,978 people, 11,880 households, and 5,880 families residing in the city of Northampton. The population density was 841.0 people per square mile. There were 12,405 housing units at an average density of 360.0 per square mile (US Census, 2000). The hydrological boundary of the Mill River Subbasin and corresponding land use classifications are as follows:

Figure 2 Land Uses of the Mill River Subbasin (See also Appendix A)



3.2 Boundaries Analysis. Literature cited in Chapter 2 demonstrates the importance of calculating the effective impervious area (EIA) of a community in order to determine the impact to stream quality (EPA 2007, DEP 2007, Brabec et al 2002, Tripathi et al 2006). Impervious area such as rooftops, streets, sidewalks, and parking areas do not allow water to infiltrate the soil. Impervious area that collects and drains the water directly to a stream or wetland system via pipes or sheet flow is considered “effective impervious area” (EIA), because it effectively drains the landscape. Impervious area that drains to landscaping, swales, parks and other impervious areas is considered “ineffective” because the water is allowed to infiltrate through the soil and into ground water, without a direct connection to the stream or wetland (Alley, 1983). EIA analysis is important because it is known that impervious surfaces interrupt the hydrologic cycle. This provides the rationale for this study’s broadest research objectives: understanding the historical and current state of land use planning and its relation to the water resource management.

The main methods of analysis for determining the impact of Northampton’s land use practices and EIA were performed via geographic information systems (GIS) and calculations in an Excel spreadsheet. Land use data layers were downloaded from MassGIS and categorized by the impervious coefficient provided by MassGIS. Land uses were clipped by hydrologic boundaries as well as by political boundaries. Figure 2 and Appendix A feature the spatial analysis using GIS and the calculations in spreadsheet format. Northampton's stream quality is generally good as any percentage less than ten is considered to be a sensitive stream without severe degradation. Stream quality decreases in proximity to the more urbanized and densely populated downtown region.

3.3 Deliberative Attribute Prioritization Process. The Deliberative Attribute Prioritization Process (DAPP) is a tool for consensus building based upon the Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty (1999), and broadened by Dr. Timothy Randhir and Deborah M. Shriver (Shriver 2005, Randhir and Shriver 2007). The AHP is a tool to build consensus and advise decision-makers through an iterative process. The AHP has broad application for decision-making in complex environments, particularly where disparate or conflicting elements must be compared and weighed. The AHP depends upon developing a hierarchy of goals, attributes or measures and rating the importance of each in relation to the others on a scale of 1 to 9 (equal importance to absolute importance of one over the other) through pairwise comparisons. The power of the AHP lies in its ability to quantify the degree of agreement among participants and allow for discussion and exchange of information to influence the ranking process. Randhir and Shriver expanded on the method by analyzing individual results with the results of the consensus. Thus it can be both a quantitative and qualitative tool.

Table 1 The Fundamental Scale for Pairwise Comparisons (Saaty, 1999)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two attributes are equal in importance to sustainability
3	Moderate importance	Experience and judgment slightly favor one attribute of sustainability over another
5	Strong importance	Experience and judgment strongly favor one attribute of sustainability over another
7	Very strong or demonstrated importance	An impairment indicator is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring the importance of one attribute of sustainability over another is of the

		highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocals of above	If attribute X has one of the above numbers assigned to it when compared with indicator J, then J has the reciprocal value when compared with X	Where the first element of a pair is judged to be less important than the second element, use the reciprocal to show the relative importance of the second element over the first

In the DAPP (Shriver 2005, Randhir and Shriver 2007) a hierarchy of criteria is created so that any element in one level can be related to some elements in the next higher level. The DAPP uses pairwise comparisons of elements of a hierarchy and asks participants to fill in a matrix in which each element of the hierarchy is compared and ranked for its importance against every other member of the hierarchy and rated on a scale of 1 (equal importance) to 9 (extreme importance). If the element is less important than the one with which it is compared, a reciprocal value is entered in the matrix (Table 2).

Table 2: Sample AHP Matrix

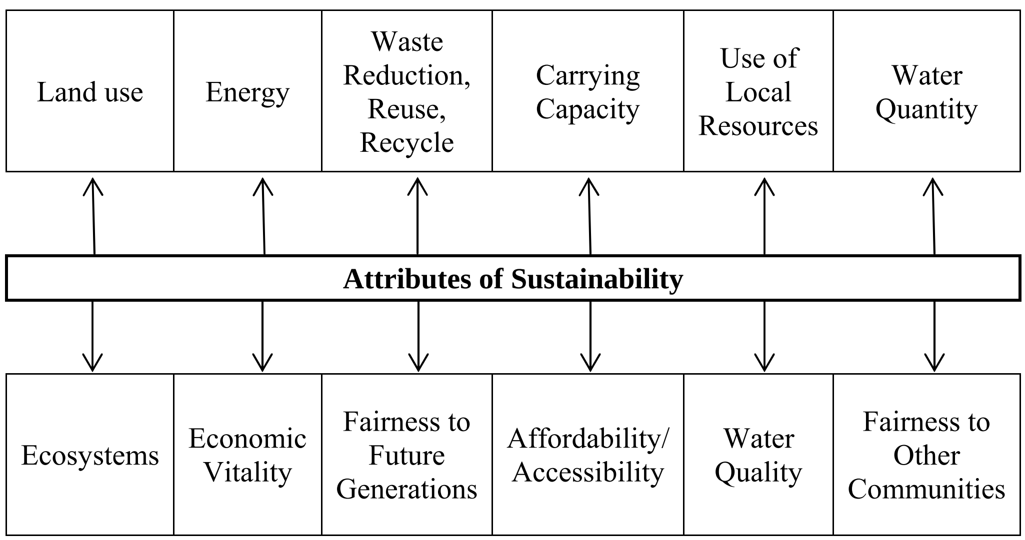
Criterion	A_1	A_2	A_3	…	A_7
A_1	1	5	3		
A_2	1/5	1			
A_3	1/3	1/5	1		
…				1	
A_7					1

Analysis follows these steps: 1.) The values in each column are summed and each entry is divided by the column total to obtain a normalized matrix of values thereby allowing a meaningful comparison of the elements. 2.) Each row is then summed and divided by the number of entries in the row to get relative weights. 3.) A test for consistency is applied by calculating λ_{max} by multiplying each paired comparison value by its respective weight derived in step 2. The new row total is divided by the relative weights from step 2. 4.) These quotients are averaged to produce λ_{max}. 5.) A Consistency Index (CI) is calculated as follows:

$$CI = \lambda_{max}-n/n-1$$

where, n is the number of elements which form the matrix. 6.) The computed CI is divided by the random value of CI for a matrix of n elements (random value for matrix of 12 elements = 1.35) to determine the Consistency Ratio. In matrices of more than 4 elements, this value should be less than or equal to 10% (Saaty, 1999, pp. 69-85).

Figure 3 Conceptual Model for the Attributes of Sustainability



In November 2007, the author made contact with stakeholders in the Mill River watershed in Northampton by phone and electronic mail (Appendix C). Stakeholders ranged from state, regional and local planners and officials to homeowners, business persons and farmers. They were informed that they would be involved in a focus group following a methodology created by Dr. Timothy Randhir and his former graduate student, Debbie Shriver, where the group (experts/officials, citizens, business community members) pairs and weights attributes that contributes to a sustainable city with a focus on structure and function of the broader ecosystem. The stakeholders were given a list of attributes of a sustainable city, like water quality, water quality, habitat protection, amount of impervious surface, land use, energy efficiency etc. Each participant was asked to rank the top twelve (12) attributes. The attributes were framed as follows (adapted from Sustainable Seattle 2005):

Table 3 Attributes of a Sustainable City

Land use	Uses land prudently, assuring quality wild and productive lands and compact urban development featuring pedestrian- and transit-oriented mixed-use development (for people of all ages) with access to green space.
Energy	Promotes use-reduction, renewable energy, and greater efficiency in the use of energy resources.
Waste Reduction, Reuse, Recycle	Reduces resource consumption, focuses on preventing waste and pollution, locally reuses and recycles materials, and responsibly manages waste.
Carrying Capacity	Keeps levels of pollution, consumption and population size within the environment's ability to handle them.
Use of Local Resources	Respects and uses local people and their knowledge, and local energy and materials.
Water Quantity	Maintains adequate supplies of surface or ground water.
Ecosystems	Maintains or enhances ecosystem functions (watershed quality, biodiversity and habitat - including wildlife corridors). (Natural)
Economic Vitality	Improves opportunities for new and existing businesses, emphasizing smaller, locally-owned businesses and value-added industries for local products.
Fairness to Future Generations	Considers the well-being of those community members who will inherit the impacts.
Affordability/ Accessibility	Promotes fair and affordable access to housing, services, and opportunities within the community.
Water Quality	Maintains chemical, physical, biological, and radiological condition of a surface or groundwater body.
Fairness to Other Communities	Does not unfairly impact people in other parts of the city or region, or in other parts of the world.

Prior to the focus group the top 12 attributes were compiled and the stakeholders were sent empty matrices to perform an individual ranking. Most matrices were returned prior to the focus group; however some were not (Appendix D). Those individual rankings were done at the focus group, prior to the group consensus building exercise, during lunch (which was provided by the author).

The Focus Group occurred on Friday, January 25, 2008 at Forbes Library in Northampton. Participants were invited to arrive at 12:00 PM for lunch and to have time to introduce themselves and briefly get to know each other. Among the nine participants were: a small business owner specializing in landscape construction; an urban forestry professor; a Massachusetts Department of Conservation and Recreation program manager; a city engineer; an environmental engineer for a regional organization; a regional land use planner, a city environmental planner, a project coordinator for a regional watershed coalition; and a resident homeowner in the Mill River subwatershed. Michael Cote, student, University of Massachusetts, assisted the author with note-taking, timing, and tracking the dynamics of the discussion during the focus group.

The author/facilitator explained the conceptual model (Chapter 1) of this thesis and the agenda (Appendix E). A large empty matrix was posted and the author asked questions in order to evaluate relative importance. For example, how important is changing land use compared to reducing energy use towards the goal of achieving a sustainable city? The participants were asked a total of sixty-five pairwise questions in random order (Appendix F). The paired comparison of all attributes allow participants to have a clearer perception of what is being ranked compared to the intermediate hierarchy obtained in the preliminary stages of the process. The questions were asked randomly, rather than orderly (starting in the upper-left-hand corner of the matrix) in order to allow for more debate about paired attribute from seemingly unrelated portions of the matrix. Shriver (2006) also found that randomly choosing the attribute pairs to be a time saver, as lengthier discussion occurs sooner than later in such a focus group.

3.4 Watershed Model Description. BasinSim is a Windows-based watershed simulation modeling programs useful to decision-makers who must weigh difficult trade-offs between human habitation and environmental protection. BasinSim was developed at the Virginia Institute of Marine Science at the College of William and Mary through a NOAA Coastal Zone Management grant. The purpose of BasinSim is to predict sediment and nutrient loads for small to medium sized watersheds to answer "what if" land use scenarios. The simulation system is based on the Generalized Watershed Loading Functions (GWLF), which was developed and tested at Cornel University.

GWLF is a mathematical model for estimating the dissolved and total monthly nitrogen and phosphorus loads in streamflows from complex watersheds. Both surface runoff and groundwater sources are included, and closely approximate the Soil Conservations Service's (now Natural Resources Conservation Service) Technical Release 55 (NRCS, 1986). GWLF also incorporates models such as the EPA's Storm Water Management Model (SWMM) (Huber and Dickinson, 1981) and Storage Treatment, Runoff Overflow Model (STORM) (USACE, 1977). SWMM is a dynamic rainfall-runoff-subsurface runoff simulation model used for single-event to continuous simulation of the surface and subsurface hydrology from primarily urban/suburban areas. STORM was created by the Army Corps of Engineers in 1977 as a means for analysis of the quantity and quality from urban and non-urban watersheds. The creators of the GWLF model provided expanded mathematical descriptions of their model as well as detailed guidance on parameter estimations in order for researchers who may wish to modify (or improve) GWLF for their own purposes.

GWLF acts as the foundation for BasinSim insofar as the natural hydrologic cycle is simulated, predicted streamflow is based on precipitation, evapotranspiration, land uses and soil characteristics. Loading functions specific to the watershed are used along with the hydrologic cycle to predict nutrient loads from surface runoff, groundwater, point sources and septic systems. Monthly streamflow, soil erosion, and sediment yield information is also obtained from BasinSim.

3.5 Local Watershed Customization and Data Input. Input data for BasinSim can be obtained through local, regional, state and federal agencies. The process of customizing the model to local watersheds consists of collecting data and entering it into input files. There are three required input files necessary to run the model: Nutrient, Transport and Weather. These three files provide the model with the necessary input data for land use, hydrology, erosion and sediment, nutrient concentrations in runoff, and daily temperature and precipitation data. A fourth file of USGS streamflow data is required for calibrating the hydrological model.

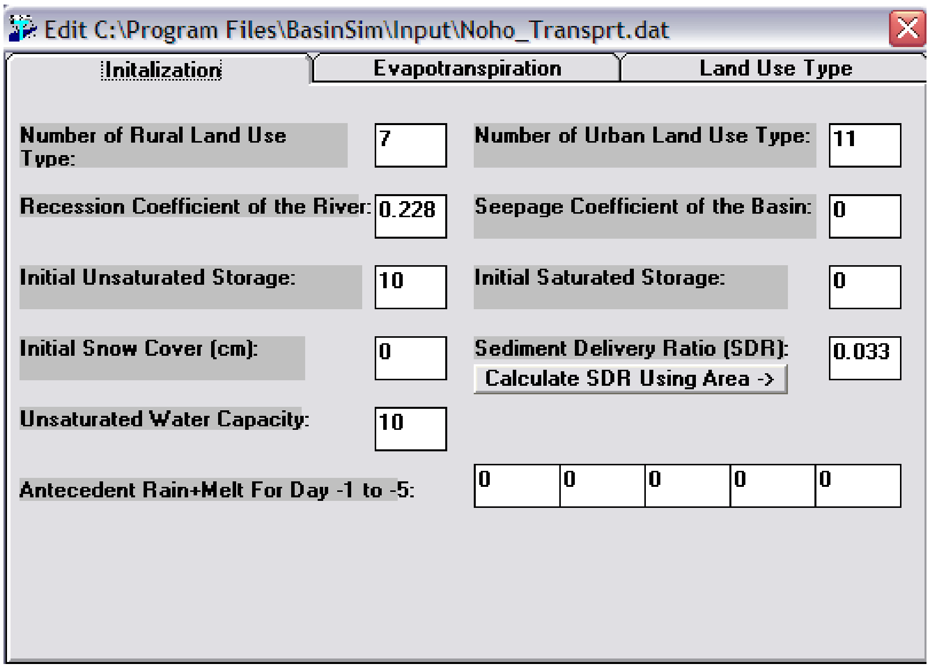
3.5.1 Weather File. BasinSim requires that the user has at least one year of temperature and precipitation data from weather stations within the watershed being modeled. Because BasinSim is a watershed model, a single point in a large watershed is not representative of the overall climate conditions, especially, the precipitation.

The weather file is created under the “Create New Weather Files” under the “File” menu. The user must first enter how many years of weather data obtained for the project. Six years of daily temperature and precipitation data was downloaded from the National Oceanographic and Atmospheric Administration (NOAA) website. The BasinSim program then brings forward a table filled with default weather data. Local temperature and precipitation data must be entered into the table. Users may enter the data in the table provided, or they may opt to create a spreadsheet or text file which can be imported and read by the program. An Excel spreadsheet was created indicating the number of days (Column A) in the corresponding month (Column B). The subsequent rows specify the temperature and level of precipitation. It is important that the user converts to the appropriate units; temperature must be in degrees Celsius and precipitation in centimeters. Other considerations include the format or structure of the data. The weather file must include at least twelve months of data which starts April 1 and ends March 31. The Excel spreadsheet was then imported into WordPad; which was then imported into BasinSim. The program calculates the Mean Daily Temperature (C) and Mean Daily Precipitation (cm) based on the number of months entered. The weather file contains 1,885 data entries**.**

3.5.2 Transport File. The transport file is a very data intensive, requiring multiple conversions and inputs. The first input of the transport file includes the following parameters: recession coefficient, seepage coefficient, initial unsaturated storage, initial saturated storage, initial snow, sediment delivery ratio and unsaturated zone available water capacity. The groundwater portion of BasinSim requires estimates of available unsaturated zone available soil moisture capacity U*, recession constant r and seepage constants.

In principle, U* is equivalent to a mean watershed maximum rooting depth multiplied by a volumetric soil available water capacity. The latter also requires determination of a mean unsaturated zone depth, and was not utilized for this analysis. BasinSim's developers point out in the User's Guide that it is probably impractical for most watershed studies and according to the manual, a default value of 10 can be assumed for pervious area, corresponding to a 100 cm rooting depth and a 0.1 cm/cm volumetric available water capacity. These values appear typical for a wide range of plants (Jensen et al 1989 and US Forest Service 1980) and soils (Rawis et al 1982).

Figure 4 Transport File - Initialization



Estimates of the recession coefficient r can be estimated from streamflow records by hydrograph separation techniques (Chow 1964). During a period of hydrograph recession, the rate of change in shallow saturated zone water S(t) (cm) is given by the linear reservoir relationship:

$$\frac{dS}{dt} = -rS$$

or,

$$S(t) = S(0)*e^{-rt}$$

Where S(0) is the shallow saturated zone moisture at t = 0. Groundwater discharge to the stream G(t) (cm) at time t is $G(t) = r * S(t) = r * S(0) * e^{-rt}$. During periods of streamflow recession, it is assumed that runoff is negligible, and therefore streamflow F(t) (cm) consists of groundwater discharge given by the preceding equation; i.e. F(t) = G(t). A recession coefficient can be estimated from two streamflows $F(t_1)$, $F(t_2)$ measured on days t_1 and t_2 ($t_2 > t_1$) during the hydrograph recession. The ratio $F(t_1)/ F(t_2)$ is

$$\frac{F(t_1)}{F(t_2)} = \frac{r * S(0)\, e^{-rt1}}{r * S(0)\, e^{-rt2}} = e^{-r(t2-t1)}$$

The recession constant is thus given by

$$r = \frac{\ln[F(t_1)/ F(t_2)]}{t_2 - t_1}$$

Recession constants are measured for a number of hydrographs and an average value is used for the simulations. Typical values range from 0.01 to 0.2.

The recession coefficient reflects the largest drop of the receding limbs of a hydrograph over a five (5) year period. The period selected was April 1, 2001through March 31, 2006. The recession coefficient for the Mill River was calculated from United States Geological Society (USGS) hydrographs downloaded from the government website (USGS, 2007). There is a monitoring station located at Latitude 42°19'08" and Longitude 72°39'56" on the left bank, 5 feet downstream from the Clement Street Bridge, and about 4 miles upstream from the mouth of the river. The drainage area that this station collects data for is 52.6 square miles.

Figure 5 USGS Monitoring Station

The data from the USGS hydrograph was formatted into an Excel spreadsheet indicating the date and discharge (in cubic feet per second). The author scanned the data for events of high precipitation. The year was divided into quarters and only the highest event was selected per quarter. The length of event was determined simply by the number of days until the hydrograph increased. Appendix B lists the entire hydrograph for the five-year period, but a sample of a large event in the hydrograph is contained in Table 4 below. A regression value of .228 was used to find the observed and predicted streamflow values. This is considered a high value; however, it is attributed to the high level of development in the watershed. As land use shifts, runoff curve numbers start to shift as well (i.e. an increase open space reflects a slower and smaller curve number).

