Web-enabled Spatial Decision Support System for Interdisciplinary Watershed Management

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by

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(ABSTRACT)

The development and use of web-enabled tools for watershed modeling and decision-making have gained popularity lately with the increase in internet speed and accessibility. Most of the web-enabled tools available today address the watershed problems related to a narrow discipline like hydrology, or ecology etc. This thesis presents the work done in the development of a web-enabled integrated system, named WebL2W, which can address watershed problems in a more holistic approach.

WebL2W integrates models from hydrology, economics, and biology in a single shell. The integration is performed using GIS as a common platform for database and interface management. A user accesses the system over the web and chooses pre-selected land development patterns to create a 'what if' scenario. The hydrologic model simulates effects of the scenario on annual runoff volume, flood peaks of various return periods, and ground water recharge. The economics model evaluates the changes in land value, tax revenue, and government expenditures as a result of the new land development scenario. The biology model evaluates effects of new land uses to fish habitats in the watershed. The design of the system is based on current software engineering practices such as object oriented programming (OOP) and relational database management system (RDBMS). The implementation uses the Visual Basic programming environment and Active Server Pages.

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1.0 INTRODUCTION

The rapid growth of the internet over the past decade has advanced our ability to understand and manage engineering issues in two important ways. First, the internet has made it easier to use physical data from a variety of sources for complex simulations and modeling. Secondly, communication between and among professionals involved in management has been improved to a degree that sharing of ideas, experiences, and information about solving problems has become commonplace (Wallace et. al 2001). The development and availability of powerful Geographic Information Systems (GIS) and visualization tools in conjunction with the internet have played an important role in the emergence of web-enabled Spatial Decision Support System (SDSS). These Decision Support Systems (DSSs) help in simulation of one or several possible decision alternatives for a particular problem. Pictures, interactive maps and other visualization techniques (in contrast to numbers) provide fast and integrated assessment of the outcomes of simulated decision alternatives.

Some of the most recent research in watershed management related web-enabled SDSS can be found on the internet at sites like http://danpatch.ecn.purdue.edu/~sprawl/LTHIA, http://cimic.rutgers.edu/digitalmeadowlands, http://www.cares.missouri.edu/dem, and http://www.esri.com/hazards etc. There are several other SDSS available for watershed management applications, like the AquaTool DSS (Andreu et al. 1996), USEPA's BASIN model (http://www/epa.gov/OST/BASINS/) etc., but these are desktop models and are yet to be ported to web. Most of these works deal with the decision problems related to a specific vertical model and lack an interdisciplinary approach. Absence of an integrated approach towards urbanization and suburbanization process in a watershed has impaired the ability to predict the consequences of watershed development management decisions. This fact is well stated in the *Watershed Approach* of the USEPA (Davis 1998). The lack of a holistic approach to watershed development decision-making can be linked, in part, to the limited availability of fast and efficient tools that can manage and analyze the heterogeneous datasets in the watershed, providing decision alternatives to the managers and decision makers. This thesis thus aims at providing a framework for development of a multi-disciplinary, web-enabled SDSS for the effective management of watershed development.

1.1 Goal and Objectives

The major goal of this thesis is to develop a prototype of a web-enabled SDSS for interdisciplinary analysis of a watershed. The prototype aims to integrate models from hydrology, economics, and ecology with GIS providing a common framework for database management and visualization. In pursuit of this major goal, the specific objectives are:

i. Research the state of the art for the web-enabled SDSS applications.
ii. Develop a computing architecture and a working prototype of an interdisciplinary web-enabled SDSS for watershed management.
iii. Demonstrate the application of the prototype SDSS using case studies.

WebL2W (Web-enabled Landscapes to Waterscapes) is the prototype web-enabled SDSS developed as a part of the thesis. The development of the prototype was initiated as a part of a multi-year project, entitled "*From Landscapes to Waterscapes: Integrating Framework for Urban Watersheds*" funded by USEPA and NSF at Virginia Tech in year 1997 – 2001 (referred to as EPA/NSF project hereafter). The SDSS is capable of estimating the effects of land development on hydrology, economics and ecology of the watershed in the study area.

1.2 Organization of the Thesis

The remaining chapters in this thesis are organized in following manner. Chapter 2 presents a comprehensive literature review on computing architecture and previous implementations of SDSS. Chapter 3 describes the design and development issues involved with WebL2W. Several case studies are presented in Chapter 4, which describe the multi-disciplinary potential of WebL2W. Chapter 5 presents future scope of this research and lists some tasks in this direction. A brief review of the discipline specific models (i.e. hydrology, economics, and fish health) that are incorporated into WebL2W is presented in Appendix A. Appendix B contains the program code of WebL2W. Appendix C contains the process of installation and implementation of WebL2W in a cookbook fashion. References of all the works cited in this thesis are presented at the end of the thesis.

2.0 LITERATURE REVIEW

A review of literature related to the design and applications of SDSS in general and watershed management applications of SDSS in particular is presented in this chapter. Other related issues like Problem Solving Environment (PSE), client/ server computing and object oriented programmings are also discussed.

2.1 Decision Support System

A DSS can be defined as a computer system, hardware and software, designed to support decision makers interactively in thinking about and making decision about relatively unstructured problems (Walsh 1993). A DSS provides a framework for incorporating modeling capabilities with database resources to improve decision-making processes. Decision makers can interact with the system using intuitively designed easy-to-use graphical user interfaces. A conceptual diagram showing the components of a typical DSS is given in Figure 2.1.