Table 4 Sample Hydrograph from the Mill River

Date	y	x	Date	y	x	Date	y	x
1/1/2006		185	1/12/2006		257	1/23/2006	6	264
1/2/2006		161	1/13/2006		200	1/24/2006	7	243
1/3/2006		174	1/14/2006		926	1/25/2006	8	219
1/4/2006		146	1/15/2006		710	1/26/2006	9	197
1/5/2006		143	1/16/2006		301	1/27/2006	10	174
1/6/2006		134	1/17/2006		260	1/28/2006	11	173
1/7/2006		119	1/18/2006	1	1480	1/29/2006		199
1/8/2006		114	1/19/2006	2	794	1/30/2006		282
1/9/2006		107	1/20/2006	3	431	1/31/2006		246
1/10/2006		111	1/21/2006	4	359			
1/11/2006		120	1/22/2006	5	305			

x= Discharge, cfs
y=days in event (duration)

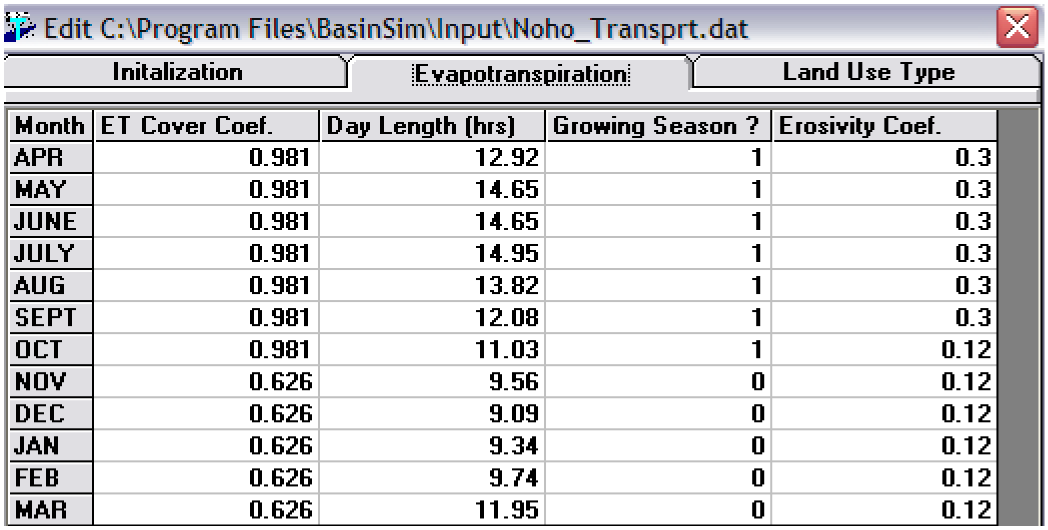
No standard techniques are available for estimating the rate constant for deep seepage loss. The most conservative approach is to assume that s = 0 because all precipitation exits the watershed in either evapotranspiration or streamflow. Otherwise the constant must be determined by calibration.

The sediment delivery ratio (SDR) is required in the transport file for the calculation of sediment output. Only a small portion of the eroded soils in a watershed is transported from the land to streams. The SDR is calculated within BasinSim. This utility calculated the SDR based on the watershed area.

3.5.3 Precipitation Parameters. The next five lines of the transport file list precipitation values in centimeters for the five days preceding the start of the simulation.

3.5.4 Monthly Parameters. The third section is a listing of monthly parameters: evapotranspiration (ET) cover coefficient, day hours, growing season and erosivity coefficient. Again, the user must enter the data starting in April and ending in March.

Figure 6 Transport File – Evapotranspiration



Month	ET Cover Coef.	Day Length (hrs)	Growing Season ?	Erosivity Coef.
APR	0.981	12.92	1	0.3
MAY	0.981	14.65	1	0.3
JUNE	0.981	14.65	1	0.3
JULY	0.981	14.95	1	0.3
AUG	0.981	13.82	1	0.3
SEPT	0.981	12.08	1	0.3
OCT	0.981	11.03	1	0.12
NOV	0.626	9.56	0	0.12
DEC	0.626	9.09	0	0.12
JAN	0.626	9.34	0	0.12
FEB	0.626	9.74	0	0.12
MAR	0.626	11.95	0	0.12

3.5.4.1 Evapotranspiration. The ET cover coefficient is the ratio of water loss by evapotranspiration from ground and plants compared to what would be lost by evaporation from an equal area of standing water (Brooks et al, 2003). Estimation of evapotranspiration cover coefficients for watershed studies can be problematic. Cover coefficients may be determined from published seasonal values. However, their use often requires estimates of crop development (i.e. planting dates, time to maturity etc.) which may not be available. Moreover, a single set of consistent values is seldom available for all of a watershed's land uses. The Hampshire County Soil Survey (1981) was consulted to verify that the growing season parameter identified in the BasinSim Users Guide.

ET cover coefficients vary by land use type and time period within the growing season. The value is usually between 0 (impervious surfaces) and 1 (water). However, some crops have values higher than 1 during the growing season; in other words, they lose more water per unit than standing water. In urban areas, ground cover is a mix of trees and grass. It follows that cover factors for pervious areas are weighted averages of the perennial crop, hardwood and softwood cover factors. It may be difficult to determine the relative fractions of more urbanized areas with these covers. Since these covers would have different values only during dormant seasons. The numbers entered into the transport file are monthly averages calculated for the entire watershed, weighted by land use percentages.

3.5.4.2 Growing Season and Erosivity Coefficient. The Hampshire County Soil Survey was consulted for the growing season and the standard erosivity coefficient from the BasinSim User's Guide was used.

Figure 7 Transport File – Land Use Types

Edit C:\Program Files\BasinSim\Input\Noho_Transprt.dat

Initalization | Evapotranspiration | Land Use Type

2.0349

Land Use Type	Area (ha)	Soil Curve #	K*LS*C*P	%Tot. Area	New %
Cropland	296.19	88	0.146	2.0349	2.0349
Pasture	43.76	88	0.0173	0.3006	0.3006
Forest	12688.12	70	0.0245	87.1707	'7.1707
Wetland	56.75	98	0.3	0.3899	0.3899
OpenLand	142.92	94	0.18025	0.9819	0.9819
Water	52.25	100	0	0.3590	0.3590
WoodyPerennia	5.37	70	0.299	0.0369	0.0369
Mining	6.02	76	0.42	0.0414	0.0414
PartRecreation	107.83	74	0.014	0.7408	0.7408
MultiFamily	33.4	90	0.046	0.2295	0.2295
Under1/4AcLot	538.79	83	0.0383	3.7016	3.7016
1/4to1/2AcLots	190.99	80	0.052	1.3122	1.3122
Over1/2AcLots	211.44	79	0.087	1.4526	1.4526
Commercial	32.11	94	0.173	0.2206	0.2206
Industrial	40.85	91	0.0955	0.2807	0.2807
UrbanOpen	102.5	74	0.0865	0.7042	0.7042
Transportation	0	98	0	0.0000	0.0000
WasteDisposal	6.19	69	0.0903	0.0425	0.0425
				Total:100.0	100.00

3.6 Land and Soil Parameters. The final portion of the transport file lists land types, area in hectares, soil curve numbers, and the components of the Revised Universal Soil Loss Equation (RUSLE) as indicated in Figure 7 by K*LS*C*P.

Land types must be listed in a specific order; specifically, all rural types first, the urban types (Table 6). Reliable land use data can be obtained from the MassGIS. The MacConnell land use series is one of the longest running time series of land use information in the State of Massachusetts (EOEA 2002). The series categorizes land uses and creates land use maps and statistics that are based on land cover digitized from aerial photographs. What make the series interesting is that it allows municipalities to track the land use changes over time back to 1971. Table 5 breaks down the land use categories identified by MassGIS and the acreage/hectares and determination of land use type, rural or urban. The author made this simplified the assumption by associating the standard definitions with the types of activities that occur in these areas.

Table 5 MassGIS Land Use Categories

CODE	CATEGORY	DEFINITION	ACRES	HECTARES	LU TYPE
1	Cropland	Intensive agriculture	731.89	296.18712	Rural
2	Pasture	Extensive agriculture	108.12	43.75644	Rural
3	Forest	Forest	31353.02	12688.11655	Rural
4	Wetland	Nonforested freshwater wetland	140.23	56.75	Rural
5	Mining	Sand; gravel & rock	14.87	6.02	Urban
6	Open Land	Abandoned agriculture; power lines; areas of no vegetation	353.15	142.91	Rural
7	Participation Recreation	Golf; tennis; Playgrounds; skiing	266.44	107.83	Urban
8	Spectator Recreation	Stadiums; racetracks; Fairgrounds; drive-ins	0	0	n/a
9	Water Based Recreation	Beaches; marinas; Swimming pools	0	0	n/a
10	Residential	Multi-family	82.54	33.41	Urban
11	Residential	Smaller than 1/4 acre lots	1331.38	538.79	Urban
12	Residential	1/4 - 1/2 acre lots	471.94	190.99	Urban

13	Residential	Larger than 1/2 acre lots	522.48	211.44	Urban
14	Salt Wetland	Salt marsh	0	0	n/a
15	Commercial	General urban; shopping center	79.35	32.11	Urban
16	Industrial	Light & heavy industry	100.93	40.84	Urban
17	Urban Open	Parks; cemeteries; public & institutional greenspace; also vacant undeveloped land	253.28	102.49	Urban
18	Transportation	Airports; docks; divided highway; freight; storage; railroads	0	0	Urban
19	Waste Disposal	Landfills; sewage lagoons	15.31	6.19	Urban
20	Water	Fresh water; coastal embayment	129.11	52.25	Rural
21	Woody Perennial	Orchard; nursery; cranberry bog	13.26	5.37	Rural
21 Land Use Categories		**Totals**	**35,967.3**	**14,555**	**Rural – 7** **Urban – 11** **n/a – 3**

The soil curve number is calculated using GIS software to overlay the land use map with the soil map. The user calculates areas for each soil type within each land use. The hydrologic group used for the soil curve number is the group expressing the highest percentage within a land use. The author clipped the Hampshire County soils GIS layer to the Mill River Subbasin Land Use layer. The layers where then joined together to be able to see attributes from both data layers, specifically to view areas and soil types. In ArcCatalog, two (2) attribute fields were added to the newly joined layer and ArcEditor was used to enter land use types (urban or rural) and hydrologic soil groups (HSG) i.e. A, B, C, or D. Soils are classified by the Natural Resource Conservation Service into four hydrologic soil groups based on the soil's runoff potential; where A's generally have the smallest runoff potential and Ds the greatest (NRCS 1986).

Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission. Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure. Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This Hydrological Soil Group has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material (NRCS 1986). TR-55 provides standard Runoff curve numbers for urban and agricultural areas and are indicated by Table 6.

Table 6 Land Uses and Hydrologic Soil Groups

Type	**Land Use**		**Hydrological Soil Group**			
Rural	Code	Description	A	B	C	D
	1	Cropland	72	81	88	91
	2	Pasture	92	81	88	91
	3	Forest	25	55	70	77
	4	Wetland	98			
	6	Open Land	39	61	74	80
	20	Water				
	21	Woody Perennial	25	55	70	77
Urban	5	Mining	76	85	89	91
	7	Participation Recreation	39	61	74	80
	10	Residential – multi-family	77	85	90	92
	11	Residential – high density	61	75	83	87
	12	Residential – medium density	54	70	80	85
	13	Residential – low density	51	68	79	84
	15	Commercial	85	92	94	95

	16	Industrial	81	88	91	93
	17	Urban Open	39	61	74	80
	18	Transportation	98	98	98	98
	19	Waste Disposal	49	69	79	84
						(NRCS 1986)

The author then calculated the dominant soils in the Mill River Subbasin by exporting the attribute table to Excel and there, the occurrences of soil types were counted. Table 7 summarizes the results as a percentage of the particular land use. The following chart represents the number of entries under each soil group to determine the dominant hydrologic soil group in each land use. (The author notes a limitation in this analysis in that she should have calculated areas of soil groups in each land use rather than number of occurrences in order to more accurately verify the dominant soil type).

Table 7 Dominant Soil Types

LU CODE	Hydrologic Soil Group					Total
	% A	% B	% C	& D	% N/A	
1	21	18	53	6	3	100%
2	14	18	64	1	4	100%
3	17	21	52	5	5	100%
4	--	--	--	--	--	*
5	50	0	40	0	10	100%
6	23	22	48	5	3	100%
7	27	27	39	0	6	100%
8	--	--	--	--	--	n/a
9	--	--	--	--	--	n/a
10	25	27	40	0	8	100%
11	16	27	45	4	8	100%
12	21	15	54	1	9	100%
13	19	23	52	4	2	100%
14	--	--	--	--	--	n/a
15	15	17	34	0	34	100%
16	18	29	32	0	21	100%
17	19	17	53	3	8	100%
18	--	--	--	--	--	n/a
19	22	33	33	0	11	100%
20	--	--	--	--	--	*
21	0	0	100	0	0	100%
* no soil groups, standard curve numbers applied						

Based on the dominant soil type, the author used the following runoff curve numbers (RCNs) in the modeling process. Rural land use types are as follows: Cropland, 88; Pasture, 88; Forest, 70; Wetland, 98; Open Land, 4; Water, 100; and Woody Perennial, 70. Urban land use types are as follows: Mining, 76; Participation Recreation, 74; Residential (multi-family), 90; Residential (high density), 83; Residential (medium density), 80; Residential (low density), 79; Commercial, 94; Industrial, 91; Urban Open, 74; Transportation, 98; and Waste Disposal, 69.

The Revised Universal Soil Loss Equation (RUSLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices (Brooks et al 2003). RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from other types of erosion such as gully, wind or tillage erosion (Brooks et al 2003). The erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites and therefore, urbanizing watersheds. The RUSLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerable soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning (Brooks 2003)

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages.

Table 8 Revised Universal Soil Loss Equation

Land Use Code		K	LS	C	P	KLSCP
1	Cropland	0.20	0.15	0.04	1	0.0012264
2	Pasture	0.20	0.02	0.04	1	0.00014532
3	Forest	0.20	0.02	0.01	1	0.0000098
4	Wetland	0.20	0.30	0.03	1	0.00192
5	Mining	0.00	0.42	0.90	1	0.00
6	Open Land	0.17	0.18	0.10	1	0.00306425
7	Participation Recreation	0.20	0.01	0.50	1	0.0014
8	Spectator Recreation	0.00	0.00	0.00	1	0.00
9	Water Based Recreation	0.00	0.00	0.00	1	0.00
10	Residential	0.20	0.05	0.80	1	0.00736
11	Residential	0.24	0.03	0.80	1	0.0073536
12	Residential	0.20	0.05	0.60	1	0.00624
13	Residential	0.20	0.08	0.50	1	0.0087
14	Salt Wetland	0.00	0.00	0.00	1	0.00
15	Commercial	0.20	0.17	0.90	1	0.03114
16	Industrial	0.00	0.09	0.90	1	0.00
17	Urban Open	0.20	0.08	0.70	1	0.01211
18	Transportation	0	0	0.9	1	0.00
19	Waste Disposal	0.17	0.09	**0.9**	1	0.0138159
20	Water	0	0	0.45	1	0.00
21	Woody Perennial	0.24	0.29	0.09	1	0.0064584

3.6.1 K Factor. K is the soil erodibility factor (average soil loss in tons/acre per unit area for a particular soil. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute. The author correlated the land use/soil type combinations for dominant soils and consulted the Hampshire County Soil

Survey (NRCS 1981) for descriptions of same with standard soil erodibility (K) factor (Table 9):

Table 9 Hampshire County Dominant Soils by Land Use

	Land Use Category		Dominant Soil	K Factor
1	Cropland	PcC	Paxton Very Stony Fine Sandy Loam 8-15% Slopes	0.20
2	Pasture	PcD	Paxton Very Stony Fine Sandy Loam 15-25% Slopes	0.20
3	Forest	PcC	Paxton Very Stony Fine Sandy Loam 8-15% Slopes	0.20
4	Wetland	PcC	Paxton Very Stony Fine Sandy Loam 8-15% Slopes	0.20
5	Mining	Pg	Pits, Gravel - steep sides, flat floor, no vegetation	--
6	Open Land	CrE	Charlton-Rock Outcrop-Hollis Complex, Steep	0.17
7	Participation Recreation	HgA	Hinkley Loamy Sand 0-3% Slopes	0.20
8	Spectator Recreation	n/a		--
9	Water Based Recreation	n/a		--
10	Residential	HgA	Hinkley Loamy Sand 0-3% Slopes	0.20
11	Residential	SrA	Sudbury Fine Sandy Loam 0-3% Slopes	0.24
12	Residential	PcB	Paxton Very Stony Fine Sandy Loam 3-8% Slopes	0.20
13	Residential	PcC	Paxton Very Stony Fine Sandy Loam 8-15% Slopes	0.20
14	Salt Wetland	n/a		--
15	Commercial	HgA	Hinkley Loamy Sand 0-3% Slopes	0.20
16	Industrial	Ud	Udorthents, smooth	--
17	Urban Open	HgA	Hinkley Loamy Sand 0-3% Slopes	0.20
18	Transportation	n/a		--
19	Waste Disposal	CrC	Charlton-Rock Outcrop-Hollis Complex, Sloping	0.17
20	Water	W	Water	--
21	Woody Perennial	PaD	Paxton Fine Sandy Loam 15-25% Slopes	0.24
			Data Source: Soil Survey of Hampshire County	

3.6.2 LS Factor. LS is the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 72.6 feet. The steeper and longer the slope, the higher is the risk for erosion. The author sampled several parcels within each land use and calculated the following slope length gradient (LS) factors (Table 10):

Table 10 Slope Length Gradient Factor

Type	Land Use		LS Factor
Rural	Code	Description	
	1	Cropland	**0.146**
	2	Pasture	**0.0173**
	3	Forest	**0.0245**
	4	Wetland	**0.30**
	6	Open Land	**0.18025**
	20	Water	**0.00**
	21	Woody Perennial	**0.299**
Urban	5	Mining	**0.42**
	7	Participation Recreation	**0.014**
	10	Residential – multi-family	**0.046**
	11	Residential – high density	**0.0383**
	12	Residential – medium density	**0.052**
	13	Residential – low density	**0.087**
	15	Commercial	**0.173**
	16	Industrial	**0.0955**
	17	Urban Open	**0.0865**
	18	Transportation	**0.00**
	19	Waste Disposal	**0.0903**

3.6.3 C Factor. C is the crop management or plant cover factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously uncultivated and tilled land. The C factor is a generalized for a specific crop or land cover that does not account for crop rotations or climate and annual rainfall distribution for the different regions of the country. C factors can vary by land use and development impacts. For example an older subdivision with established landscapes and tree armoring may be closer to zero (0) while a new development with recent construction and increased soil disturbance and loading will be closer to one (1). This generalized C factor, however, provides relative numbers for the different cropping and tillage systems; thereby helping weigh the merits of each system. Rural and urban land use types and their C factor are shown in Table 11.

Table 11 Crop Management Factor

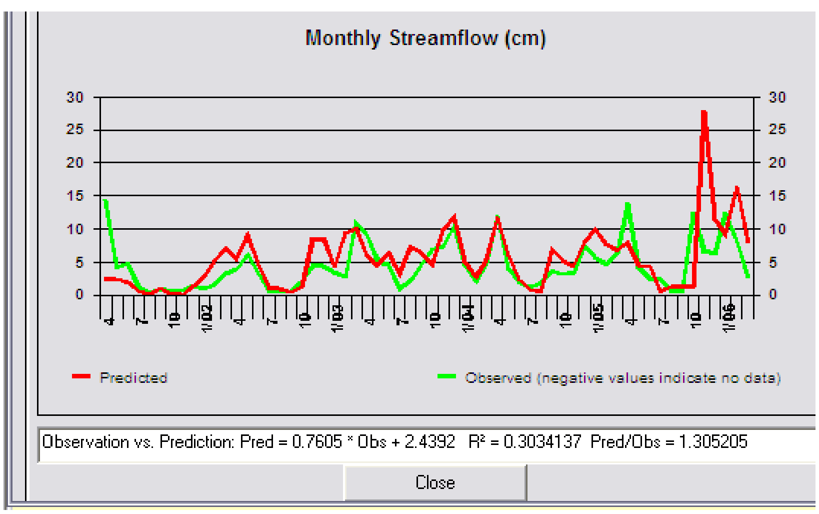
Type	Land Use		C Factor
Rural	Code	Description	
	1	Cropland	**0.042**
	2	Pasture	**0.042**
	3	Forest	**0.002**
	4	Wetland	**0.032**
	6	Open Land	**0.10**
	20	Water	**0.45**
	21	Woody Perennial	**0.09**
Urban	5	Mining	**0.9**
	7	Participation Recreation	**0.5**
	10	Residential – multi-family	**0.8**
	11	Residential – high density	**0.8**
	12	Residential – medium density	**0.6**
	13	Residential – low density	**0.5**
	15	Commercial	**0.9**
	16	Industrial	**0.9**
	17	Urban Open	**0.7**
	18	Transportation	**0.9**
	19	Waste Disposal	**0.9**
			(Wischmeier and Smith. 1978)

3.6.4 P Factor. P is the support practice factor. It reflects the effects of soil conservation practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross slope cultivation, contour farming and stripcropping. In the baseline scenario, the author assumed no soil conservation measures or best management practices (BMPs) were in place, thus a P factor of 1. BMPs would reduce sediment loading and are the prime variable in future scenarios.

3.7 Percent Total Area. This is the final data input for the Transport File. It is a constant in determining the baseline and will also be a variable in future scenarios by fluctuating the % Total Area field.

3.8 Calibration. The following section summarizes the calibration process. Calibration is a crucial step in the modeling process. The hydrologic cycle of BasinSim is calibrated by comparing predicted streamflow to actual streamflow observations. BasinSim allows the user to adjust for both seepage loss and delayed streamflow response to precipitation events. Standardized adjustments can be made to curve numbers in the calibration process. In addition to improving the accuracy of the model, the process of calibration can also give valuable information about the hydrology of the watershed being modeled. The user has the ability to compare the model output to USGS streamflow data. This utility compares the simulated monthly stream flow with the USGS observed data in both tabular and graphic format and calculates the coefficient of determination (R^2) for the comparison. The author used the graphic format to visually identify streamflow regressions and R^2 values.

Figure 8 Initial Calibration

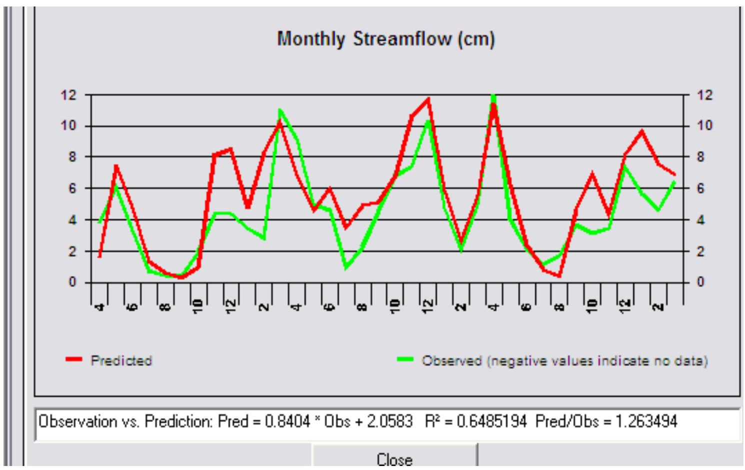


Several frustrating attempts were made during the calibration process. The initial calibration of the model showed an R^2 value of 0.303 (Figure 8). The regression value ranges from 1 to 0, with 1 corresponding to a perfect match between the observed versus predicted streamflow. As the deviation increases, the regression value decreases, with a lower limit of 0. Since the values will depend on factors such as the seepage, streamflow, and inputs such as curve numbers and soil factors, there is no single critical regression value that automatically corresponds to "bad" data. Instead, the user must determine what are acceptable streamflow levels and regression values. A fundamental difficulty in BasinSim calibration is that for some watersheds, the user may find that no matter how various parameters are adjusted (within reasonable ranges) the model always overestimates streamflow compared to the USGS observations.

The author performed calibrations with slight variations on the inputs. For example, the User's Guide states that the seepage coefficent may be altered; however, the author used the default value of zero (0). This indicated the calibration is not overestimating. Alternatively, it may take days or longer for water to travel from one place to another within a watershed. The streamflow at a certain point in a watershed often relate more closely to the climatic events that occurred previously. The delay between stream responses and weather events can be estimated by modification of the weather file. There were no improvements in calibration with delays in weather files.

Improvements in calibration, or higher R^2 values, began to appear as modifications to the curve number data input to the Transport File were made. The author took liberty in increasing curve numbers by 8% to account for miscalculations in determining dominant soil types. Other modifications included reducing the recession coefficient and playing with the ET cover coefficient. Ultimately, the author was the most successful by performing regression analysis for each year of observed streamflow periods for a way to identify individual years. Shortening the observed streamflow periods from five years to three gave the highest R^2 value of 0.648 (Figure 9). The years used were 2003, 2004, and 2005; discarded years were 2002 and 2006. The number is not ideal, but assumptions were made given the intensiveness of the data input and limited time frame.

Figure 9 Improved Calibration



3.9 Scenarios Analysis. In order to perform the aforementioned scenarios, the following modifications were made to the calibrated baseline analysis.

3.9(a) Scenario 1, Aggressive. For this analysis the baseline data was copied into a new data folder. The urban curve numbers were adjusted to the highest existing value to reflect the intensified impacts of aggressive increase in development practices. The highest curve number used is 98.2.

3.9(b) Scenario 2, New Development with BMPs. In this scenario, urban curve numbers were decreased by 20% to reflect the incorporation of best management practices. Urban land use areas were revised based on current zoning, not land use. To do this MassGIS zoning data was clipped to the Mill River watershed and a new land use category was applied. Additionally, the P factor was reduced 20% to a value of 0.8.

3.9(c) Scenario 3, New Development without BMPs. Unlike the previous scenario, no best management practices were incorporated into the analysis. Only the revised urban land use areas based on current zoning (not land use) were used.

3.9(d) Scenario 4, Combination 1. This scenario models a combination of aggressive urban development while incorporating the use of best management practices. To reflect the intense development the highest urban curve numbers from Scenario 1 are used as well as the revised land use areas based on future zoning. The use of best management practices is reflected by a universal soil loss equation coefficient of 0.8.

3.9(e) Scenario 5, Combination 2. The final scenario is a combination of the most aggressive land use development and the most aggressive incorporation of best management practices. The model was modified by the lowest urban curve number, the revised land use areas based on future zoning and a P factor further reduced by 20% to 0.6.

3.10 Chapter Summary

This chapter guides readers through the arduous processes of a specific type of watershed modeling and a method of stakeholder valuation. The foundation of the ecosystem approach is a collaboratively derived vision that integrates science and policy. The next chapter describes the results of the analyses.

CHAPTER 4

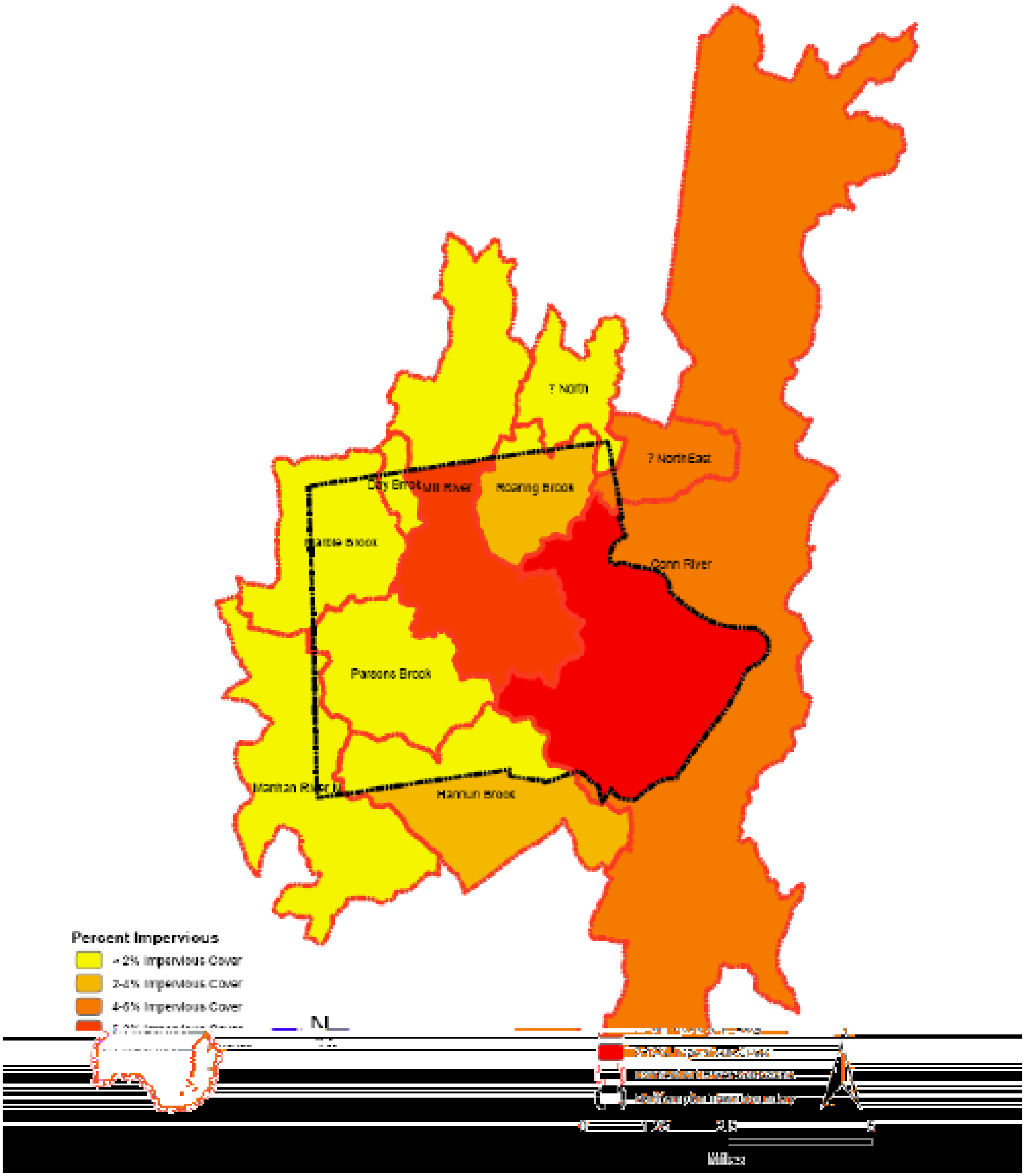
RESULTS OF ANALYSIS

This chapter describes the results of the three main objectives of the study: watershed boundary analysis, DAPP focus group and the watershed simulation model. The author performed the analysis as described in Chapter 3 in order to provide scientific environmental, economic, and social analysis into land use planning. It is anticipated that the combination of these analyses will provide context for scientifically sound and transferable land use policies.

4.1 Boundaries Analysis. Figure 10 shows the results of the Boundary analysis, which asks the question: Does the City of Northampton absorb its own impact of development or are the impacts deflected downstream to other watersheds or communities? This dark orange to red area are the more urbanized areas of the Mill River Subbasin and the DAPP analysis will provide qualitative contribution to address this question, as well as clarify potential water quality and water quantity ramifications of such intense development.

The recommendations for reducing effective impervious area can benefit water quality, quantity management, and stream habitat conditions. However, the level of benefit will depend in large part on the existing watershed and riparian area conditions. Implementing the recommendations of best management practices will be easier and more effective in areas with low EIA. Retrofitting more developed areas will present greater challenges and require a stronger commitment from individual property owners.

Figure 10 Boundary Analysis Percent Impervious



To be effective, solutions must address the issue at the watershed, community and site specific levels. At the watershed level, protecting the most diverse, healthy and functioning landscapes and enhancing degraded streams in low density areas should be a priority. At the community level, new developments should implement innovative techniques to reduce runoff and maximize the function of the riparian corridors. Older developments should retrofit by amending soils in landscaping and significantly increasing tree cover in yards and open spaces. At the site-specific scale, individuals could incorporate features to infiltrate or re-use rainfall. Near stream owners using captured rainwater could help augment flow by irrigating near stream. The cumulative result of effective impervious cover reduction may take years to realize and will rely upon a commitment of watershed stakeholders to achieve the goal of sustaining a healthy stream system.

4.2 Deliberative Attribute Prioritization Procedure. Table 12 shows the results of the focus group indicating the pairwise levels of importance each attribute of a sustainable city. The results are not ranked as one of the fundamental aspects of DAPP is its ability to compare disparate attributes of a topic. As discussed in Chapter 3, the Fundamental Scale for Pairwise Comparisons provided the value range for consensus.

Since the focus group was comprised of expert stakeholders (primarily planners, engineers or persons familiar with the mechanisms of sustainability), it is not surprising to see moderate to strong levels of importance amongst the attributes. Most attributes scaled a weak or moderate intensity of importance thus indicating that the panelists' experience and judgment slightly favor to strongly favor one activity over another. There was lengthier discussion during the earlier stages of the focus group and debate was fairly limited as the participants became familiar with the process.

Table 12 Group Consensus Values

	Land Use	Energy	Waste Reduction, Reuse, Recycling	Carrying Capacity	Use of Local Resources	Water Quantity	Ecosystems	Economic Vitality	Fairness to Future Generations	Affordability / Accessibility	Water Quality	Fairness to Future Generations
Land Use	**1**	3	3	1	3	3	1	2	3	1	1	2
Energy	1/3	**1**	2	1	2	1	3	2	3	3	1	5
Waste Reduction, Reuse, Recycling	1/3	1/2	**1**	1	3	2	2	1	1	2	1	2
Carrying Capacity	1	1	1	**1**	4	1	1	4	1	4	1	2
Use of Local Resources	1/3	1/2	1/3	1/4	**1**	1/2	1/4	1	1/3	1	1	1/3
Water Quantity	1/3	1	1/2	1	2/1	**1**	1	3	1	1	1/2	1
Ecosystems	1	1/3	1/2	1	4/1	1	**1**	4	1	3	1	2
Economic Vitality	1/2	1/2	1	1/4	1	1/3	1/4	**1**	1	1	1/3	4
Fairness to Future Generations	1/3	1/3	1	1	3/1	1	1	1	**1**	2	2	3
Affordability / Accessibility	1	1/3	1/2	1/4	1	1	1/3	1	1/2	**1**	1/3	2
Water Quality	1	1	1	1	1	2/1	1	3/1	1/2	3/1	**1**	3
Fairness to other Communities	1/2	1/5	1/2	1/2	3/1	1	1/2	1/4	1/3	1/2	1/3	**1**

Another rational for the consistency in response is the desire to reach consensus. As the focus group was occurring, not all panelists were in agreement, but in the few comparisons where disagreements arose, consensus was achieved relatively easily by taking a few moments to discuss identify particular aspects of the attribute that the panelist resonated with. One such pair was, "*How important is increasing protection of natural* ***Ecosystems*** *compared to increasing* ***Economic Vitality*** *towards the goal of achieving a sustainable city?"*

Responses ranged from 5, 7, ¼, 3, 1 indicating that the protection of natural Ecosystems was more important to all respondents except one who believed that Economic Vitality was moderately important than the protection of natural Ecosystems. The matrix indicates that consensus was reached and the panel was able to agree to the following statement: the protection of natural Ecosystems is moderately (plus) more important than Economic Vitality in achieving a sustainable city.

While each attribute contributes in its unique way, each on its own on is limited in achieving paramount sustainability. The attributes were individually ranked prior to the focus group and then ranked in comparison to one another during the focus group. It is worth noting that four factors of sustainability are represented in the watershed model and boundary analysis: Land Use, Water Quality, Water Quantity, and Fairness to other Communities; while also noting that these factors represent a combined 35% of the top twelve attributes. The author acknowledges this that a conglomerate of several attributes which are highlighted in the table of relative weights (Table 13).

Table 13 Relative Weights of Attributes

Attribute	Relative Weights
Land Use	**0.14**
Energy	0.13
Carrying Capacity	0.11
Ecosystems	0.10
Water Quality	**0.10**
Waste Reduction, Reuse, Recycling	0.09
Fairness to Future Generations	0.09

Water Quantity	**0.07**
Economic Vitality	0.05
Affordability / Accessibility	0.05
Use of Local Resources	0.04
Fairness to other Communities	**0.04**

The author followed the method described in Chapter 3 (Table 13) to determine the relative weights and continued the consistency test by summing the relative weights of the attributes and averaged to produce λ_{max} , which equals 19.51, and then calculating the Consistency Index (CI):

$$CI = \lambda_{max}\text{-}n/n\text{-}1 = 0.68$$

The Consistency Index is divided by the prescribed random value of 1.35 to result in a Consistency Ratio (CR) of 0.51 or 5.1%, which is within the acceptable range of accuracy of under 10%. The Deliberative Attribute Prioritization Process provides a method for determining the consistency of the pairwise comparisons. This analysis had a result of 5%, which falls within the range of acceptable inconsistencies (<10%).

4.3 Watershed Model. Water quality is a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. To determine water quality, scientists measure and analyze characteristics of the water such as temperature, dissolved nutrient or mineral content, or existence of bacteria. Selected characteristics are then compared to standards and guidelines to decide if the water is suitable for a particular use. Water quality characteristics produced by BasinSim for this study are: erosion, evapotranspiration, dissolved and total nitrogen and dissolved and total phosphorous.

Water quantity, or water supply, protection programs have been used in many states to ensure the integrity of potable water supply sources for industry, agriculture and municipal users. Water quality characteristics identified in this study are: evapotranspiration, groundwater, runoff and streamflows.

This study fundamentally addresses land use in a watershed and how changes in land use practices can or do influence the non-point source loading of nutrients and sediments to water bodies. Directly related to this is water quality and specifically two pressing management issues: total maximum daily loads and best management practices.

Total Daily Maximum Load (TMDL) regulations apply to all water bodies that appear on the State's impaired waters listing (i.e. 303d list). This regulation requires that all sources of pollutants that contribute to a specific impairment be identified, quantified and reduced to a level that will eliminate the impairment. Since this regulation applies to all potential pollutant sources (both point and non-point) it requires a much better understanding of the sources, quantities and routes of non-point pollutants than is likely to be currently available in most cases. Thus remediation plans or strategies resulting from the TMDL process will require the development of better methods for understanding and quantifying non-point source pollutants, including the land use activities that produce them, their routes through the watershed (surface flow or deep/surficial groundwater), and loading rates.

4.3.1 Baseline Outputs

Streamflow nutrient flux contains dissolved and solid phases. Dissolved nutrients are associated with runoff, point sources and groundwater discharges to the stream. Solid-phase nutrients are due to point sources, rural soil erosion or wash off of material from urban surfaces. Point sources are added as constant mass loads which are assumed known. Water balances are computed from daily weather data but flow routing is not considered. Therefore, daily values are summed to provide monthly estimates of streamflow, sediment and nutrient fluxes. The following represents the baseline model output for water quality and quantity in the Mill River Subbasin, the product of the extensive data inputs previously discussed.

Table 14 Mill River Watershed Baseline Output

The Mill River Watershed Baseline Output Mean					
Water Quantity					
	Precipitation (cm)	**Evapotranspiration (cm)**	**Groundwater (cm)**	**Runoff (cm)**	**Streamflow (cm)**
APR	13	4.04	8.26	0.51	8.77
MAY	10.83	7.47	5.71	0.33	6.04
JUNE	11.19	9.8	4.39	0.38	4.76
JULY	8.36	11.61	2.4	0.26	2.66
AUG	14.94	10.55	1.37	1.42	2.78
SEPT	23.32	6.42	2.03	2.31	4.34
OCT	9.63	3.35	7.06	0.44	7.49
NOV	9.47	1.18	7.14	0.43	7.57
DEC	8.76	0.47	8.67	0.78	9.44
JAN	7.71	0.23	6.96	0.8	7.76
FEB	5.44	0.26	4.79	0.41	5.2
MAR	6.65	1.04	5.6	0.45	6.04
YEAR	**129.3**	**56.41**	**64.37**	**8.49**	**72.87**

Water Quality						
	Erosion (kt)	**Sediment (kt)**	**Dissolved Nitrogen (t)**	**Total Nitrogen (t)**	**Dissolved Phosphorus (t)**	**Total Phosphorus (t)**
APR	355.2345	0.5581	188.8624	191.5906	9.8744	10.812
MAY	244.3086	0.1787	123.1126	123.5538	4.8827	5.1386
JUNE	252.0861	0.2707	98.8791	100.0739	4.7131	5.1539
JULY	175.5053	0.2715	53.4398	53.9	2.1388	2.5061
AUG	466.5944	8.9042	114.827	129.9824	16.5056	28.5539
SEPT	1319.729	46.4712	180.8394	251.4075	27.1069	89.0438
OCT	103.6963	2.4131	165.2711	170.1571	8.775	12.1213
NOV	102.3709	2.7839	167.9167	173.7944	9.1942	13.0781
DEC	24.9927	10.629	232.3653	250.9371	16.6996	31.1227
JAN	19.3826	21.0016	203.3019	234.8293	15.7763	43.7319
FEB	7.6984	4.1893	128.9895	137.5392	9.5712	15.3851
MAR	33.0052	4.7806	141.4402	150.8375	9.2459	15.8415
YEAR	**3104.604**	**102.4519**	**1799.245**	**1968.603**	**134.4836**	**272.489**

4.3.2 Scenarios Results. Appendix G contains the results of each scenario performed. This section is meant to provide a summary of the results in terms of land use. Table 15 depicts the factors associated with water quality output from BasinSim and the difference from baseline. The data is aggregated yearly but individual output tables reflect seasonal changes. It shows that the parameters change once the scenarios are implemented however the change is more discrete for Erosion and Sediment.