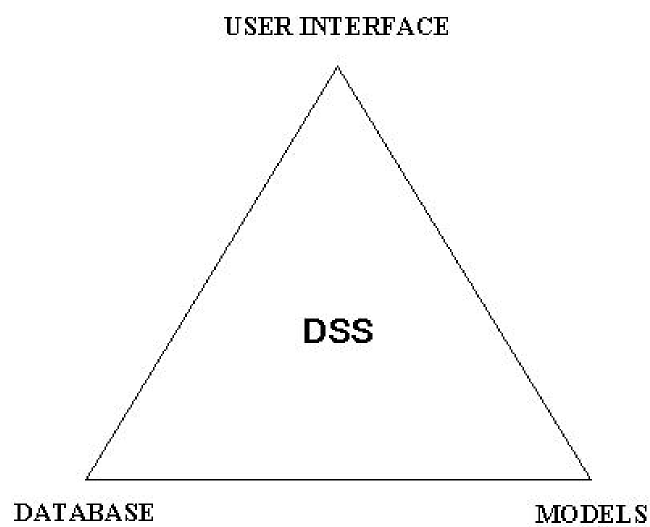

Figure 2.1. Representation of major parts of a decision support system (adapted from Walsh, 1993)

From a historical perspective, development of the DSSs can be attributed to the ineffectiveness of the decision-making tools available in the 1960s and 1970s. The old-fashioned Management Information Systems (MIS) were data oriented, most of which simply retrieved data from large databases on selected queries. The demand for better modeling facilities and a greater degree of interaction with solution processes thus evolved the new tool known as the DSS (Armstrong et al. 1990).

2.2 Spatial Decision Support System

SDSSs are a class of computer systems that combine the technologies of GIS and DSS to aid decision-makers with problems that have spatial dimensions (Walsh 1993). Like any other DSS, a SDSS is designed to solve complex problems and the main focus of design is oriented towards decision-makers. A SDSS focuses on a limited problem domain, makes use of a variety of data, and brings analytical and statistical modeling capabilities to solve the problems. It further relies on graphical displays to convey information to the users, is adaptable to decision-maker's style of problem solving, and can easily be extended to include new capabilities as needed (Densham et al. 1989, Armstrong et al. 1990). Leipnik et al. (1993) defined SDSSs as integrated environments, which utilize the databases that are both spatial and non-spatial, models, decision support tools like expert systems, statistical packages, optimization packages, and enhanced graphics to offer the decision makers a new paradigm for analysis and problem solving. These definitions show "problem solving", "spatial dimensions" and "decision making" as the key phrases which describe an SDSS. Thus an SDSS can be considered as a class of PSE, which is explicitly designed to aid in spatial decision problems. A brief discussion on PSE is presented in section 2.3.

2.2.1 SDSS versus GIS

USGS website (2002) provides definition of a GIS as a computer system capable of assembling, storing, manipulating, analyzing, and displaying geographically referenced information, i.e. data identified according to their locations. Many other definitions of GIS place varying degrees of emphasis on the functions of capturing, manipulating, analyzing, and displaying spatial data (Cowen 1988, Sadek et al. 1999, Gunes et al. 2000, Parsons et al. 2000). Implicit in many of these definitions is that GIS are designed to support spatial decision-making. But these definitions are too vague to capture the emphasis on discipline specific analytical modeling and decision-making processes explicit in a SDSS.

Though a GIS can be used in a decision-making process, its performance cannot be expected to be as effective as that of a SDSS because i) insufficient attention is given to the process and context in which decisions are made; and ii) many GIS provide only capabilities for map analysis and do not support the domain specific analytical and statistical modeling required by many decision-makers. These shortcomings of GIS led to development of SDSSs, which are explicitly meant for spatial problem solving. Thus, SDSS evolved from GIS in a manner, which parallels that of DSS in the business data processing community. Further, SDSSs are developed explicitly to accommodate the context and the chosen process of spatial decision-making, and this can be viewed as spatial analogue of DSS developed in operational research and management science to address business problems (Armstrong et al. 1990).

Decision problems are often semi or ill structured where the fundamental variables and relationships of the problem are not easy to identify, to measure, and to represent in a mathematical model. These types of problems, therefore, are often addressed by selecting variable solutions from among a set of competing alternatives. The goal of a SDSS is thus to help decision-makers generate and evaluate these alternative solutions or the 'what-if' solutions. Densham et al. (1989) suggested the following three key characteristics of effective decision processes, which can be used as the basic guideline in identifying the goals of a SDSS.

a. "Iterative: Decision problem is iterative because decision makers generate and evaluate a set of alternative solutions, gaining insights which are input to, and used to define, further analyses."
b. "Integrative: Integration occurs because decision-makers, who hold the expert knowledge that must be incorporated into the analysis with the quantitative data in the models, evaluate alternatives across a broad range of pertinent criteria, making value judgments that materially affect the final outcome."
c. "Participative: The participation by decision-makers returns control over the decision-making process to them, enhancing the quality of that process."

Geoffrion (1983) suggested five distinguished styles in a DSS design, which were further simplified by Densham et al. (1989) as six characteristics of SDSS. These characteristics, as given below, distinguish a SDSS from a GIS.

a. SDSSs are designed to tackle semi or ill-structured problems where either the problems or the objectives or both are not fully and coherently specified.
b. They often adopt interactive and recursive ways of system development known as multi-pass approach, which contrasts the more traditional serial approach involving clearly defined phases like requirements specifications, detailed design, programming, testing and implementation.
c. The designs place high value on the flexibility of system use and ease of adaptation to the evolving needs of the users.
d. They strive for a genuine integration of data sources and models, including appropriate interfaces to transaction processing and database management systems.
e. Users are of prime importance during DSS design. The underlying technology comes second. That is why much emphasis is given on the interface to be user-friendly.
f. The users should be able to generate a series of possible solutions by running different 'what-if' scenarios in the models.

2.2.2 Architecture of SDSS

Densham et al. (1989) suggested following five key modules for a SDSS design:

1. Database Management System
2. Analytical Modeling
3. Graphical Display and Report Generation
4. User Interfaces
5. Expert Knowledge

1. Database Management System

Database management system for a SDSS must support cartographic display, spatial query, and spatial modeling by integrating three types of data - locational, topological and thematic. The database should be able to construct and use complex spatial relations between all three types of data at various scales. As the data requirement for SDSS can be very large, relational database management systems are preferred over the traditional flat-file database systems.

2. Analytical Modeling

Analytical models are often libraries of procedures included within the system. An obvious disadvantage of this approach of analytical modeling is that the system will end with lots of replicated and redundant codes which degrades overall performance of the system as well as make the system difficult for future maintenance. A new approach of analytical modeling as a part of a model-based management system (MBMS) is considered to be more effective. Analytical models often involve an algorithm for solutions and MBMS approach separates the algorithm into a series of discrete steps, which can be programmed separately using object oriented programming. The whole model can be implemented through the combination of these discrete modules of codes into necessary sequence. Sometimes third party analytical models external to the system is used. In such cases standard procedure should be developed to establish communication between the user interface and the model. An example of such a system can be found in Dietz (2000), where the SDSS uses the third party model HSPF (USGS) for hydrologic simulation.

3. Graphical Display

A SDSS should have the capabilities of generating a set of graphical and tabular reports. A SDSS reporting includes two and three- dimensional plots, tabular reports, in addition to general cartographic display to represent the output from statistical analysis and different analytical models. In addition, a user should be able to interact with a SDSS, and change its model parameters and scenarios by interacting with graphical display.

4. User Interfaces

The user interface of a SDSS is different from those commonly available. In addition to the commonly available user interfaces like buttons, text boxes, menus, and check boxed, a user interface for a SDSS should contain a graphical display to input to the analytical models. A user should be able to define different 'what-if' scenarios to input to the models by interacting with the graphical display. An interactive and intuitive user interface therefore becomes a must for a successful performance of a SDSS.

5. Expert Knowledge

A decision support system should contain a repository of expert knowledge. This repository will help as a guide to the users at all states of decision-making process, and the users do not have to turn to expert analysts every time they have complex analytical problems. Further, other modules within the system may use the knowledge base. The expert system therefore can be thought as a shell enclosing all other modules of the system within it (Armstrong et al. 1990). The knowledge repository for a SDSS should include environmental knowledge, procedural knowledge and structural knowledge. Environmental knowledge describes the fabric of the problem. Procedural knowledge is derived from the problem domain and is used to help design the solution process and determine the values of the model parameters. Structural knowledge is used during analysis to solve problems efficiently, using minimum computing resources. The knowledge can be synthesized in various ways to solve problems during different stages of decision-making process. The knowledge is included in a SDSS as a recommender system or a help system.

In addition to these five modules, Waters (1990) suggested a sixth module, which plays a key role in the success of a SDSS. Due to the huge amount of data involved in spatial decision problems, SDSS requires an elaborate computing platform. This always makes the SDSS an expensive alternative, and this is the main reason for the failure of many SDSS in the past. A data compression module contained within the system, therefore, can solve this problem and make a SDSS more useful and affordable.

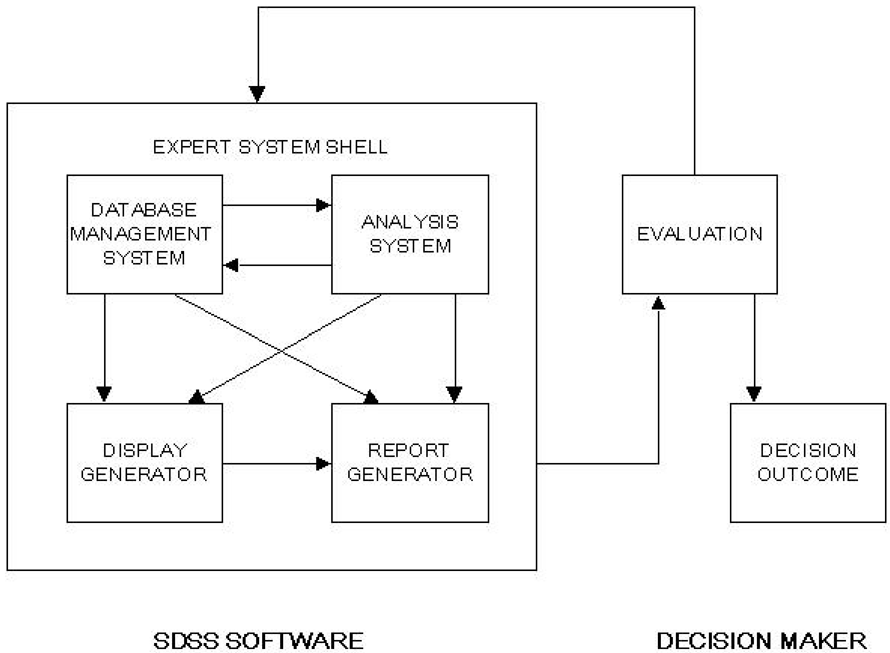

Figure 2.2. Software modules in a spatial decision support system (adapted from Armstrong et al., 1991)