Table 15 Water Quality Scenario Results

	Erosion (kt)	Sediment (kt)	Total Nitrogen (t)	Total Phosphorus (t)
Baseline	3104.604	102.4519	1968.603	272.489
Scenario 1	207.527	6.848	1610.481	247.517
Scenario 2	207.527	6.848	165.218	21.877
Scenario 3	207.527	6.848	4641.212	786.760
Scenario 4	207.527	6.848	922.709	157.315
Scenario 5	207.527	6.848	1335.088	227.541

The effects of the scenarios within the model on water quality showed no reduction on erosion or sediment characteristics after initial manipulation. However, higher reductions in nutrients (nitrogen and phosphorus) were recognized. The reason for this result is that the model divides land uses into “rural” and “urban” categories, which determines how the model calculates loading of sediment and nutrients. Again, for the purposes of modeling, “rural” land uses are those with predominantly pervious surfaces, while “urban” land uses are those with predominantly impervious surfaces. Monthly sediment delivery from each “rural” land use is computed from erosion and the transport capacity of runoff, whereas total erosion is based on the universal soil loss equation. Thus, erosion can occur when there is precipitation, but no surface runoff to the stream. However, delivery of sediment depends on surface runoff volume. Sediment available for delivery is accumulated over a year, although excess sediment supply is not assumed to carry over from one year to the next. Nutrient loads from rural land uses may be dissolved (in runoff) or solid-phase (attached to sediment loading as calculated by the model.

Overall, the introduction of best management practices into new development indicated positive results in water quantity as shown in Table 16 (for Scenarios 2, 4, and 5). All scenarios factor in some form of new development while varying the development style and treatment of the landscape. One of the critical limitations in this study was the assumption that onsite wastewater systems would remain unchanged for both existing and proposed development. This assumption was made based on time and the complexity of analyzing existing septic systems and calculating future changes toward sewers or decentralized innovated alternative systems.

Table 16 Water Quantity Scenario Results

	ET (cm)	Groundwater (cm)	Runoff (cm)	Streamflow (cm)
Baseline	56.41	64.37	8.49	72.87
Scenario 1	57.18	55.89	16	71.89
Scenario 2	57.64	63.25	8.19	71.44
Scenario 3	57.41	56.26	15.34	71.6
Scenario 4	57.64	63.62	7.83	71.46
Scenario 5	57.64	62.96	8.47	71.42

Flow in streams derives from surface runoff during precipitation events or from groundwater pathways. The amount of water available to the shallow groundwater zone is strongly affected by evapotranspiration, which the model estimates from available moisture in the unsaturated zone, potential evapotranspiration, and the land cover coefficient. As indicated in the previous chapter, potential evapotranspiration is estimated from the relationship to mean daily temperature and the number of daylight hours.

The model requires input of groundwater nutrient concentrations excluding loads due to septic systems, which are accounted for separately. Even in the absence of septic system loads, groundwater concentrations are expected to increase in urbanizing watersheds, with a shift from rural to urban, due to the applications of fertilizer on crops, lawns, and gardens. The effect is greatest for nitrogen, which is highly soluble, but some elevation of groundwater concentrations of phosphorus is also expected with increased development.

4.4 Chapter Summary. Best management practices are the primary means of reducing nutrient loading from non-point sources and increasing groundwater and reducing runoff to assist in nutrient reduction. Thus, evaluating the effectiveness of various BMPs is an integral part of developing nutrient remediation strategies directed at reducing or eliminating water quality impairments in receiving waters. Toward this end it is imperative that planners have available to them a user-friendly and timely means to reliably evaluate the potential effect of various BMP implementation strategies on nutrient loading.

CHAPTER 5

CONCLUSIONS

This study highlights the incorporation of the ecosystem approach into land use planning by interconnecting water, air, land, and wildlife, and the need to consider the broad impacts on the whole system while incorporating group consensus values before taking action. As discussed, land use impacts can directly affect public and environmental health. The effects of sprawling patterns of development can be seen in the many impacts to quality of life issues related to crowding and congestion. Other more physical impacts can be seen in reduced drinking water quality as a result of increase impervious surfaces and reduction in natural vegetation. Land development affects the hydrologic system and pollutes surface and groundwater whereby sources of drinking water, including groundwater, rivers, surface waters and reservoirs, are susceptible to contamination from non-point source pollution from land runoff.

5.1 Policy Implications in Northampton and Beyond. Every city and town in Massachusetts has a zoning ordinance or bylaw and so zoning has long been the principal land use regulation used by municipalities. Although conventional zoning and subdivision ordinances have done much to separate incompatible land uses and standardize subdivision practices, they have not met all the land use control needs of many communities. One critique of conventional zoning is that it assumes use and density restrictions can protect environmental and community values. These restrictions are not sufficient because they assume all land is the same (i.e. there are no environmentally sensitive areas).

There have been several innovations in land use regulations that have responded to the critique of conventional zoning and aimed to protect environmental resources more effectively. Agricultural zoning aims to preserve agricultural land use, production and rural character. Similarly, Open Space Residential Design or Conservation Subdivisions are a common zoning technique to preserve community character. The purpose of a conservation subdivision is to protect natural resources while allowing for the maximum number of residences under current community zoning and subdivision regulations. Both techniques seek to preserve large tracts of land either through large lots or deed restrictions (Paster, 2004).

Performance zoning varies from conventional zoning by providing performance criteria or standards rather than prescriptive requirements for development. Performance criteria allows more creativity in a development design by specifying goals and leaving it up to the developer decide and demonstrate how the requirement will be met. Some performance-based zoning specifies land coverage or open space percentages or ratios that must be met for certain environmentally sensitive areas (Paster, 2004).

One technique of performance zoning is to incorporate Low Impact Development (LID) into a site plan review requirement. In Massachusetts, this can be done via zoning or general bylaws depending on which governing entity the community prefers. It is recommended that the Planning Board be the permit granting authority because this is often the body that is forward thinking in land use. LID adds to the resiliency of an ecosystem by identifying site sensitive best management practices and retaining the natural hydrology of the land to avoid impacting abutting properties, sensitive resources, or neighboring communities. This highlights the overarching topic of this thesis which is to recommend an effective, science based policy. Incorporating low impact development into policy makes sense on a broad level because although requires on-site infiltration and pretreatment of nonpoint source pollution but it allows developers the autonomy to choose the most appropriate BMP for the site.

The model stormwater regulation found in Appendix H uses runoff curve numbers found in TR-55. By virtue of this study, the author came to realize that the curve numbers may be outdated as they were originally published in 1975 but based on precipitation data from 1961. The intensity and frequency of storms have increased in the resulting in inadequate models for proper treatment and infiltration of stormwater.

The regulation requires the applicant to focus on site planning first. This makes sense from a planning perspective, but engineers may not be trained to think like this. The applicant's engineer or designer must, on a plan and in narrative form, provide an overall description of the low impact development techniques and strategies incorporated into the proposed site's design. Effective management of both existing and proposed site vegetation can reduce a development's adverse impacts on groundwater recharges and runoff quality and quantity. The applicant must identify the vegetation and landscaping strategies and best management practices that have been incorporated into the proposed development's design to help maintain existing recharge rates and/or minimize or prevent increases in runoff quantity and pollutant loading.

5.2 Limitations and Future Research. The author experienced a three-year delay in the production of this thesis, thus limiting some potentially modified land use information in Northampton. No updated data was presented as the challenge of data input into the watershed model would have presented a challenge in both time and resources.

As a planner, having had the opportunity to go through the process of data collection, input, analysis, and results, the author recognizes and appreciates the complexity of water quality and quantity science and land use management. The ecosystem approach is based on the foundation of appropriate scientific methodologies focused on biotic and abiotic factors that encompasses the processes, functions and interactions among the environment and humans. The human component or public participation in planning is always important, but not always easy to quantify.

This thesis adds to the existing planning literature in that it links science and policy for a municipal planner. It merges three distinct analytical methods in that the understanding of boundary impacts, sustainability values and land use data on water resources. However, future research exists for understanding and implementation of techniques to reduce impacts to water resources based on community values and scientific studies.

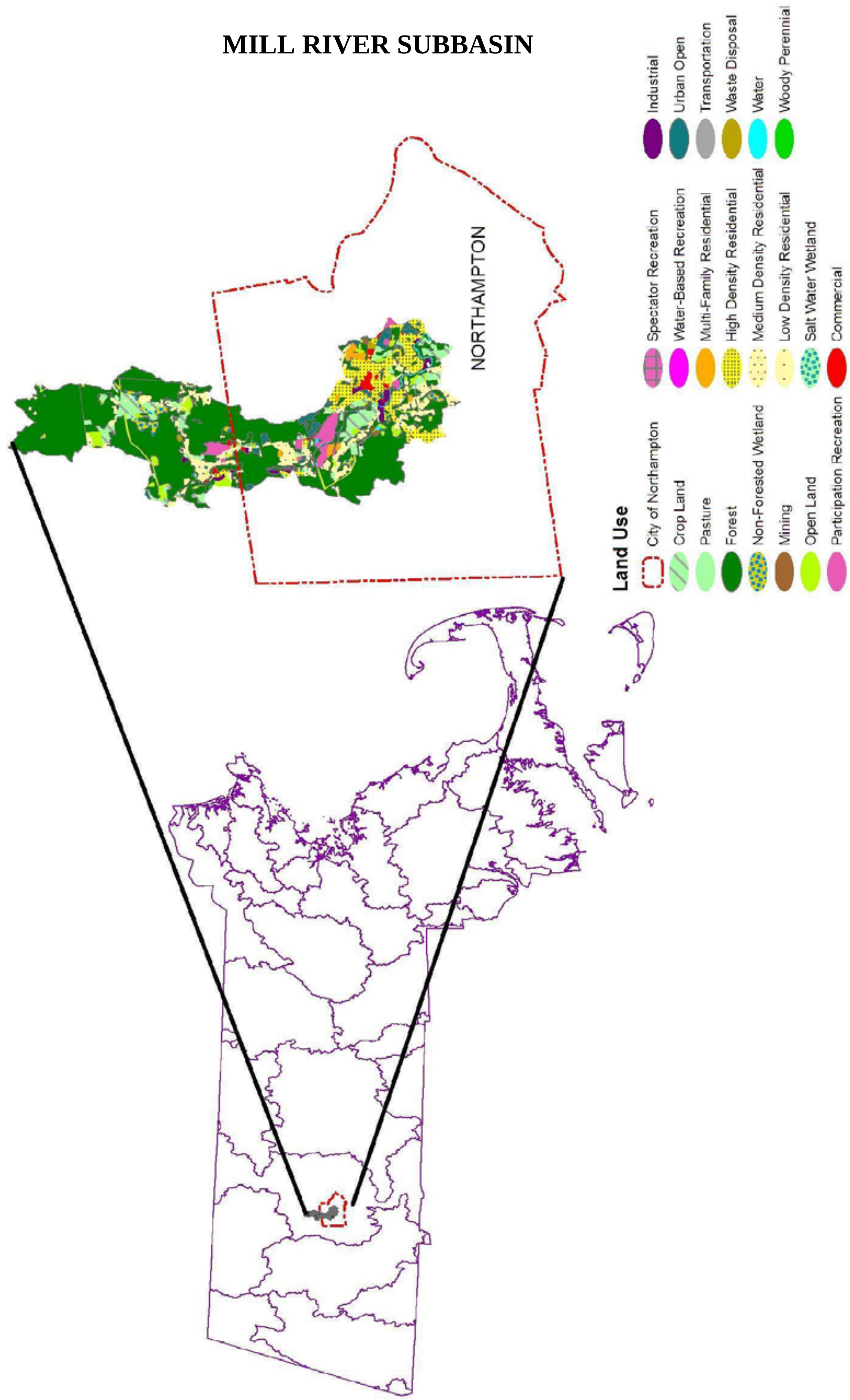
5.3 Overall Conclusion. In this study a quantitative assessment was performed which modeled certain land use practices in a specific watershed. The author incorporated a qualitative consensus component to the analysis for water properties and concentrations of compounds and contaminants in order to define water quality and quantity priorities. The author anticipated that the watershed model and DAPP would be time consuming and data intensive. Given that the premise of this study is seeking streamlined and transferrable land use policies, the author cannot recommend that this approach to most municipal planners. That is not to say that it is unsuitable, but given time and resources attributed to municipal planning departments, the author would recommend partnering with its regional planning agency, a local watershed group or land trust to assist with the modeling and participation with the focus group.

This study provided the author the experience of both theoretical and practical, science-based policy-making. This thesis contains performance-based sustainable policy suggestions that can be implemented based on scientific approaches to land use and water resource planning in municipalities as well as an adding to existing planning literature. It creates a more powerful argument for planners to consider integrating a watershed approach with community values where various measures can work together for a common objective – better environmental land use management. The foundation of any local program is a comprehensive plan based on sound technical information, including and ecological inventory and other studies as well as extensive public involvement. The results of this study will be submitted for acceptance to a municipality for incorporation into its land use policies.

APPENDIX A

NORTHAMPTON, MA AND LAND USES IN THE

MILL RIVER SUBBASIN



APPENDIX B

MILL RIVER HYDROGRAPH

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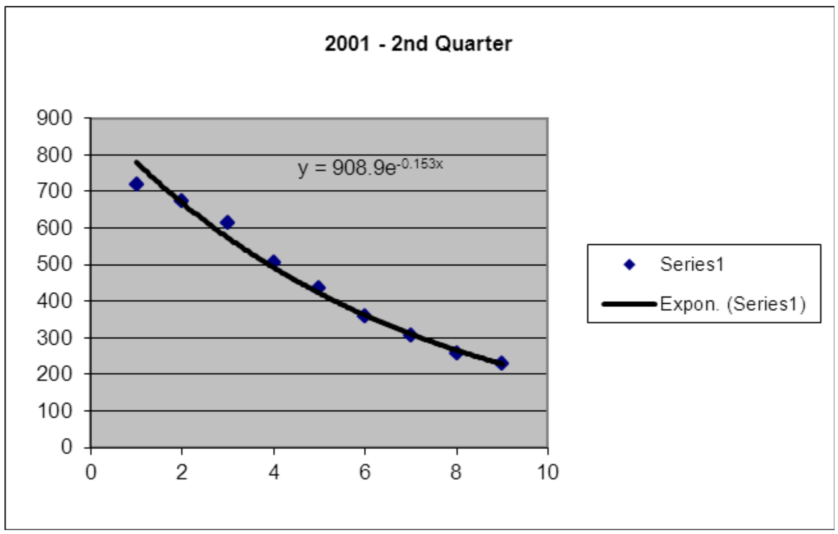

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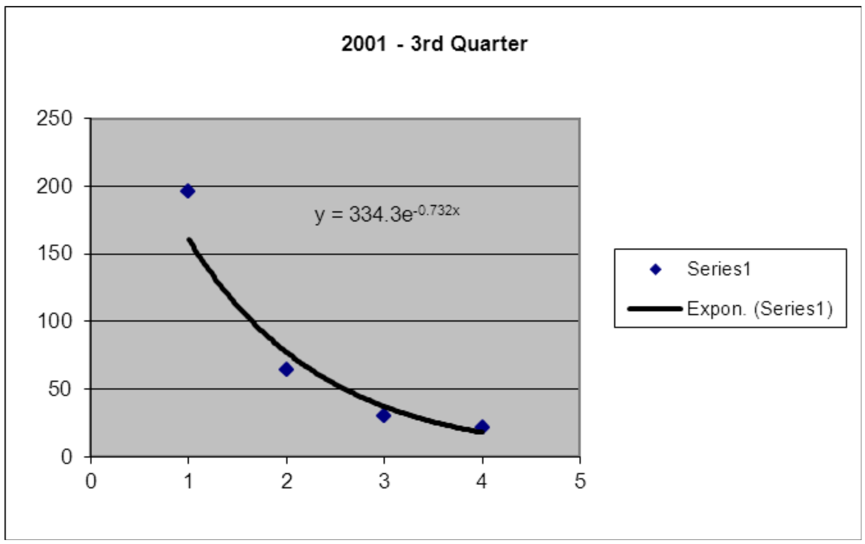

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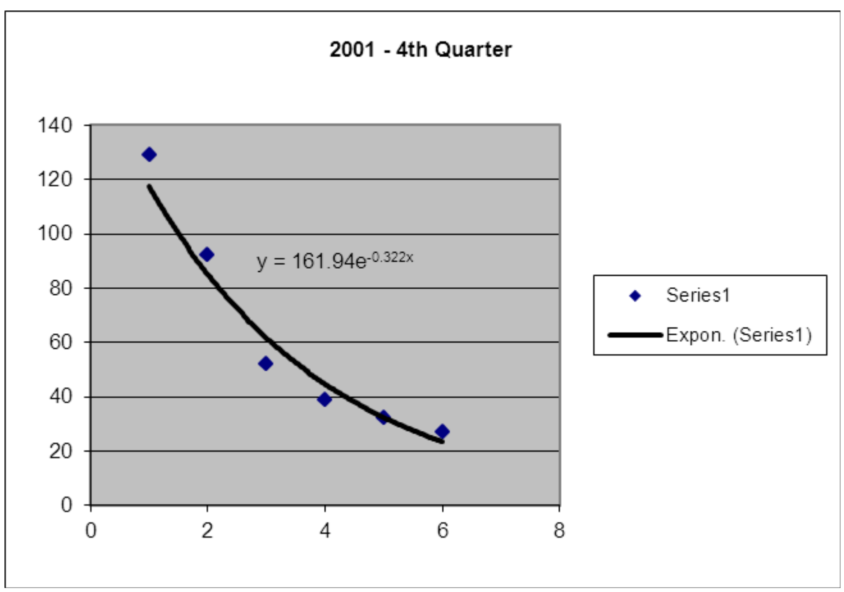

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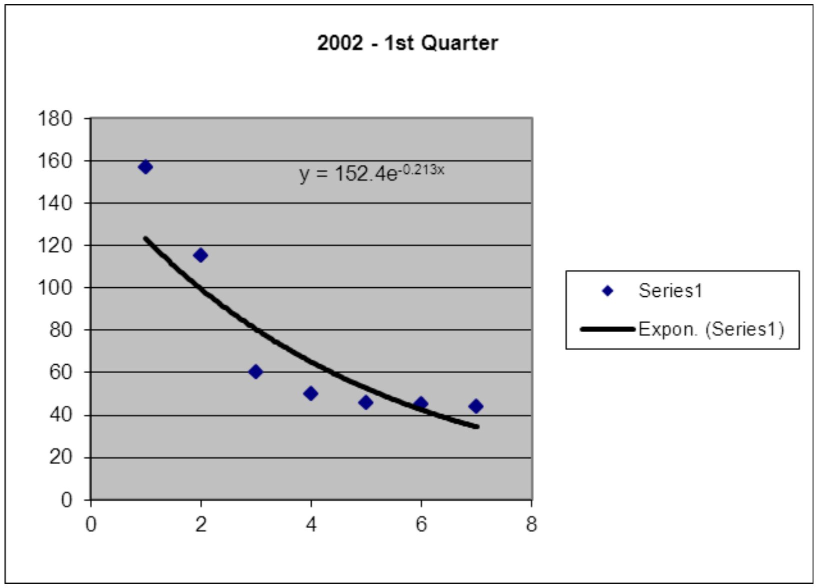