2.3 Problem Solving Environment

A PSE is a computer system that provides a complete, integrated, and usable set of high-level facilities to solve a target class of problems. A PSE seeks to combine discipline specific software tools into integrated systems for decision-making and problem solving (Gallopoulos et al. 1994). This term 'PSE' is more often used in computer science domain to refer to the simulation codes, network access and knowledge base of a DSS with emphasis of a problem domain (such as watershed management) (Watson et al. 2002). PSEs allow users to define and modify problems, choose solution strategies, interact with and manage appropriate hardware and software resources, visualize and analyze results, and record and coordinate extended problem solving tasks. In complex problem domains, PSEs may provide intelligent and expert assistance in selecting solution strategies, e.g., algorithms, software components, hardware resources, data, etc. Users communicate with a PSE in the language of the target class of problems, not in the language of a particular operating system, programming language, or network protocol. Therefore users can run PSEs without expert knowledge of the underlying hardware or software. In principle PSEs should enable more people to solve more problems more rapidly, and they should enable more people to do things that they could not otherwise do. PSEs therefore free the computational scientist from managing individual software components and enable the specification of parameters of the problem at higher domain, rather than in term of low-level modeling subsystems of software. PSEs integrate results of the sub models into coherent, visual feedback suitable for high-level comprehension. PSEs are designed to be used by people who have diverse backgrounds and levels of expertise, and who are certainly not to be expert in all the domains that are modeled (Rubin et al. 2000).

2.4 Web-Enabled SDSSs

The DSSs were traditionally developed for single users, which require data management, model management, and the user interface component to reside on the same machine. This requires platform specific development, a costly, and a nonextensible alternative. Additionally, few small businesses have the resources to build or buy their own DSSs. Rapid growth of the internet technology over the past decade has opened up new methods to supply and share data, models, tools and other information to potential users. Wallace et al. (2001) identified the impact of internet on decision problems into two major issues. First, the Internet warehouses a large repository of physical data, which are needed for various decision support systems. These include important conventional data sources as well as a vast array of new data sources. For example, the USGS stream gaging data at a number of gaging stations can be monitored and downloaded almost on a real time basis. Secondly, communication between and among the professionals and the decision-makers has been improved to the degree that sharing of ideas, experiences, and information about solving problems has become a common place.

Additional benefits of web-enabled DSSs include accessibility, efficient distribution, efficient administration, and cross-platform flexibility (Molenaar et al. 2001). The implementation of SDSS via the internet provides opportunities to increase involvement of stakeholders in the decision-making and planning process by providing knowledge and data through a widely accessible, fast, cost-effective, and easy-to-use medium.

Unlike traditional desktop decision tools, users of web-enabled Decision Support System don't need to purchase specialized hardware or software. Computational and data intensive applications run in powerful servers while the users choose the scenarios and view output reports in their web browsers. Data input in the model can be verified as data are located in the server and thus errors due to input data can be minimized. Maintenance and distribution of models is easy as the models are stored in a single location. Also all the users can have access to the same version of the model.

2.5 SDSS for Integrated Watershed Management

Most traditional models for water resources analysis can be a part of a SDSS because those models address the problems with a spatial dimension. Especially, the hydrologic models, economic models, and environmental models for water resource analysis have the potential to be included in a SDSS (Walsh 1993). Hydrologic models deal with the spatial extent and variability of water runoff over and beneath land surfaces. Economic models, such as resource demand forecasting, revenue generation models, and input-output models would be enhanced if the output of the models can be displayed graphically and visually via maps. Environmental models, such as those estimating nonpoint source pollution in a water body and those predicting the integrity of aquatic life benefit from the spatial analysis and display capability.

Most of the water resources models available today were developed before the availability of new spatial analysis and display capability. These traditional models are often lumped-parameter models that do not take advantage of the ability to display the distributed aspects of spatial data. A new approach of model design is therefore necessary to include the models into SDSS framework. A cross discipline collaboration is needed to develop an effective water resource management SDSS. It involves active participation and inputs from GIS developers, water resource modelers, DSS designers, and decision makers. Moreover, data requirements for the model will increase to include the spatial analysis capability, which sometimes can be challenging.

2.5.1 Integration Approach

Good research models can demonstrate the effects of "what-if" assumptions and hypothesis and help frame further questions, which will lead to better models and eventually to better applications for routine use. A SDSS application with multiple models residing in its model-base will be more effective than separate applications for each model. For example, a land development SDSS, which includes hydrologic, economic, and environmental models within its model-base, can be more effective than separate systems for each model. The integrated system can share a common database and a common input-output interface. The models can communicate with each other to provide more holistic outputs. This ultimately helps decision-makers to find more realistic impacts of land development. An obvious disadvantage of the integration approach is that the complexity of these multi-model applications increases with the increase in the number of models since each model type has its own unique set-up parameters, constraints, and input files. A user interface that gives a common look and feel across disparate models is critical in hiding the inherent complexity of a multi-model application (Knox et al. 1997).

Many of the models included in the integrated applications can be legacy models (example, HSPF model in Dietz 2000). Encapsulation of legacy models in a model base minimizes the chances of introducing new software errors. These applications should have the capability to incorporate the updates of the legacy models easily when they are released; or the application will fall behind the state of art.

2.5.2 Analysis of SDSSs for Watershed Management

While most of the existing watershed management related SDSS have been developed as standalone applications, some efforts have been made in last couple of years to develop web-enabled SDSS. A brief discussion of some of the standalone and web-enabled DSSs in watershed management is presented in the following paragraphs.

Standalone SDSS

Davis et al. (1991) developed a DSS consisting of three modules, a policy module, a catchments module, and a query module, to examine the effects of potential land use and land management on water quality policies in South Australia. The AquaTool DSS has been developed and used by two river basin agencies in Spain for water resources planning and operational management, and the modeling capability includes basin simulation and optimization modules, an aquifer flow modeling module and two modules for risk assessment (Andreu et al. 1996). In 1996 USEPA released the BASINS model that integrated GIS with a watershed database for major basins and several vertical modeling tools into a single package for performing assessment and water quality analysis (http://www/epa.gov/OST/BASINS/).

Web-enabled SDSS

Researchers at the University of Arizona developed a DSS for runoff simulation and flood forecasting named HyDSS (Hydrology Decision Support System) (Ram et al. 2000). Though HyDSS works as a DSS, it lacks GIS support and cannot be considered as a SDSS. At Purdue University, researchers have been involved in the development of a web-enabled system named L-THIA, which was developed to analyze impacts of land use changes using SCS curve number technique. A user accesses this GIS based system online and chooses location, land use and soil information and the system provides the curve number values of selected location along with long term precipitation record. The output of the system includes runoff depths and volumes and non-point source pollution in the form of tables, bar charts, and pie charts (Pandey et al. 2000). The Finnish Environmental Administration (FEA) has been developing a web-enabled Hydrologic Information and Decision Support System, the objective of which is for monitoring and planning of Finnish waters (FEA Website 2002). Another web-enabled decision support tool, called WFAT, is used for floodplain management in St. Charles County, Missouri and is described by Sugumaran et al. (2000). WFAT uses data from both remote sensing and GIS based thematic layers to interactively query and display different flood-plain related data layers and determine the elevation of land parcel and its locations with regard to the FEMA 100-year flood plain. Wang et al. (1999) discussed a web-enabled SDSS that was developed for issuing flood warning in the Cincinnati region along the Ohio River. The system is accessed by local governments online and displays the possible flooded areas (including buildings and streets) as a function of user entered water levels available from a National Weather Service (NWS) water level monitoring station.

A critical comparison of some available web-enabled systems is given in Table 2.1. Most of these systems appear to be at a preliminary stage of development with restricted web access. However, the scope of most of these systems appears to be vertical in nature, i.e., limited to particular problem domain. WebL2W, which is the prototype SDSS system developed as a part of this thesis, has potential to carry out hydrologic, economic, and ecological analyses of land use changes. The integration of various vertical models and the use of a continuous hydrologic modeling are some of the features unique to WebL2W. Detailed discussion about WebL2W is presented in Chapter 3.

2.6 SDSSs for Other Application Areas

The SDSSs have been developed in several other areas including transportation planning and route alignment (Sadek et al. 1999), location planning for infrastructure and facility development (Sikder et al. 1997), emergency management operations (Gunes et al. 2000), agricultural farm analysis and comparison (Thomas et al. 1999), agricultural nonpoint source pollution (NPS) assessment (Srinivasan et al. 1994), construction project management (Molenaar et al. 2001), floodplain management (Sanders et al. 2000, Ji et al. 1994, Ford, 2001), and prioritization and identification of crime suspects (Alexander et al. 1997). The rapid development of SDSS in diverse application areas has been critical in the development of more efficient computing and modeling techniques to support the needs of these SDSS.

Table 2.1. Features of some web-enabled DSSs

	L-THIA[1]	Digital Meadowlands[2]	Management Oriented Watershed Simulation Environment[3]	WFAT[4]	HyDSS[5]	Online Hazard Map[6]	PLM[7]
Web Address	http://danpatch.ecn.purdue.edu/~sprawl/LTHIA	http://cimic.rutgers.edu/digitalmeadowlands	N/A	http://www.cares.missouri.edu/dem	http://krishna.bpa.arizona.edu/HyDSS	http://www.esri.com/hazards	http://kabir.cbl.umces.edu/PLM/
Scope	Land use, Hydrology	Land use, Zoning	Watershed (Multidisciplinary)	Floodplain Management	Hydrology	Hazard Mapping	Watershed (Multidisciplinary)
Transferability	Flexible	Site Specific	N/A	Site Specific	Flexible	Flexible	Site Specific
Development Stage	Intermediate	Initial	Proposed	Final	Final	Already Implemented	N/A
Web Access	Unrestricted	Restricted	N/A	Unrestricted	Restricted	Unrestricted	Unrestricted
User Interface	Novice/ Expert		Novice	Novice	Expert	Novice	Expert
Reporting Mechanism	Graphical/ Tabular	Graphical/ Tabular	N/A	N/A	Tabular	Graphical	N/A
Partners/ Funding Agencies	EPA	NASA	N/A	NASA/ Stennis Space Center	NASA	ESRI/ FEMA	NSF/ EPA
GIS Support	Yes	Yes	Yes	Yes	N/A	Yes	Yes