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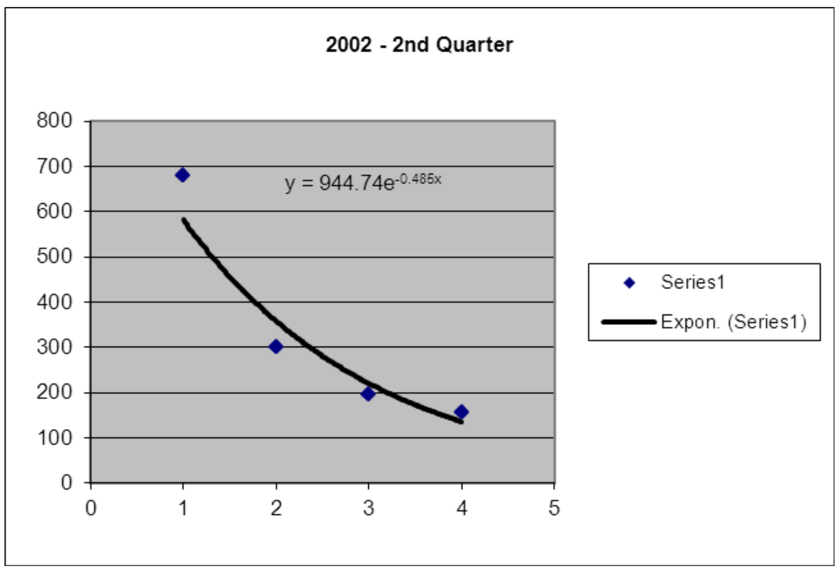

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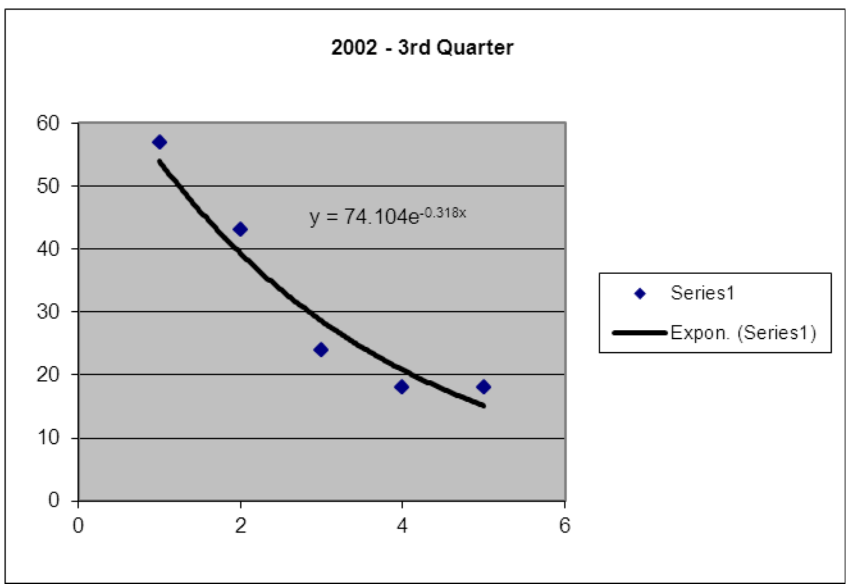

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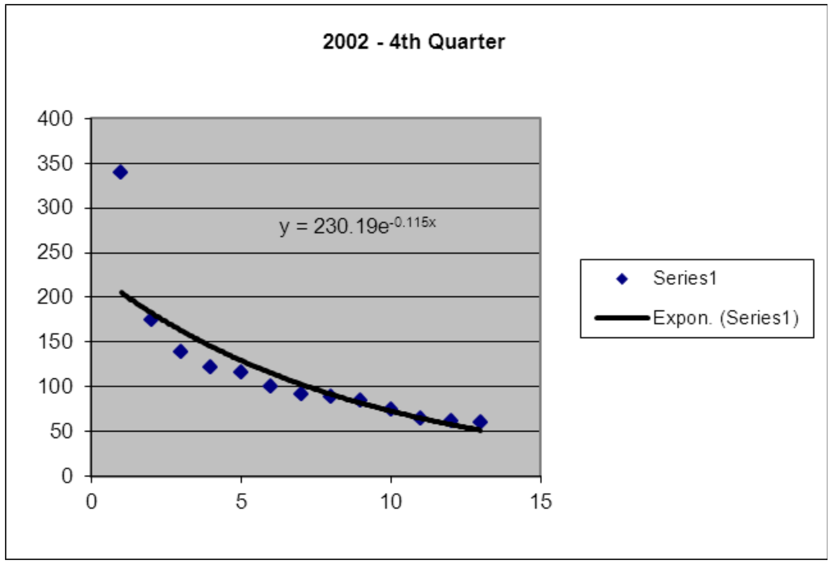

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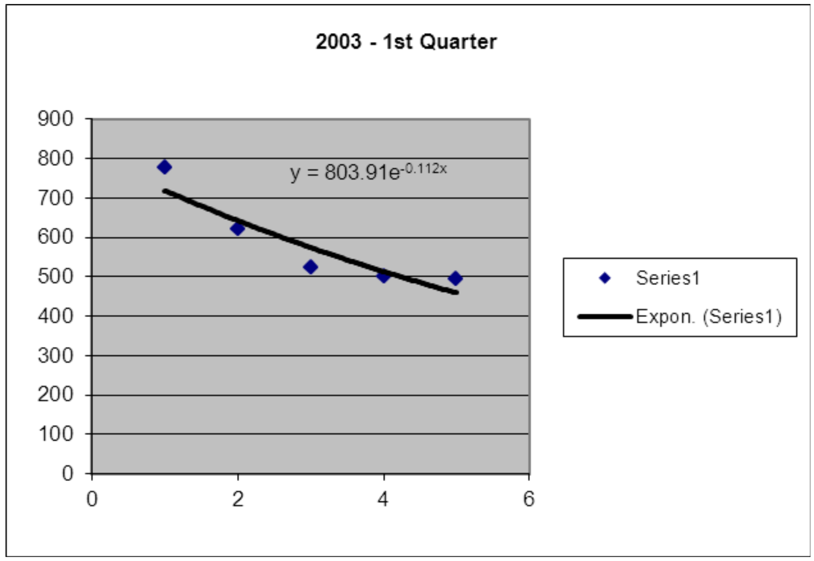

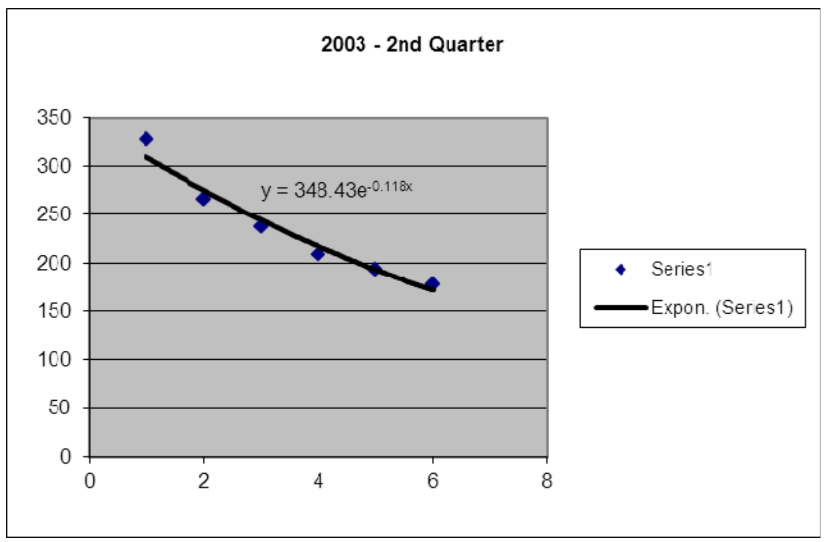

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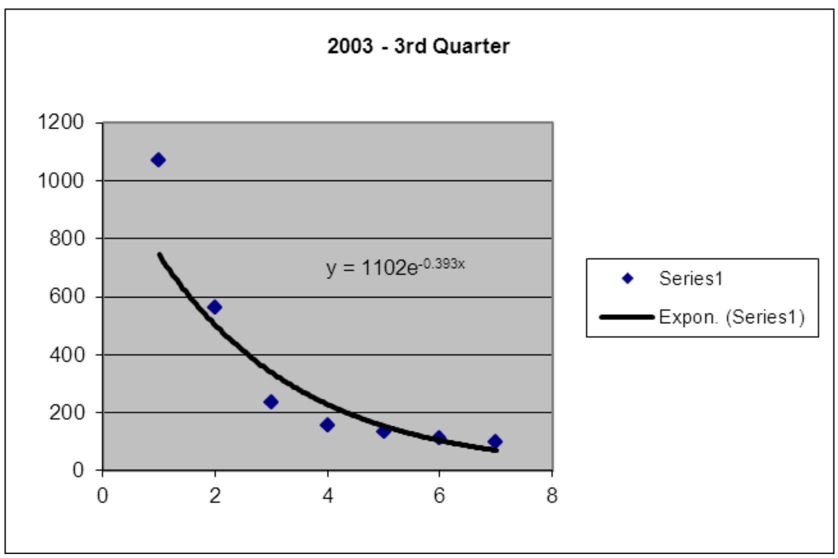

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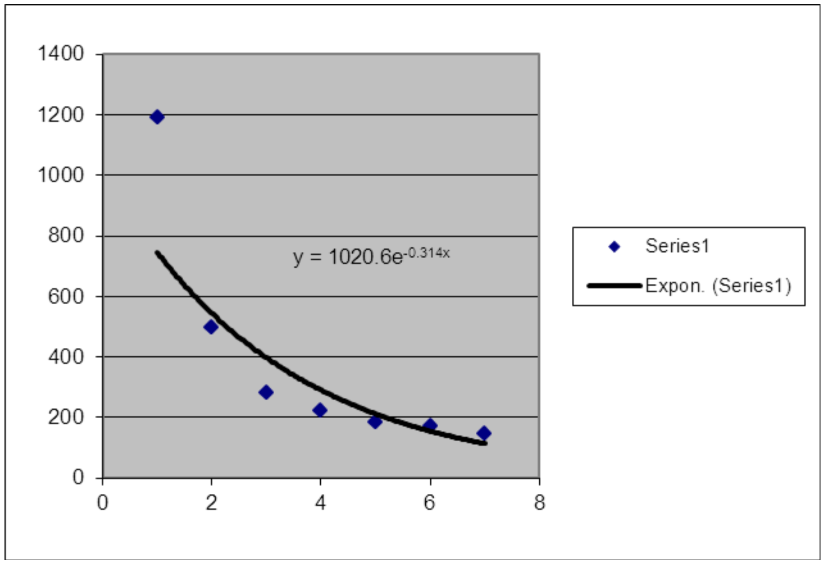

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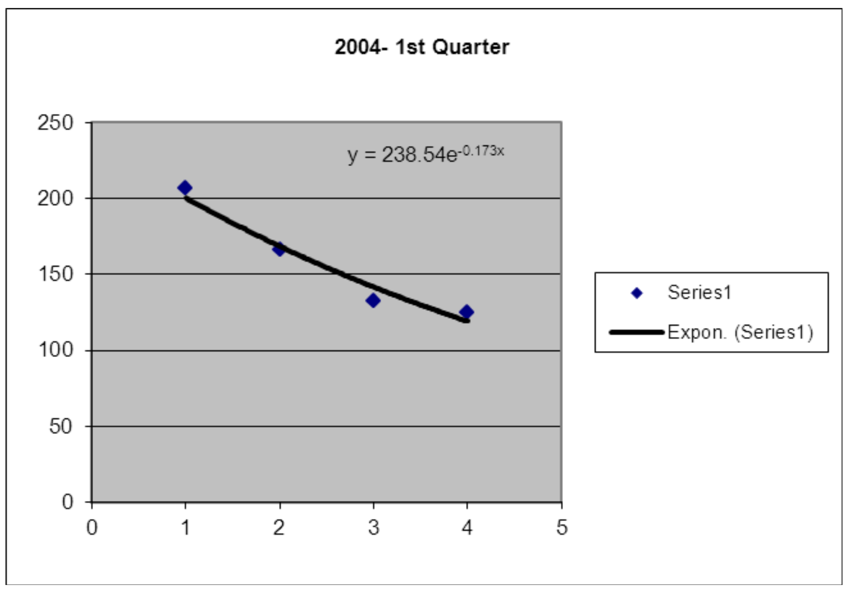

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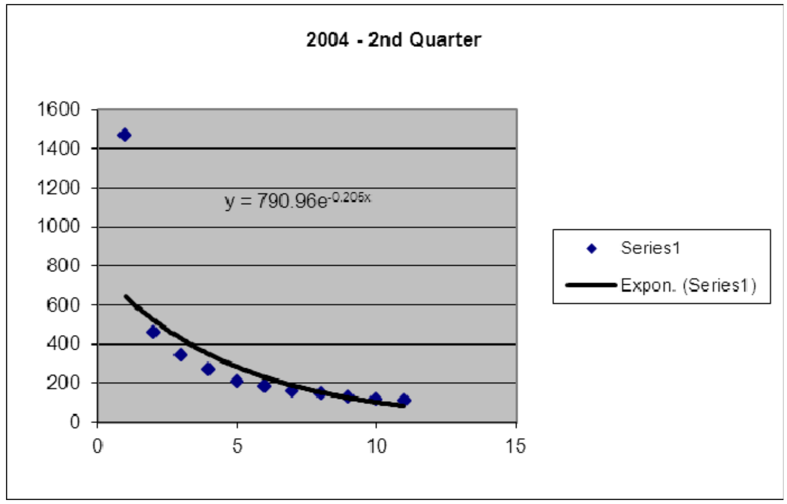

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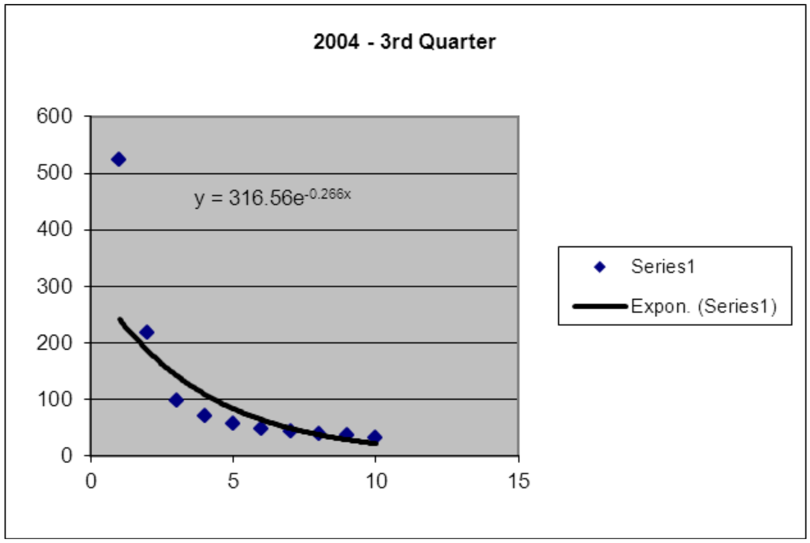

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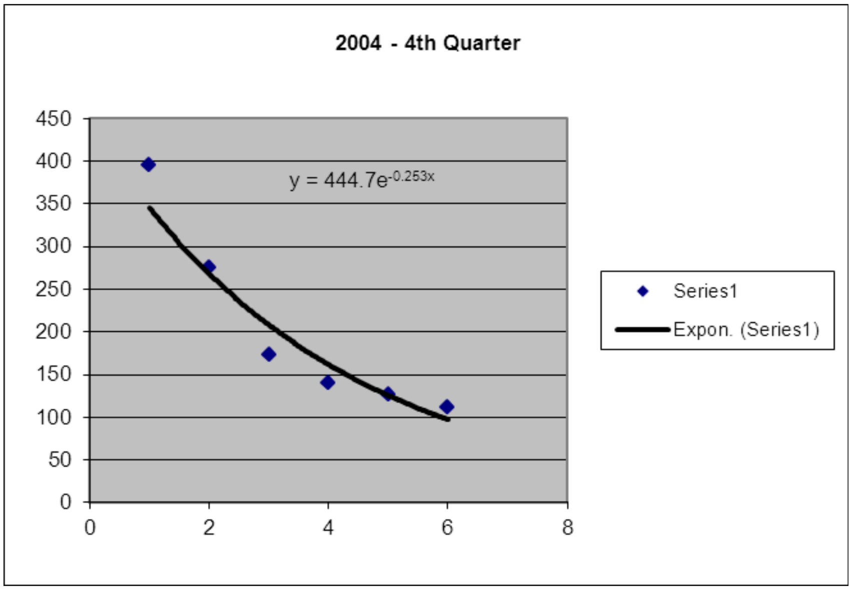

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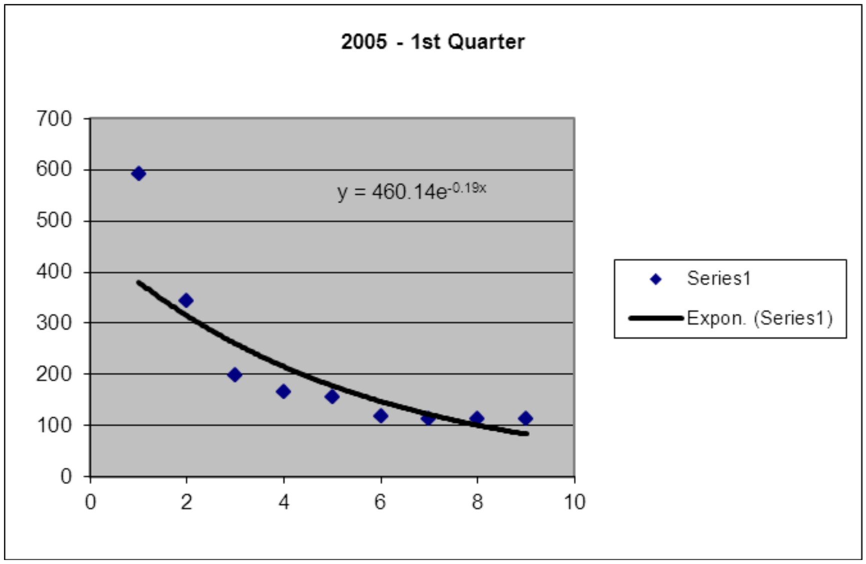

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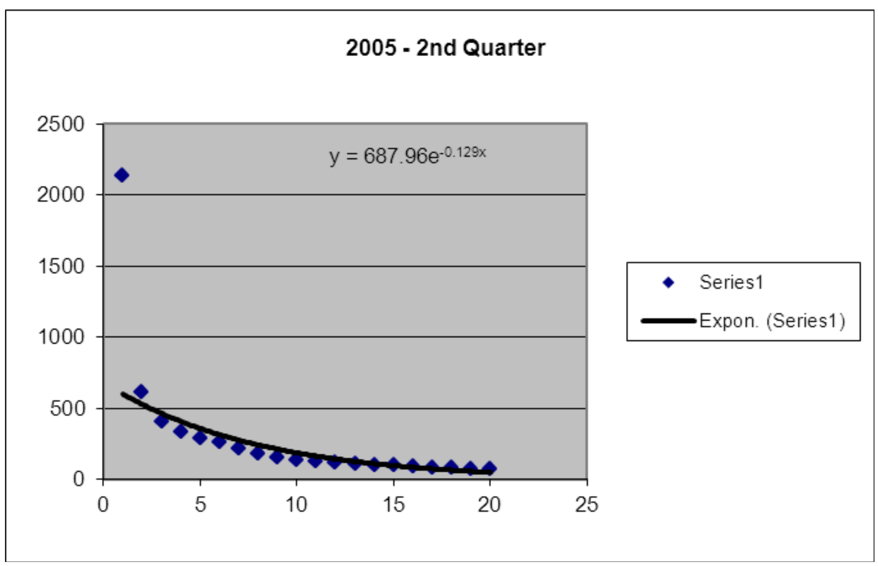