[1] Pandey et al. 2000
[2] Artigas et al. 2000
[3] Weatervelt et al.
[4] Sugumaran et al. 2000
[5] Ram et al. 2000
[6] ESRI/ FEMA : http://www.esri.com/hazards
[7] http://kabir.cbl.umces.edu/PLM/Welcome.html

2.7 Client/ Server Computing and Object Oriented Programming

As discussed earlier, internet technology has made significant impacts on the ways decision problems are handled in several engineering disciplines. The internet is a “connectionless” process, based on Client/ Server architecture (Wallace et al. 2001). A brief discussion of Client/ Server process is presented in the following paragraphs.

Client: A Client is a general-purpose application program that becomes client temporarily when acquisition of remote data is necessary, but also performs local operations. A client executes locally in user’s host computer, and is active for single user session. Depending upon particular application and need, client can access multiple servers at a time, and also actively contact a single server at one time. Clients are not dependent on special hardware, or proprietary operating environment. Web browsers are the most common client software on internet. Programming languages like HTML, JavaScript are used in the client to view and retrieve the information from the server and to submit input data and requests to the server.

Server: A server is typically a special purpose program designed to provide a single service, but may be implemented to handle multiple remote clients simultaneously. The process is initiated when the host computer boots and runs continuously. Servers can be executed in shared computing resources. As the client request is triggered, the server provides data and/ or services requested to the client. Application servers provide services to the client and database servers provide required data to client applications. Server applications are generally programmed in server side scripting languages like ASP, Perl, server side JavaScripts etc. These scripting languages are suitable for less resource consuming processes like submission of data to the database or to access another software process in the application server. Heavy processes like water resources simulation models can be written in full scale programming language like C/ C++, Visual Basic, Java etc. Object oriented programming provides an effective way to program and manage the server applications.

In a Client/ Server architecture communication on the network takes place between server processes – program that operate continuously awaiting requests for services, and client processes – program that initiate requests for services when needed. As long as these software processes recognize a common set of protocols, they need not depend on specific hardware or operating system requirements. The client and the server can exist in the same host computer, or be distributed across a wide variety of computers at widely distant locations (Wright et al. 2000). Figure 2.3 shows the Client/Server workload models. Client/server computing developed from a distributed database model (configuration 1), where everything except data management is handled in the client computer. The client needs more computing resources, both hardware and software, in this configuration. Later on more and more application processes shifted towards server part, and nowadays we have the state-of-art distributed system (configuration 5). A distributed system is a 'thin client' architecture where interface management is distributed between client and server and application logic and data management part is entirely handled by powerful servers. The term 'thin client' refers to the minimal amount of processes that take place in the client part in comparison to the huge amount of processes that take place in the server part.

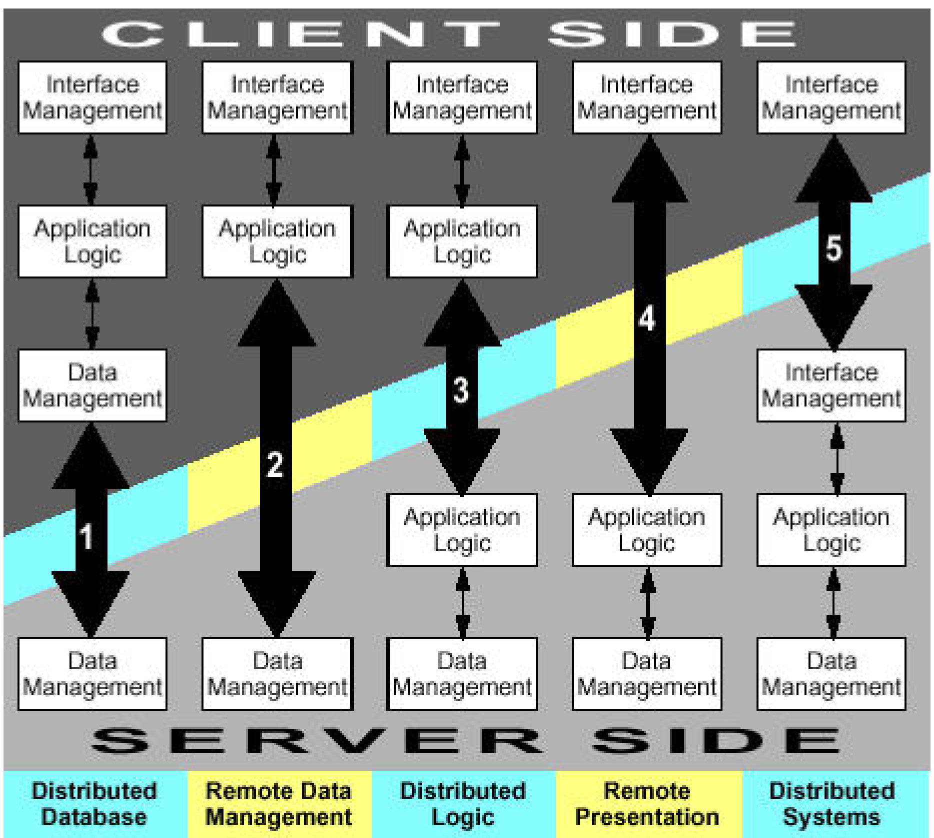

Figure 2.3. Representative client/server system configurations (adapted from Ensor et al., 1997)

Object Oriented Programming

Object-oriented programming offers a new and powerful model for writing computer software. Objects are "black boxes" which send and receive messages. A black box actually contains code (sequences of computer instructions) and data (information which the instructions operate on). This approach speeds the development of new programs, and, if properly used, improves the maintenance, reusability, and modifiability of software. Traditionally, code and data have been kept apart (Montlick 1995).

Object oriented principles enable not only the computer code to be written in a more organized and sustainable fashion, but also enable software to model the real world more closely (Collis et al. 2000). For example object oriented principles have facilititated rivers and reservoir systems as networks of discrete entities such as reservoirs, power plants, reaches, diversions, and so on (Reitsma 1997). This new approach provides a new way to encompass the function of the user interface, database, and models for the SDSS.

2.8 Summary

As web-enabled SDSSs are network-based applications, issues like data availability, ease of use and access limitations are to be addressed thoroughly before implementing these systems. It is important to stress that above tools may help to study one or several decision alternatives. So, adequate usable data should be available to analyze all the decision alternatives. As these tools are targeted for diverse range of users from decision-makers and planners to general citizens, these tools can have more than one input interface. The advanced users can have a choice to input and analyze through expert interface while general users can use the basic input interface through which they can visualize the possible ‘what-if’ situations for the problem being addressed. As any other system running via internet the system should support fast and reliable access to multiple users using the system simultaneously. Most GIS data sets are too large to deliver via a phone modem. Hence availability of fast direct connections to the potential users can be an important factor for the success of a web-enabled SDSS.

The application of computer models, which provide insight into water resources problem by representing physical, environmental, economic, and/or social processes, for the planning and operation of water resource systems has been a major field of research among engineering, and social and natural science communities. These models include simulation models where processes are simulated to test alternative “what-if” scenarios, and optimization models where objectives are specified and parameters are adjusted to meet the objectives (Walsh 1993). The progress in GIS technology and SDSS has led to significant advances on different types of watershed analysis models. However, most of these watershed analysis models are not directly implemented into the GIS technology, and only few models have a well-developed capability to analyze and display information (Xu et al. 2001). Most of the water resources problems are spatial in nature. Many available models work around the spatial aspects of a problem by simplifying assumptions and parameterization. Clearly water resources model applications could benefit from spatial analysis and display capabilities of GIS, and GIS could benefit from the modeling capability of water resource models. Integrating these two systems will result in more powerful tools to aid the planning and management of water resource problems (Walsh 1993, Xu et al. 2001).

3.0 DESIGN AND DEVELOPMENT OF WEBL2W

This chapter describes issues involved in the design and development of WebL2W. The development of Web-L2W can be divided into the following major parts.

1. Study area
2. Data collection and processing
3. Construction of development framework
4. Integration of discipline specific models
5. Design and construction of the software
6. Testing of the software

3.1 Study Area

While the design and development of WebL2W is independent of the watershed selection and delineation process, a brief introduction to the study area used in the case study described in Chapter 4 of this thesis is important. The overall study area for the EPA/ NSF project is the Upper Roanoke River Watershed (URRW) in southwest Virginia. This 1,480-km^2 watershed reaches into four counties – Roanoke, Montgomery, Floyd, and Botetourt, and the cities of Roanoke and Salem (Figure 3.1). The outlet point of the watershed is set just downstream of the confluence of the Upper Roanoke River and Back Creek. Land uses in the area range from the urban streets of Roanoke to the heavily forested slopes of Jefferson National Forest. Hydrologic conditions within the watershed are as diverse as the land uses. Elevation varies from 237 to 1,197 meters above sea level. The 145 km^2 Back Creek sub watershed of the URRW was used for hydrologic, economic, and fish health modeling works in the EPA/ NSF project (Figure 3.2).