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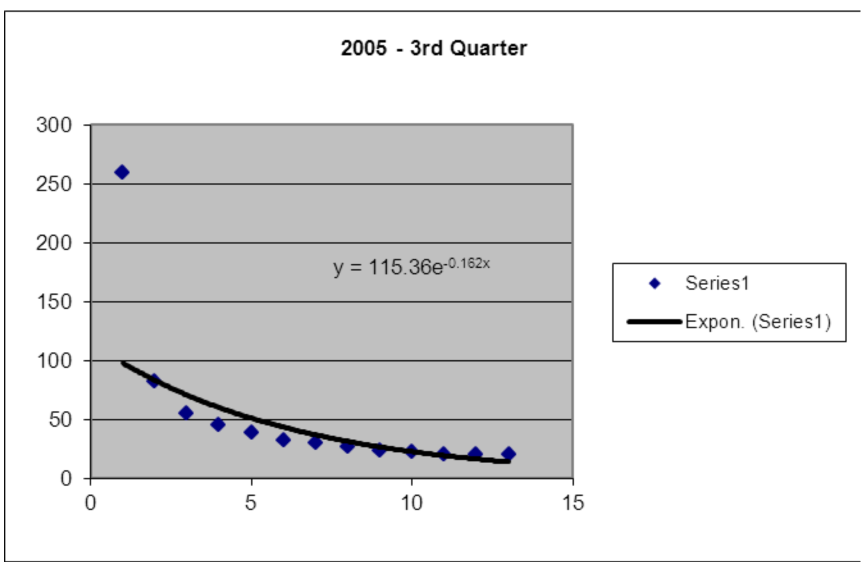

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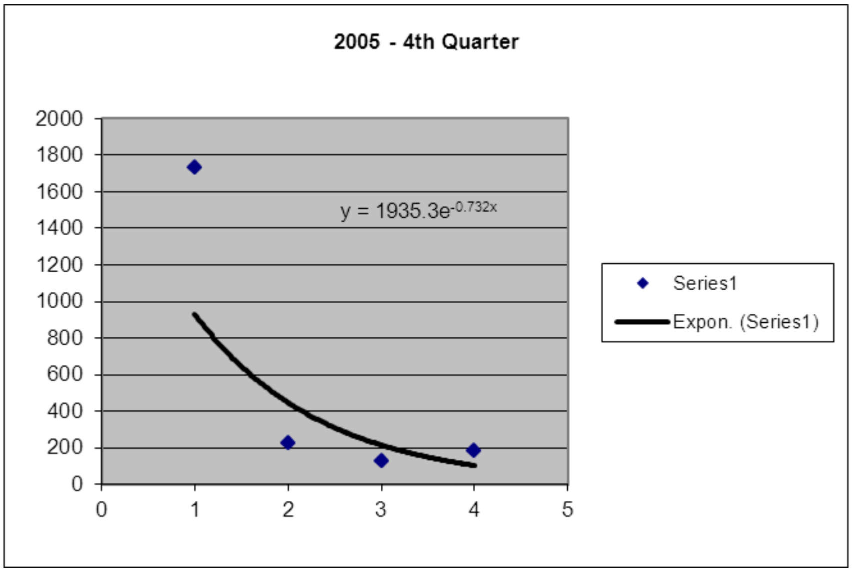

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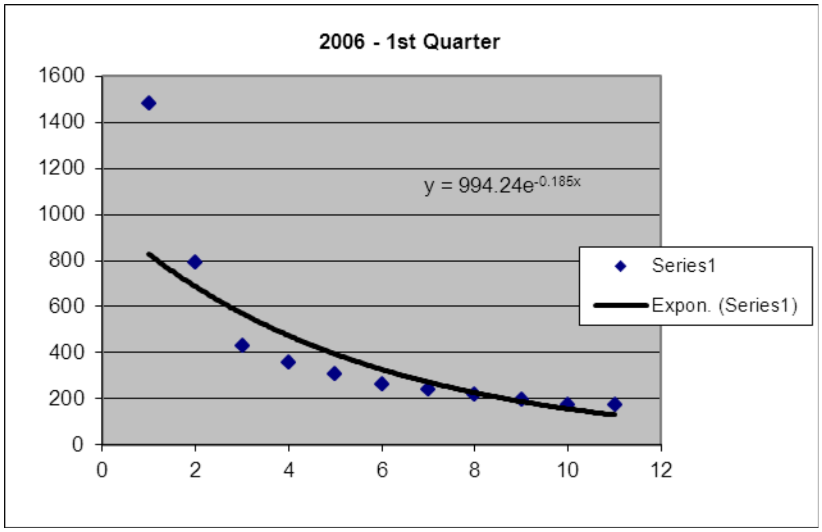

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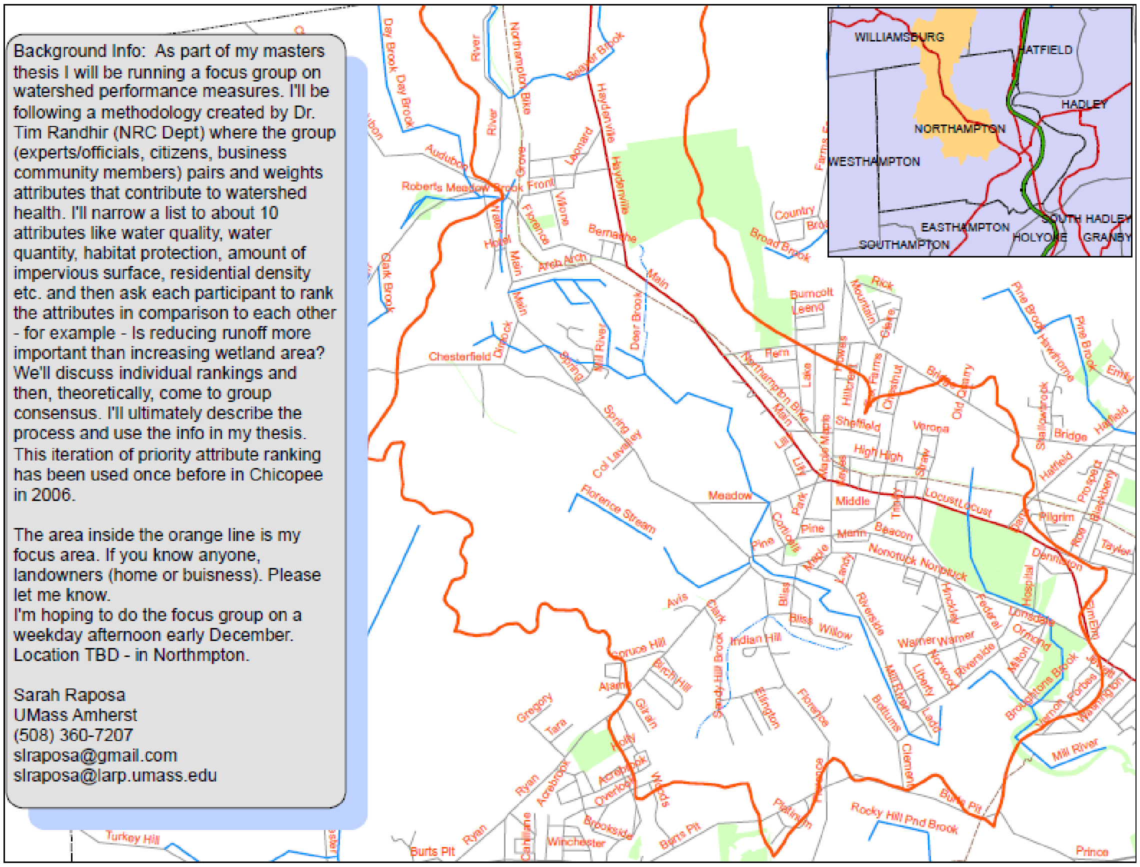
3/31/2006		51

APPENDIX C

FOCUS GROUP INVITATION



APPENDIX D

FOCUS GROUP INDIVIDUAL RANKINGS

Participant 1:

1. Carrying capacity
2. Land use
3. Economic feasibility
4. Energy
5. Use of local resources
6. Water Quality
7. Water Quantity
8. Waste reduction, reuse, and recycling
9. Ecosystems
10. Fairness to other communities

Participant 2:

1. Land use
2. Neighborliness
3. Economic vitality
4. Resource use
5. Who pays the costs
6. Economic self-reliance
7. Waste reduction, reuse, and recycling
8. Use of local resources
9. Fairness to future generations
10. Energy

Participant 3:

1. carrying capacity
2. land use
3. energy
4. waste reduction, reuse, recycling
5. water quantity
6. public safety
7. use of local resources
8. economic feasibility
9. affordability and access
10. fairness to other communities

Participant 4:
1. Land Use
2. Ecosystems
3. Civic Engagement
4. Education
5. Economic Vitality
6. Affordability and Access
7. Quality of Life
8. Energy
9. Waste Reduction, Reuse and Recycling
10. Recreational Opportunities

Participant 5:

1. Land Use
2. Water Quality
3. Water Quantity
4. Fairness to neighboring communities
5. Economic Vitality
6. Ecosystems
7. Fairness to Future Generations
8. Amount of Impervious Surfaces
9. Energy
10. Accessibility

APPENDIX E

FOCUS GROUP AGENDA

Northampton Focus Group
January 25, 2008
12:30-3:30 pm
Forbes Library, 20 West St
Northampton, MA 01060

12:30	Collect individual matrices on arrival
12:30-1:00	Lunch with presentation
1:00-3:30	Panel discussion of weights
3:30	Adjourn

APPENDIX F

FOCUS GROUP QUESTIONS

Matrix Questions:

1. How important is changing **Land use** compared to reducing **Energy** use towards the goal of achieving a sustainable city?
2. How important is changing **Land use** compared to increasing **Waste Reduction, Reuse, Recycling** activities towards the goal of achieving a sustainable city?
3. How important is changing **Land use** compared to protecting the **Carrying Capacity** of the watershed towards the goal of achieving a sustainable city?
4. How important is changing **Land use** compared to increasing use of more **Local Resources** towards the goal of achieving a sustainable city?
5. How important is changing **Land use** compared to **increasing water supplies** towards the goal of achieving a sustainable city?
6. How important is changing **Land use** compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
7. How important is changing **Land use** compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
8. How important is changing **Land use** compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
9. How important is changing **Land use** compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
10. How important is changing **Land use** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
11. How important is changing **Land use** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
12. How important is reducing **Energy** use compared to increasing **Waste Reduction, Reuse, Recycling** activities towards the goal of achieving a sustainable city?
13. How important is reducing **Energy** use compared to protecting the **Carrying Capacity** of the watershed towards the goal of achieving a sustainable city?
14. How important is reducing **Energy** use compared to increasing use of more **Local Resources** towards the goal of achieving a sustainable city?
15. How important is reducing **Energy** use compared to **increasing water supplies** towards the goal of achieving a sustainable city?
16. How important is reducing **Energy** use compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
17. How important is reducing **Energy** use compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
18. How important is reducing **Energy** use compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
19. How important is reducing **Energy** use compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?

20. How important is reducing **Energy** use compared to increasing **Water Quality** towards achieving a sustainable city?
21. How important is reducing **Energy** use compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
22. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to protecting the **Carrying Capacity** of the watershed the goal of achieving a sustainable city?
23. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing use of more **Local Resources** towards the goal of achieving a sustainable city?
24. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to **increasing water supplies** towards the goal of achieving a sustainable city?
25. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
26. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
27. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
28. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
29. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
30. How important is increasing **Waste Reduction, Reuse, Recycling** activities compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
31. How important is protecting the **Carrying Capacity** of the watershed compared to increasing use of more **Local Resources** towards the goal of achieving a sustainable city?
32. How important is protecting the **Carrying Capacity** of the watershed compared to **increasing water supplies** towards the goal of achieving a sustainable city?
33. How important is protecting the **Carrying Capacity** of the watershed compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
34. How important is protecting the **Carrying Capacity** of the watershed compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
35. How important is protecting the **Carrying Capacity** of the watershed compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?

36. How important is protecting the **Carrying Capacity** of the watershed compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
37. How important is protecting the **Carrying Capacity** of the watershed compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
38. How important is protecting the **Carrying Capacity** of the watershed compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
39. How important is increasing use of more **Local Resources** compared to **increasing water supplies** towards the goal of achieving a sustainable city?
40. How important is increasing use of more **Local Resources** compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
41. How important is increasing use of more **Local Resources** compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
42. How important is increasing use of more **Local Resources** compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
43. How important is increasing use of more **Local Resources** compared to **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
44. How important is increasing use of more **Local Resources** compared to **Fairness to Other Communities** towards the goal of achieving a sustainable city?
45. How important is **increasing water supplies** compared to increasing protection of natural **Ecosystems** towards the goal of achieving a sustainable city?
46. How important is **increasing water supplies** compared to **Economic Vitality** towards the goal of achieving a sustainable city?
47. How important is **increasing water supplies** compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
48. How important is **increasing water supplies** compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
49. How important is **increasing water supplies** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
50. How important is **increasing water supplies** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
51. How important is increasing protection of natural **Ecosystems** compared to increasing **Economic Vitality** towards the goal of achieving a sustainable city?
52. How important is increasing protection of natural **Ecosystems** compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
53. How important is increasing protection of natural **Ecosystems** compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
54. How important is increasing protection of natural **Ecosystems** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?

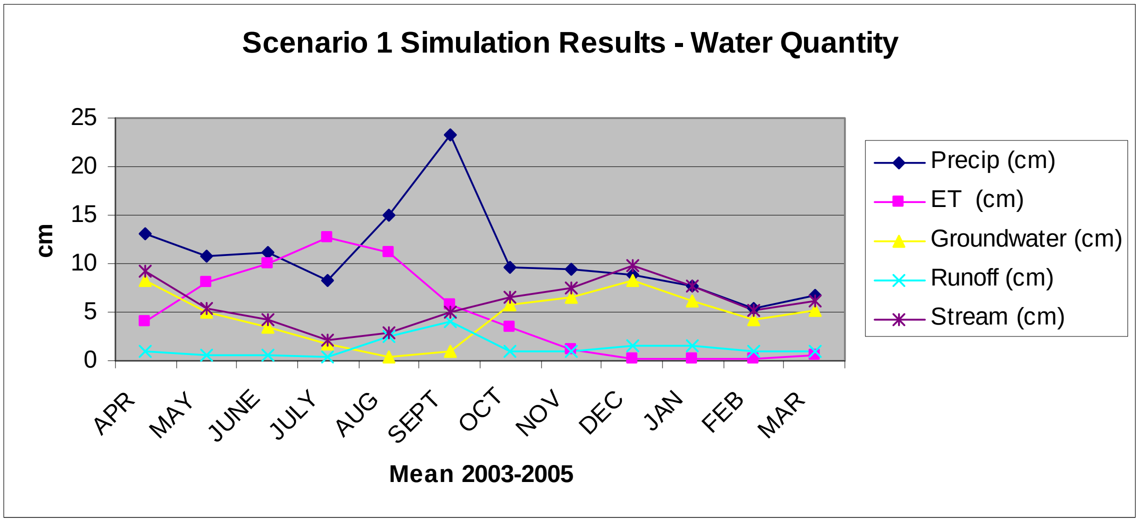
55. How important is increasing protection of natural **Ecosystems** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
56. How important is increasing **Economic Vitality** compared to increasing **Fairness to Future Generations** towards the goal of achieving a sustainable city?
57. How important is increasing **Economic Vitality** compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
58. How important is increasing **Economic Vitality** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
59. How important is increasing **Economic Vitality** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
60. How important is increasing **Fairness to Future Generations** compared to increasing **Affordability/ Accessibility** towards the goal of achieving a sustainable city?
61. How important is increasing **Fairness to Future Generations** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
62. How important is increasing **Fairness to Future Generations** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
63. How important is increasing **Affordability/ Accessibility** compared to increasing **Water Quality** towards the goal of achieving a sustainable city?
64. How important is increasing **Affordability/ Accessibility** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?
65. How important is increasing **Water Quality** compared to increasing **Fairness to Other Communities** towards the goal of achieving a sustainable city?

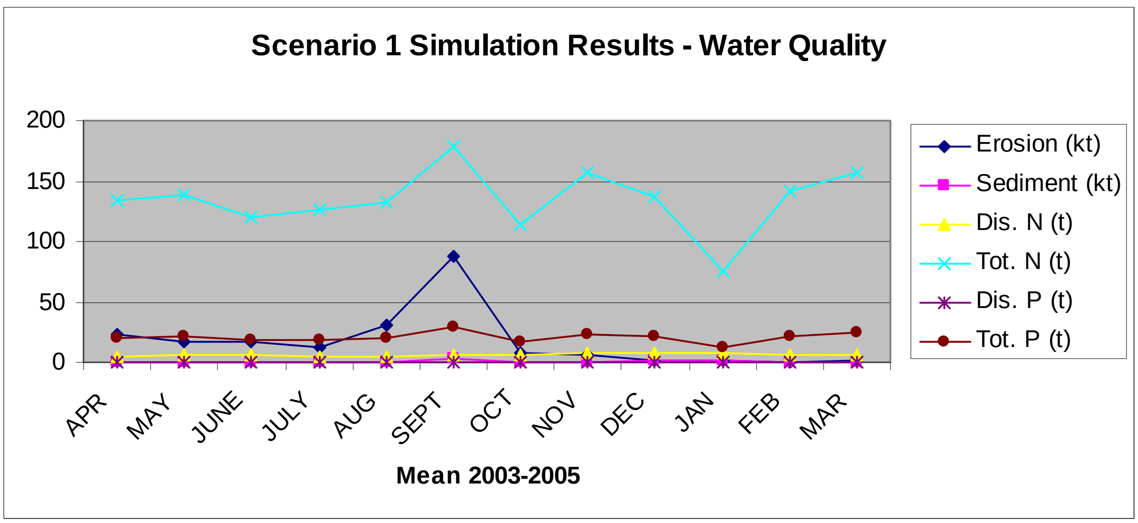
APPENDIX G

SCENARIOS RESULTS

Scenario 1: Aggressive

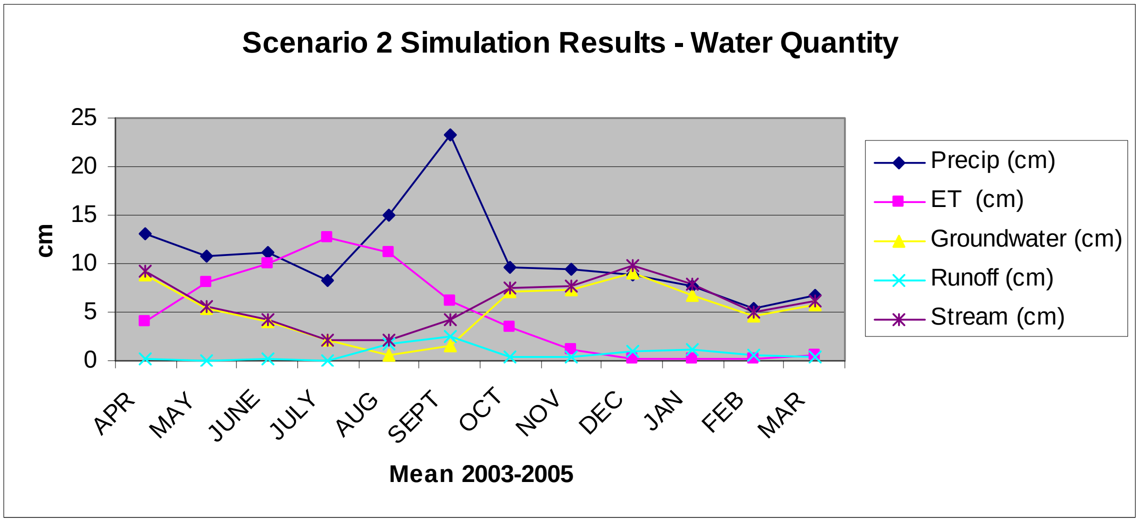
Aggressive: The Mill River Watershed				Tot area (h)=	14555.48	Rows/Yr=
	YEAR	2-3 Mean				
	Precip (cm)	**ET (cm)**	**Groundwater (cm)**	**Runoff (cm)**	**Stream (cm)**	
APR	13	3.99	8.21	1.02	9.23	
MAY	10.83	8.17	4.91	0.54	5.45	
JUNE	11.19	10.01	3.54	0.62	4.17	
JULY	8.36	12.69	1.8	0.4	2.2	
AUG	14.94	11.22	0.37	2.52	2.89	
SEPT	23.32	5.72	0.97	4.12	5.09	
OCT	9.63	3.37	5.72	0.87	6.59	
NOV	9.47	1.09	6.55	0.93	7.47	
DEC	8.76	0.21	8.21	1.59	9.8	
JAN	7.71	0.1	6.19	1.45	7.65	
FEB	5.44	0.1	4.17	0.96	5.13	
MAR	6.65	0.51	5.27	0.97	6.23	
YEAR	129.3	57.18	55.89	16	71.89	
	Erosion (kt)	**Sediment (kt)**	**Dis. N (t)**	**Tot. N (t)**	**Dis. P (t)**	**Tot. P (t)**
APR	23.7456	0.0455	4.4811	134.0732	0.1896	19.9216
MAY	16.3308	0.0118	6.387	139.1427	0.5941	20.7694
JUNE	16.8507	0.0207	5.7439	119.9632	0.5706	17.9404
JULY	11.7316	0.017	4.7864	126.2432	0.53	18.995
AUG	31.1895	0.6247	5.0486	132.2261	0.5577	20.5644
SEPT	88.2172	2.8664	6.0171	177.9516	0.6123	29.8989
OCT	6.9316	0.2215	6.9116	113.386	0.6154	17.0314
NOV	6.843	0.2654	7.3363	157.163	0.632	23.6807
DEC	1.6706	0.7752	8.4427	136.2457	0.6778	20.9462
JAN	1.2956	1.2272	7.44	75.4032	0.635	12.3158
FEB	0.5146	0.3766	6.1665	141.5287	0.5844	21.5595
MAR	2.2062	0.3964	6.7196	157.1552	0.6077	23.8939
YEAR	207.5271	6.8484	75.4809	1610.481	6.8067	247.5172

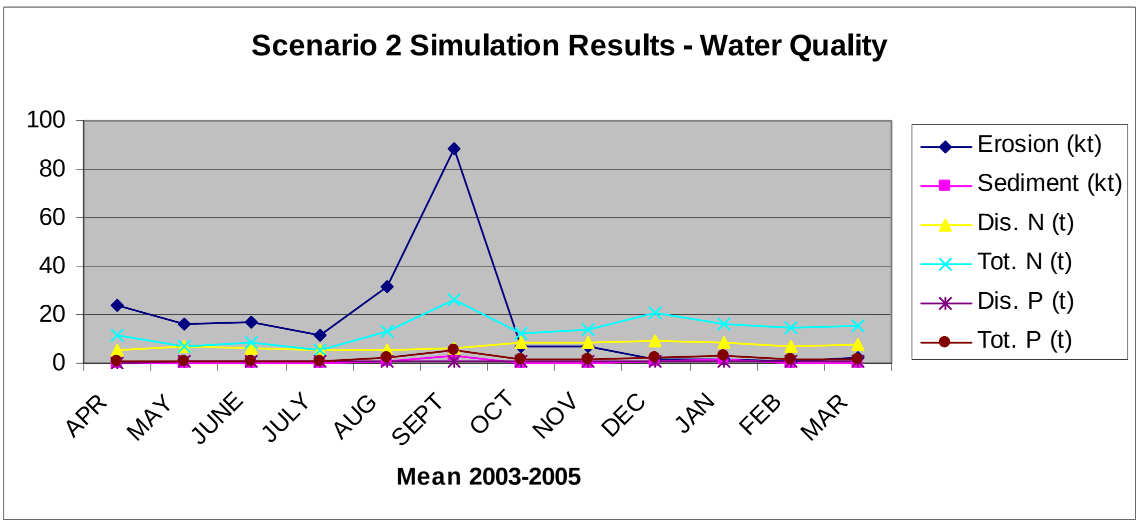

Scenario 1 Simulation Results - Water Quantity
25
20
15
10
5
0
cm
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Precip (cm)
ET (cm)
Groundwater (cm)
Runoff (cm)
Stream (cm)


Scenario 1 Simulation Results - Water Quality
200
150
100
50
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Erosion (kt)
Sediment (kt)
Dis. N (t)
Tot. N (t)
Dis. P (t)
Tot. P (t)

Scenario: 2 New Development with BMPs

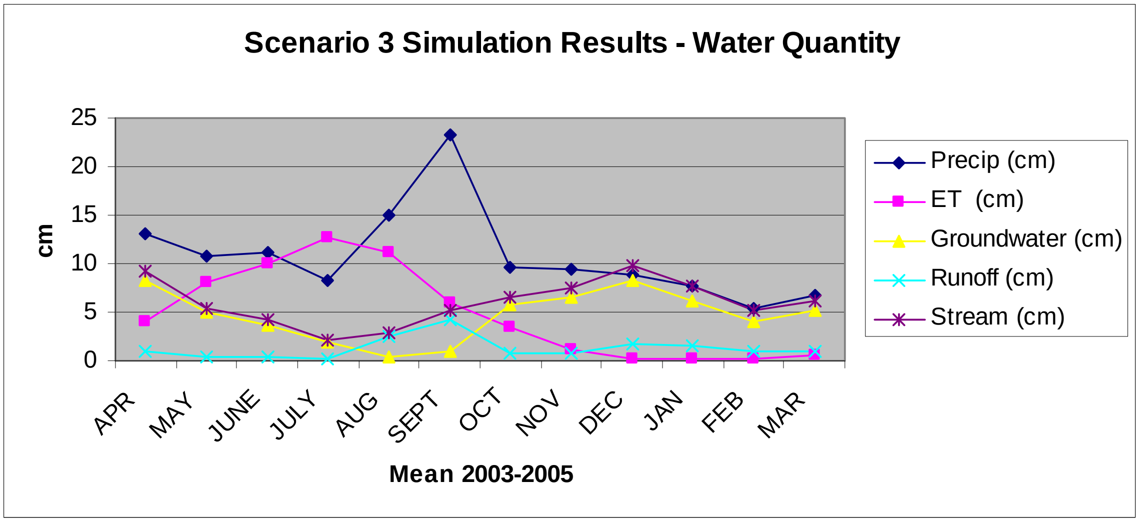
New Development with BMPs: The Mill River Watershed				Tot area (h)=	16558.99	Rows/Yr=
	YEAR	2-3 Mean				
	Precip (cm)	ET (cm)	Groundwater (cm)	Runoff (cm)	Stream (cm)	
APR	13	3.99	8.91	0.26	9.17	
MAY	10.83	8.17	5.44	0.06	5.5	
JUNE	11.19	10.01	4.08	0.11	4.19	
JULY	8.36	12.69	2.04	0.04	2.08	
AUG	14.94	11.22	0.51	1.64	2.16	
SEPT	23.32	6.18	1.63	2.54	4.18	
OCT	9.63	3.37	7.21	0.32	7.53	
NOV	9.47	1.09	7.32	0.34	7.66	
DEC	8.76	0.21	8.99	0.9	9.89	
JAN	7.71	0.1	6.78	1.06	7.84	
FEB	5.44	0.1	4.58	0.5	5.08	
MAR	6.65	0.51	5.75	0.42	6.17	
YEAR	129.3	57.64	63.25	8.19	71.44	
	Erosion (kt)	Sediment (kt)	Dis. N (t)	Tot. N (t)	Dis. P (t)	Tot. P (t)
APR	23.7456	0.0177	5.437	11.1646	0.2261	0.7014
MAY	16.3308	0.0005	7.0173	7.2082	0.6183	0.6339
JUNE	16.8507	0.0027	6.2898	8.5561	0.5914	0.7741
JULY	11.7316	0.0007	5.0468	5.0478	0.54	0.5409
AUG	31.1895	0.63	5.1567	13.0914	0.5619	1.9532
SEPT	88.2172	2.8996	6.4562	25.8342	0.6291	5.672
OCT	6.9316	0.1321	8.1411	12.4824	0.6624	1.1665
NOV	6.843	0.1478	8.215	14.043	0.6656	1.3066
DEC	1.6706	0.7491	9.4428	21.1278	0.716	2.5485
JAN	1.2956	1.6173	8.193	16.133	0.6637	3.2492
FEB	0.5146	0.3276	6.6829	14.8579	0.6042	1.6486
MAR	2.2062	0.3232	7.3514	15.6722	0.6319	1.6825
YEAR	207.5271	6.8484	83.4302	165.2187	7.1106	21.8773

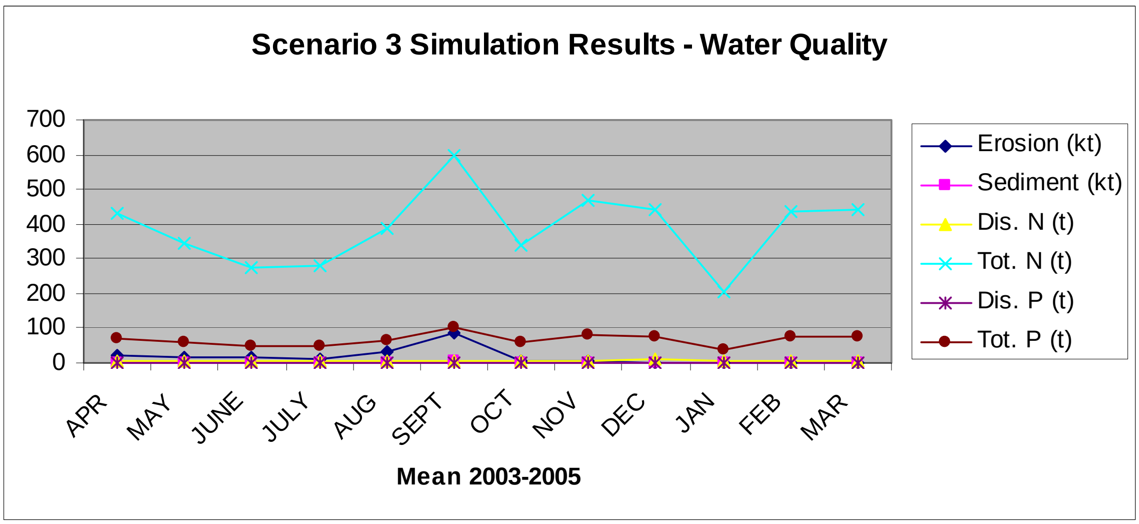

Scenario 2 Simulation Results - Water Quantity
cm
25
20
15
10
5
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Precip (cm)
ET (cm)
Groundwater (cm)
Runoff (cm)
Stream (cm)


Scenario 2 Simulation Results - Water Quality
100
80
60
40
20
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Erosion (kt)
Sediment (kt)
Dis. N (t)
Tot. N (t)
Dis. P (t)
Tot. P (t)

Scenario: 3 New Development without BMPs

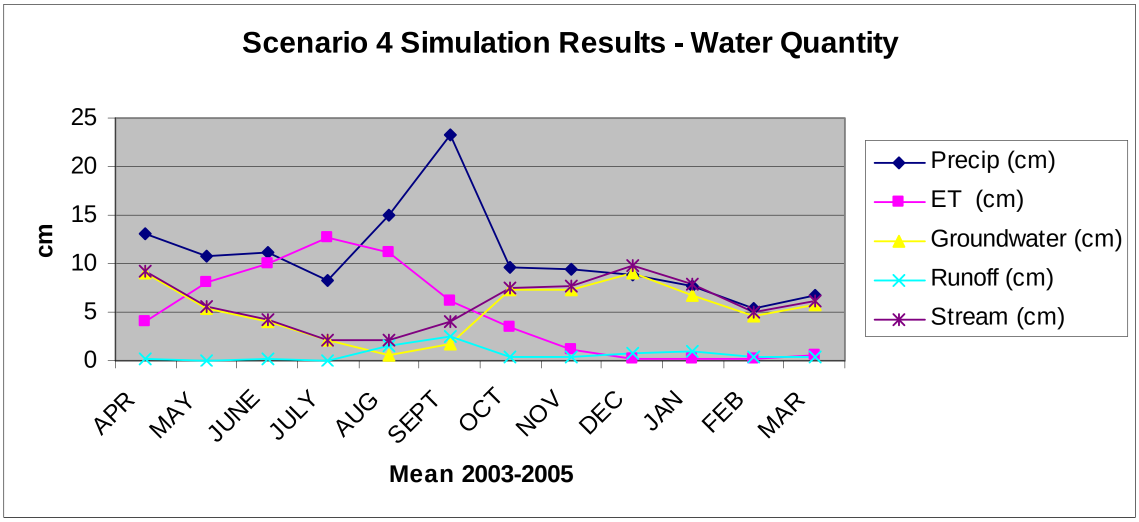
New Development without BMPs: The Mill River Watershed				Tot area (h)=	16558.99	Rows/Yr=
	YEAR	2-3 Mean				
	Precip (cm)	**ET (cm)**	**Groundwater (cm)**	**Runoff (cm)**	**Stream (cm)**	
APR	13	3.99	8.23	0.9	9.14	
MAY	10.83	8.17	5.05	0.33	5.38	
JUNE	11.19	10.01	3.75	0.44	4.19	
JULY	8.36	12.69	1.86	0.21	2.07	
AUG	14.94	11.22	0.38	2.49	2.87	
SEPT	23.32	5.95	0.95	4.28	5.23	
OCT	9.63	3.37	5.71	0.76	6.47	
NOV	9.47	1.09	6.61	0.83	7.44	
DEC	8.76	0.21	8.21	1.67	9.88	
JAN	7.71	0.1	6.15	1.51	7.66	
FEB	5.44	0.1	4.12	1.01	5.13	
MAR	6.65	0.51	5.23	0.92	6.15	
YEAR	129.3	57.41	56.26	15.34	71.6	
	Erosion (kt)	**Sediment (kt)**	**Dis. N (t)**	**Tot. N (t)**	**Dis. P (t)**	**Tot. P (t)**
APR	23.7456	0.0425	5.056	429.3969	0.2116	72.24
MAY	16.3308	0.0051	6.7988	343.5039	0.6099	57.4359
JUNE	16.8507	0.0153	6.1034	274.2737	0.5843	45.8372
JULY	11.7316	0.0061	4.9468	278.2292	0.5361	46.4543
AUG	31.1895	0.6305	5.0813	389.6259	0.559	66.3714
SEPT	88.2172	2.8872	6.0725	599.1391	0.6145	104.4566
OCT	6.9316	0.1982	7.2924	341.4249	0.63	57.4709
NOV	6.843	0.2412	7.8157	466.1398	0.6504	78.5354
DEC	1.6706	0.8002	9.0039	439.4283	0.6993	74.6318
JAN	1.2956	1.2339	7.8379	205.7463	0.6502	35.485
FEB	0.5146	0.3911	6.4242	434.4956	0.5943	73.5753
MAR	2.2062	0.397	7.0609	439.8092	0.6208	74.267
YEAR	207.5271	6.8484	79.4939	4641.212	6.9601	786.7607


Scenario 3 Simulation Results - Water Quantity
25
20
15
10
5
0
cm
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Precip (cm)
ET (cm)
Groundwater (cm)
Runoff (cm)
Stream (cm)

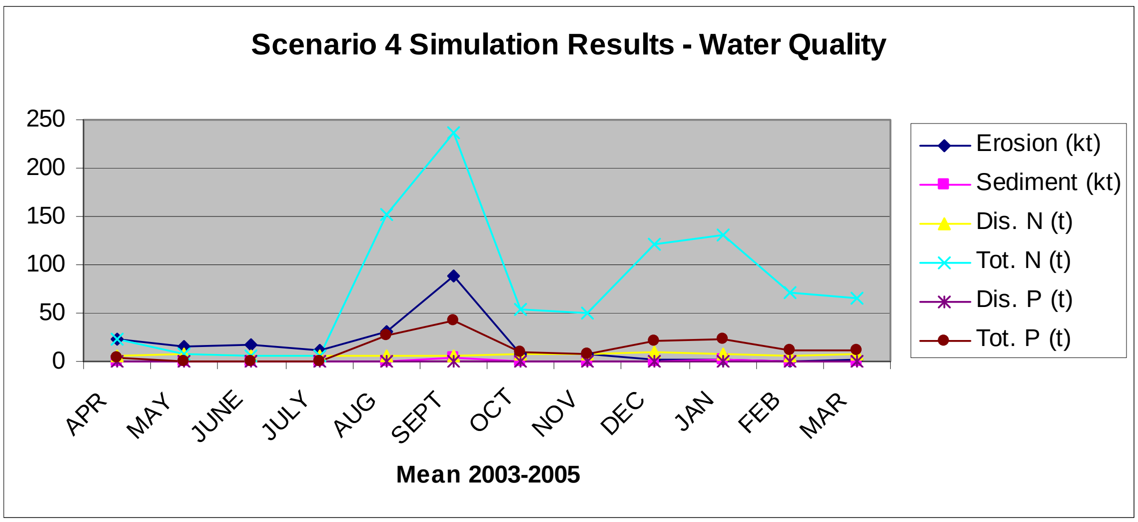

Scenario 3 Simulation Results - Water Quality
700
600
500
400
300
200
100
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Erosion (kt)
Sediment (kt)
Dis. N (t)
Tot. N (t)
Dis. P (t)
Tot. P (t)

Scenario: 4 Combination 1 – Aggressive Urban CN/Regular BMPs

Combination 1: The Mill River Watershed				Tot area (h)=	16558.99	Rows/Yr=
	YEAR	2-3 Mean				
	Precip (cm)	**ET (cm)**	**Groundwater (cm)**	**Runoff (cm)**	**Stream (cm)**	
APR	13	3.99	8.95	0.23	9.18	
MAY	10.83	8.17	5.45	0.06	5.51	
JUNE	11.19	10.01	4.09	0.1	4.19	
JULY	8.36	12.69	2.05	0.04	2.09	
AUG	14.94	11.22	0.54	1.6	2.14	
SEPT	23.32	6.18	1.67	2.46	4.13	
OCT	9.63	3.37	7.27	0.3	7.57	
NOV	9.47	1.09	7.35	0.32	7.66	
DEC	8.76	0.21	9.04	0.85	9.89	
JAN	7.71	0.1	6.82	1.03	7.85	
FEB	5.44	0.1	4.61	0.46	5.07	
MAR	6.65	0.51	5.79	0.39	6.18	
YEAR	129.3	57.64	63.62	7.83	71.46	
	Erosion (kt)	**Sediment (kt)**	**Dis. N (t)**	**Tot. N (t)**	**Dis. P (t)**	**Tot. P (t)**
APR	23.7456	0.0159	5.4594	22.3293	0.227	3.115
MAY	16.3308	0.0005	7.0236	7.0244	0.6185	0.6192
JUNE	16.8507	0.0022	6.2928	6.2959	0.5915	0.5944
JULY	11.7316	0.0008	5.05	5.0511	0.5401	0.5411
AUG	31.1895	0.6233	5.1728	150.9982	0.5625	26.0526
SEPT	88.2172	2.9292	6.4778	237.4632	0.63	43.1067
OCT	6.9316	0.1241	8.1709	54.4314	0.6636	8.6702
NOV	6.843	0.1349	8.232	50.1697	0.6663	7.949
DEC	1.6706	0.7364	9.4684	120.4475	0.717	20.3995
JAN	1.2956	1.6635	8.2148	130.2815	0.6646	23.2368
FEB	0.5146	0.3085	6.7022	72.1028	0.6049	12.0683
MAR	2.2062	0.309	7.3741	66.1142	0.6327	10.963
YEAR	207.5271	6.8484	83.6388	922.7091	7.1186	157.3159



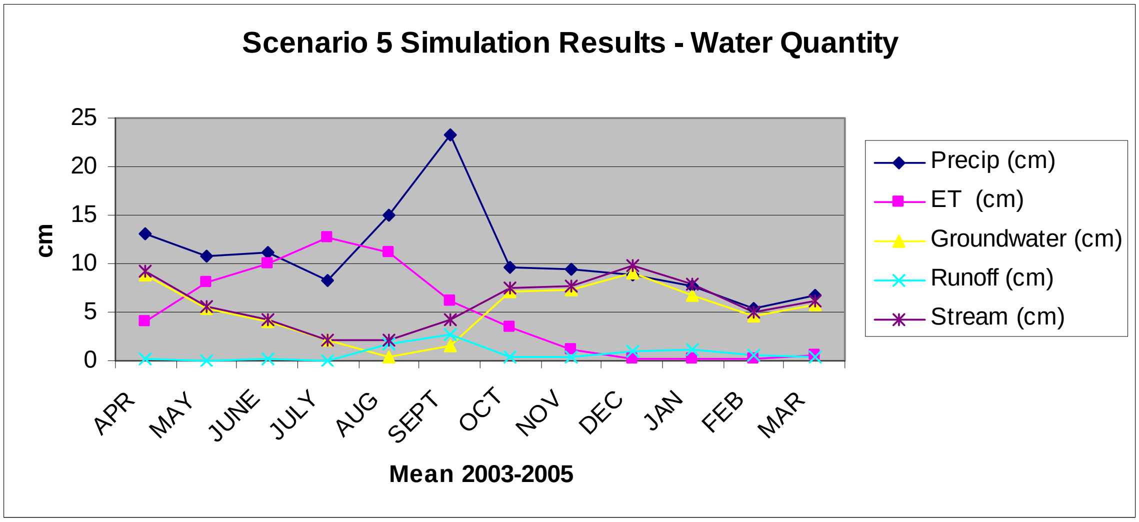
Scenario 4 Simulation Results - Water Quantity
25
20
15
10
5
0
cm
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Precip (cm)
ET (cm)
Groundwater (cm)
Runoff (cm)
Stream (cm)

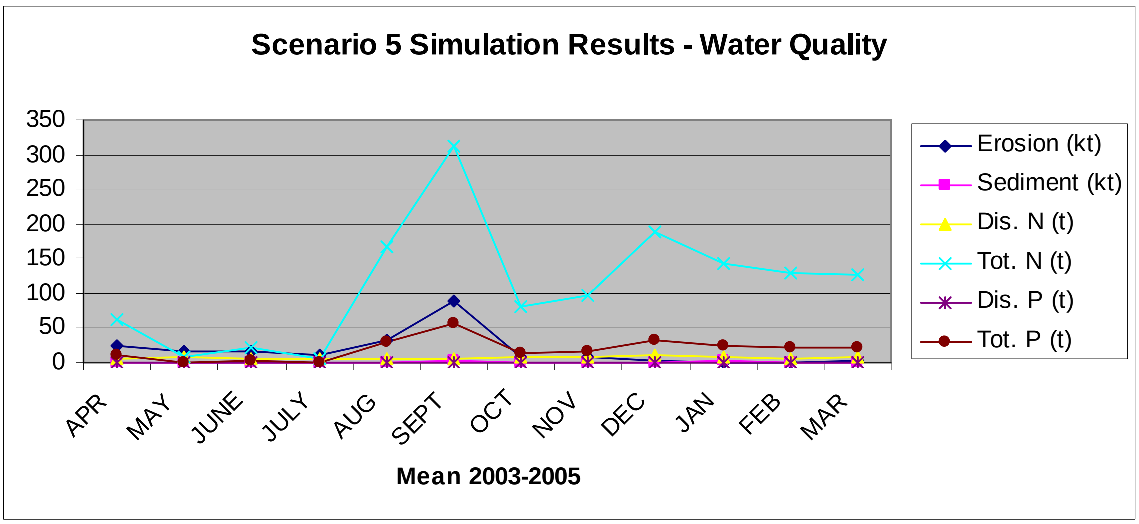


Scenario 4 Simulation Results - Water Quality
250
200
150
100
50
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Erosion (kt)
Sediment (kt)
Dis. N (t)
Tot. N (t)
Dis. P (t)
Tot. P (t)

Scenario: 5 Combination 2 – Aggressive Urban CN/Aggressive BMPs

Combination 2: The Mill River Watershed				Tot area (h)=	16558.99	Rows/Yr=
	YEAR	2-3 Mean				
	Precip (cm)	**ET (cm)**	**Groundwater (cm)**	**Runoff (cm)**	**Stream (cm)**	
APR	13	3.99	8.89	0.25	9.15	
MAY	10.83	8.17	5.43	0.06	5.49	
JUNE	11.19	10.01	4.08	0.11	4.19	
JULY	8.36	12.69	2.04	0.04	2.09	
AUG	14.94	11.22	0.48	1.71	2.19	
SEPT	23.32	6.18	1.59	2.64	4.23	
OCT	9.63	3.37	7.14	0.32	7.47	
NOV	9.47	1.09	7.29	0.35	7.64	
DEC	8.76	0.21	8.97	0.93	9.9	
JAN	7.71	0.1	6.74	1.1	7.85	
FEB	5.44	0.1	4.56	0.51	5.06	
MAR	6.65	0.51	5.73	0.43	6.17	
YEAR	129.3	57.64	62.96	8.47	71.42	
	Erosion (kt)	**Sediment (kt)**	**Dis. N (t)**	**Tot. N (t)**	**Dis. P (t)**	**Tot. P (t)**
APR	23.7456	0.0168	5.4281	60.9733	0.2258	9.6964
MAY	16.3308	0.0005	7.0159	7.0165	0.6182	0.6188
JUNE	16.8507	0.0024	6.29	21.908	0.5914	3.2518
JULY	11.7316	0.0007	5.0474	5.0483	0.54	0.5409
AUG	31.1895	0.6289	5.1358	166.1773	0.5611	28.6467
SEPT	88.2172	2.9026	6.4326	312.1144	0.6282	55.7876
OCT	6.9316	0.1299	8.1016	81.2444	0.6609	13.2485
NOV	6.843	0.1441	8.2013	96.696	0.6651	15.8805
DEC	1.6706	0.7456	9.4305	187.569	0.7156	31.8369
JAN	1.2956	1.6348	8.1708	141.8007	0.6629	25.1718
FEB	0.5146	0.3229	6.6694	129.3275	0.6037	21.8264
MAR	2.2062	0.3193	7.342	125.2126	0.6315	21.0355
YEAR	207.5271	6.8484	83.2653	1335.088	7.1043	227.5418


Scenario 5 Simulation Results - Water Quantity
cm
25
20
15
10
5
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Precip (cm)
ET (cm)
Groundwater (cm)
Runoff (cm)
Stream (cm)


Scenario 5 Simulation Results - Water Quality
350
300
250
200
150
100
50
0
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
Mean 2003-2005
Erosion (kt)
Sediment (kt)
Dis. N (t)
Tot. N (t)
Dis. P (t)
Tot. P (t)

APPENDIX H

MODEL TRANSFERRABLE

STORMWATER REGULATION

Article ## To create a Low Impact Development (LID) Site Plan Approval Bylaw

To see if the Town will vote to amend the *Zoning By-Laws* by adding a new Article ## and/or take any other action relative thereto.

1. Purpose

The purpose of this By-law is to protect, maintain and enhance the public health, safety, environment and general welfare by establishing minimum requirements and procedures to control the adverse effects of increased post-development stormwater runoff and non-point source pollution associated with new development and re-development. It has been determined that proper management of post-development stormwater runoff will minimize damage to public and private property and infrastructure, safeguard the public health, safety, environment and general welfare of the public, protect water and aquatic resources, and promote groundwater recharge to protect surface and groundwater drinking supplies.

2. Applicability

This bylaw shall apply to all activities that result in a land disturbance activity of 40,000 sq. ft. of land, or that will disturb less than 40,000 sq. ft. of land but is part of a larger common plan of development or sale that will ultimately disturb equal to or greater than 40,000 sq. ft. of land. No person shall perform any activity that results in a land disturbance activity of 40,000 sq. ft. or more of land without an LID site plan approval by the Planning Board, by majority vote, following review at a duly posted meeting, but without a formal public hearing, of an approved soil erosion and sediment control plan and a stormwater management plan. Normal maintenance and/or improvement of land in agricultural or aquaculture use, as defined by the Wetland Protection Act Regulation 310 CMR 10.4, shall be exempt from this by-law. In addition, as authorized in the Phase II Small MS4 General Permit for Massachusetts, stormwater discharges resulting from the above activities that are subject to jurisdiction under the Wetland Protection Act and demonstrate compliance with the Massachusetts Stormwater Management Policy as reflected in an Order of Conditions or Request for Determination of Applicability issued by the Conservation Commission shall be deemed to be in compliance with this bylaw.

3. Statutory Authority

This stormwater site plan review bylaw is adopted under the authority granted by the Home Rule Amendment of the Massachusetts Constitution, the Home Rule statutes G.L. c.40 and G.L. c.40A, and the regulations of the Federal Clean Water Act and applicable regulations, including found at 40 CFR 122.34.

4. Responsibility

The Planning Board shall administer, implement and enforce this bylaw. Any powers granted to or duties imposed upon the Planning Board may be delegated in writing by the Planning Board to employees or agents. The Planning Board may distribute plans to other boards, commissions, departments, and outside technical and legal consultants and agencies for their review and recommendations.

5. Design Standards

The applicant shall submit a plan to the Planning Board that illustrates how the following LID site design standards were utilized to the maximum extent feasible and explains any site and financial constraints which limited application of items 1 through 10 below and how items 11 and l2 were considered for implementation:

1. Preservation of the site's natural features and environmentally sensitive areas such as wetlands, existing vegetation, slopes, drainage ways, permeable soils, flood plains, woodlands and soils to the greatest extent possible;
2. Minimization of grading and clearing;
3. Clustering of buildings and a reduction in size of building footprints;
4. Use of stormwater management components that provide filtration, treatment and infiltration such as vegetated areas that slow down runoff; maximizing infiltration and reducing contact with paved surfaces;
5. Creation of subwatersheds to treat and micromanage runoff in smaller, decentralized, innovative stormwater management techniques to treat and recharge stormwater close to the source;
6. Lengthen flow paths and maximize sheet flow;
7. Emphasis on simple, nonstructural, innovative, low-cost methods including open drainage systems, recharging of roof runoff, parking areas and/or roadways, to recharge on site as close to the source as possible.
8. A maintenance program including information on regular street and parking lot sweeping shall be provided to the Planning Board for approval;
9. Reduction of impervious surfaces wherever possible through alternative street design, such as omission of curbs and use of narrower streets, the use of porous pavement or permeable pavers, shared driveways and through the use of shared parking areas;
10. Reduction of the heat island effect;
11. Use of vegetation in buffer strips and in rain gardens (small planted depressions that can trap and filter runoff);
12. Techniques integrated into every part of site design to create a hydrologically functional lot or development site, including but not limited to the following:
    1. Grass swales along roads;
    2. Rain gardens;

iii. Buffer areas;

iv. Use of roof gardens where practicable;

v. Use of amended soils that will store, filter and infiltrate runoff;

vi. Bioretention areas;

vii. Use of rain barrels and other cisterns to provide additional stormwater storage;

viii. Use of permeable pavement and/or pavers in driveways, overflow parking, outside sales areas, etc.

ix. Use of native plants and grasses

6. LID Plan Contents

The LID Management Plan shall contain sufficient information for the Planning Board to evaluate the environmental impact, effectiveness, and acceptability of the site planning process and the measures proposed by the applicant for reducing adverse impacts from stormwater runoff. This plan shall be in accordance with the criteria established in these Bylaws and must be submitted with the stamp and signature of a Professional Engineer (PE) licensed in the Commonwealth of Massachusetts. The LID Management Plan shall fully describe the project in drawings, narrative, and calculations. It shall include:

a. Contact Information. The name, address, and telephone number of all persons having a legal interest in the property and the tax reference number and parcel number of the property or properties affected;

b. A locus map;

c. Existing site plan (for comparison to "o" below);

d. The existing zoning, and land use at the site;

e. The proposed land use;

f. The location(s) of existing and proposed easements;

g. The location of existing and proposed utilities;

h. The site's existing & proposed topography with contours at 2-foot intervals,

i. The existing site hydrology (both groundwater recharge and surface runoff);

j. A description and delineation of existing stormwater conveyances, impoundments, wetlands, drinking water resource areas, shellfishing areas, swimming beaches or other critical environmental resource areas, on or adjacent to the site or into which stormwater flows;

k. A delineation of 100-year flood plains, if applicable;

l. Estimated seasonal high groundwater elevation in areas to be used for stormwater retention, detention, or infiltration;

m. The existing and proposed vegetation and ground surfaces with runoff coefficients for each;

n. A drainage area map showing pre and post construction watershed boundaries, drainage area and stormwater flow paths, including municipal drainage system flows;

o. A recharge area analysis that calculates pre-and post-project annual groundwater recharge rates on the parcel;

p. A description and drawings of all components of the proposed LID Management system including:

i. Locations, cross sections, and profiles of all brooks, streams, drainage swales and their method of stabilization;

ii. All measures for the detention, retention or infiltration of water;

iii. Description of non-structural BMPs;

iv. All measures for the protection of water quality;

v. The structural details for all components of the proposed drainage systems and LID Management facilities;

vi. Notes on drawings specifying materials to be used, construction specifications, and expected hydrology with supporting calculations;

vii. Proposed site plan including location of buildings or other structures, impervious surfaces, and drainage facilities, if applicable;

viii. Any other information requested by the Planning Board

q. Hydrologic and hydraulic design calculations for the pre-development and post-development conditions for the design storms specified in this Bylaw. Such calculations shall include:

i. Description of the design storm frequency, intensity and duration;

ii. Time of concentration;

iii. Soil Runoff Curve Number (RCN) based on land use and soil hydrologic group. For the LID land uses listed below, use the RCN provided: New Runoff Curve Numbers (not currently found in TR-55)

- Greenroofs - 88
- Paved areas w/tree canopy - 92
- Gravel road or parking lot - 95
- Gravel road or parking lot w/tree canopy - 89
- Water - 100
- Bioretention facility - 80
- Pervious pavers - 75
- Bioretention facility - 80
- Bioretention w/tree canopy -74
- Lawn, no soil amendment - 80

- Lawn w/ 4" Compost Soil Amendment: HSG A – 36, HSG B – 58, HSG C-72, HSG D-77;

iv. Peak runoff rates and total runoff volumes for each watershed area;

v. Information on construction measures used to maintain the infiltration capacity of the soil where any kind of infiltration is proposed;

vi. Infiltration rates, where applicable;

vii. Culvert capacities;

viii. Flow velocities

ix. Data on the increase in rate and volume of runoff for the specified design storms, and

x. Documentation of sources for all computation methods and field test results.

r. Post-Development downstream analysis if deemed necessary by the Planning Board;

s. Soils Information from test pits performed at the location of proposed LID Management facilities, including but not limited to soil descriptions, depth to seasonal high groundwater, depth to bedrock, and percolation rates. Soils information will be based on site test pits logged by a Massachusetts Registered Soil Evaluator, or a Massachusetts Registered Professional Engineer;

t. Landscaping plan describing the woody and herbaceous vegetative stabilization and management techniques to be used within and adjacent to the stormwater practice.

7. Owners Association

As a condition of approval of a LID Management Plan the Applicant shall create and properly fund a Owners Association and all purchasers of land within the project shall be required to belong to the Owners Association. The Owners Association shall be responsible for the perpetual operations and maintenance of the components of the approved LID management Plan. The Owners Association shall maintain permanent ownership of any drainage basins or ponds in the subdivision, including all pipes and other appurtenant devices, and shall have the permanent responsibility of maintaining, repairing and replacing said drainage systems, as necessary. The Owners Association documents shall be reviewed and approved by the Planning Board, in consultation with Town Counsel, and the Owners Association shall have an initial fund that is deemed satisfactory to the Planning Board, in consultation with the Planning Board’s technical consultant. The Owners Association shall send correspondence to all members of the Association twice a year, once during March and once during September, to advise each member of the Association’s duties and responsibilities to: (1) operate and maintain the components of the approved LID management Plan; and (2) maintain, repair and replace the drainage systems. At the same time, the Owners Association shall provide a written reminder to each individual member to maintain any portion of the systems on each member’s property, including the mowing and clearing of drainage swales and berms.

8. Illicit Connections

There shall be no connections to the Municipal Storm Drain Systems (MS4)

9. Promulgation of Rules and Regulations

The Planning Board may promulgate rules and regulations to effectuate the purpose of this bylaw. Failure by the Planning Board to promulgate such rules and regulations shall not have the effect of suspending or invalidating this bylaw.

10. Inspections, Submission of Final Plans, Maintenance

The Planning Board, or designated agent, shall make inspections as hereinafter required and either shall approve that portion of the work completed in accordance with the approved plans or shall notify the owner or person responsible for the implementation of the plans wherein the work fails to comply with the approved soil erosion and sediment control plan, or the approved stormwater management plan as described in Planning Board's Rules and Regulations. Plans for grading, removal, stripping, excavating, and filling work approved by the Planning Board and shall be stored on site during the progress of the work. To obtain inspections, the permittee shall notify the Planning Board agent at least two working days before each of the following:

- Installation of sediment and erosion control measures.
- Start of construction.
- Completion of site clearing.
- Completion of rough grading.
- Installation of stormwater controls.
- Close of the construction season.
- Completion of final landscaping.

The person responsible for the implementation of the approved plans shall make regular inspections of all control measures in accordance with the inspection schedule outlined on the approved soil erosion and sediment control plan(s). The purpose of such inspections will be to determine the overall effectiveness of the control plan and the need for additional control measures. All inspections shall be documented in written form and submitted to the Planning Board Agent at the time interval specified in the approved permit.

The Planning Board, or designated agent, shall enter the property of the applicant as deemed necessary to make regular inspections to ensure the validity of the reports filed as noted above.

The applicant shall submit an "as-built" plan for the stormwater controls after the final construction is completed. The plan must show the final design and specifications of all stormwater management systems and must be prepared by a professional land surveyor.

An Operation and Maintenance plan (O&M Plan) is required at the time of application for all projects. The maintenance plan shall be designed to ensure compliance with the Permit and this Bylaw during all seasons and throughout the life of the system. The Operation and Maintenance Plan shall remain on file with the Planning Board and shall be an ongoing and enforceable requirement. The O&M Plan shall include:

1. The name(s) of the owner(s) for all components of the system;
2. A map showing the location of the systems and facilities including catch basins, manholes/access lids, main, and stormwater devices;
3. Maintenance agreements that specify:
    a) The names and addresses of the person(s) responsible for operation and maintenance;
    b) The person(s) responsible for financing maintenance and emergency repairs;
    c) An Inspection and Maintenance Schedule for all LID Management facilities including routine and non-routine maintenance tasks to be performed;
    d) A list of easements with the purpose and location of each;
    e) The signature(s) of the owner(s).
4. LID Management Easement(s)
    a) LID Management easements shall be provided by the property owner(s) as necessary for:
        i. Access for facility inspections and maintenance;
        ii. Preservation of stormwater runoff conveyance, infiltration, and detention areas and facilities, including flood routes for the 100-year storm event;
        iii. Direct maintenance access by heavy equipment to structures requiring regular maintenance.
    b) The purpose of each easement shall be specified in the maintenance agreement signed by the property owner.
    c) Stormwater Management easements are required for all areas used for off-site stormwater control, unless a waiver is granted by the Planning Board.
    d) Easements shall be recorded with the County Registry of Deeds prior to issuance of a Certificate of Completion by the Planning Board
5. Changes to Operation and Maintenance Plans
    a) The owner(s) of the LID Management system shall notify the Planning Board of changes in ownership or assignment of financial responsibility.
    b) The maintenance schedule in the Maintenance Agreement may be amended to achieve the purposes of this Bylaw by mutual agreement of the Planning Board and the Responsible Parties. Amendments shall be in writing and signed by all Responsible Parties. Responsible Parties shall

include owner(s), persons with financial responsibility, and persons with operational responsibility.

11. Project Change

The permittee, or his or her agent, shall notify the Planning Board in writing of any change or alteration of a land-disturbing activity authorized in either the soil erosion and sediment control plan or the stormwater management plan before any change or alteration occurs. If the Planning Board determines that the change or alteration is significant, based on the design requirements listed in this bylaw and accepted construction practices, the Planning Board may require that an amended soil erosion and sediment control plan and/or stormwater management plan application be filed. If any change or deviation from these plans occurs during a project, the Planning Board may require the installation of interim measures before approving the change.

12. Fees

The appropriate application fee as established by the Planning Board shall accompany each application. Applicants shall pay review fees, as determined by the Planning Board, sufficient to cover any expenses connected with any public hearing, review of the soil erosion and sediment control plan, and site inspection.

13. Appeal

The appeal of any decision of the Planning Board hereunder shall be made in accordance with the provisions of Mass. Gen. L. Ch. 40A or other such provision of the General Laws.

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