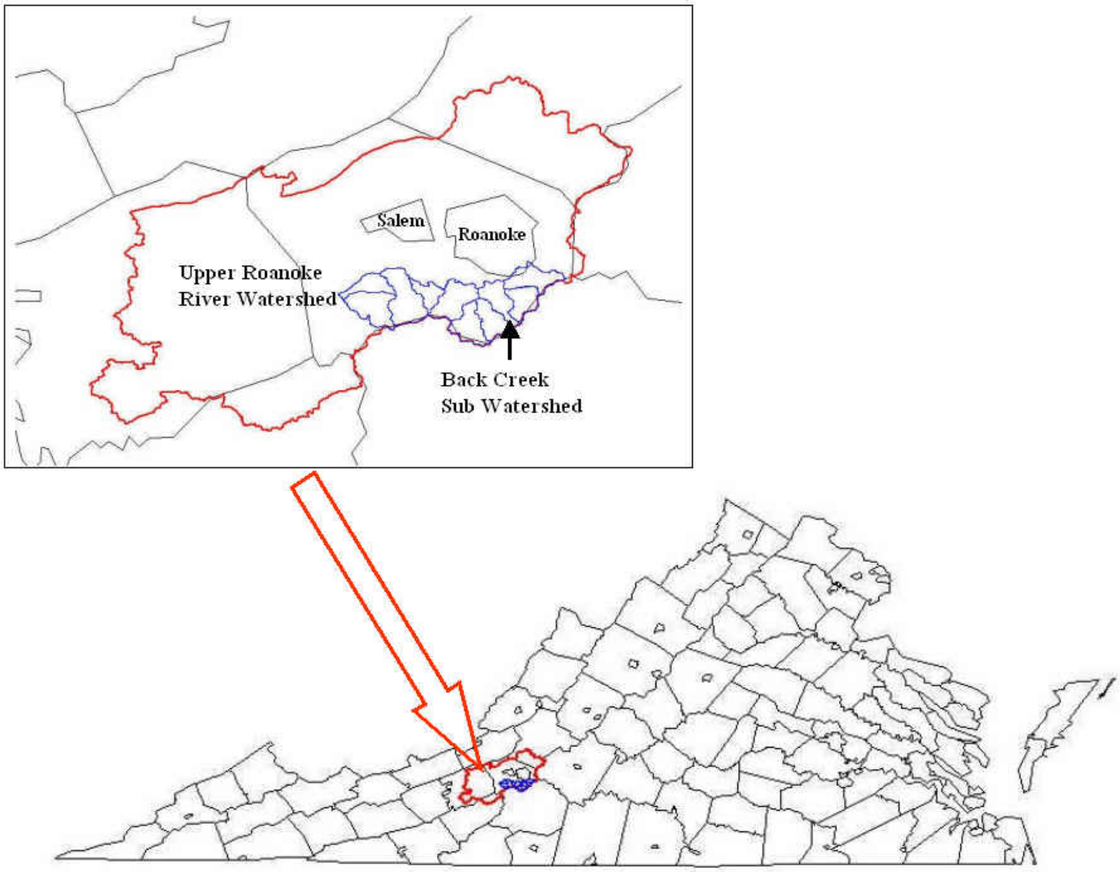

Figure 3.1. Upper Roanoke River watershed in Virginia

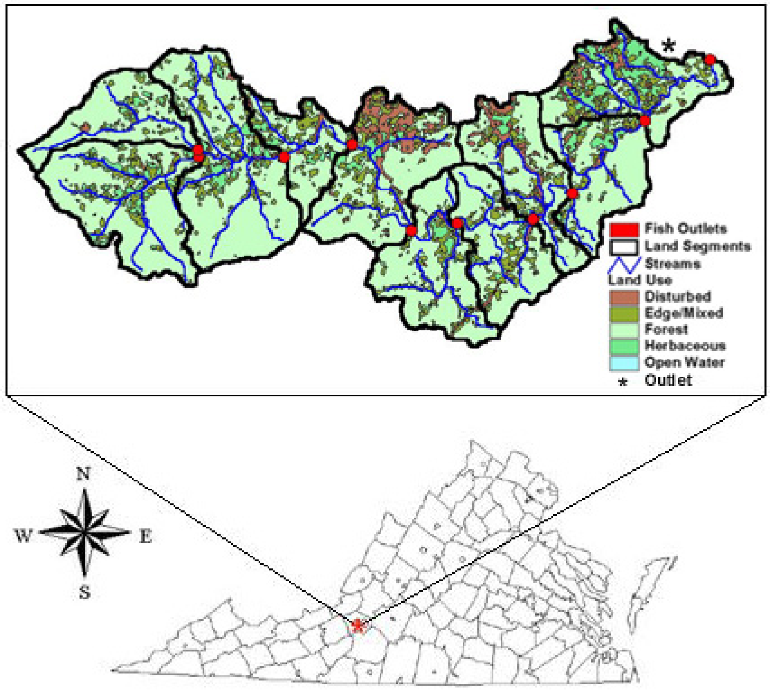

Figure 3.2. Back Creek sub watershed in Virginia

3.2 Data Collection and Processing

As part of the EPA/ NSF project, data was collected from several sources for carrying out the hydrologic, economic, and fish health modeling. A brief description of data collection and processing efforts for various models is given in following sections. This description has been adopted from Dietz, 2000[8].

Each individual model in the interdisciplinary SDSS requires different sets of data layers. Yet, there are some common data sets, which are necessary for the watershed. These data sets are referred to as base data layers, and they include Digital Elevation Model (DEM), Digital Line Graphs (DLG) streams, watershed boundaries, and land use (Dietz 2000). Additional GIS base data layers used for this study includes base data such as flood plains from the Federal Emergency Management Agency (FEMA), land ownership/ tax parcels from Roanoke County, soils from the Natural Resource Conservation Service (NRCS), and TIGER (Topologically Integrated Geographic Encoding and Referencing system - vector lines) files from the U.S. Census Bureau. Some of the base data layers were also used to create derived data layers, which

[8] Note: Rob Dietz was a former graduate student from whom the author took over the WebL2W development work.

in turn act like the base data. For example, slope grid, which is derived from DEM mosaic, provides input data for discipline specific models. ArcView 3.2 GIS software was utilized for converting, mosaicing, and formatting of spatial data layers.

Hydrology Model

The surface hydrology group of the EPA/ NSF project employed HSPF (Hydrologic Simulation Program Fortran) for simulating hydrologic responses to land use change. GIS data layers, such as DEMs, DLG streams, and land use, were used to provide physical watershed data for HSPF. Hourly precipitation data for water years 1995 through 1998 was used to calibrate and validate the HSPF model, which was obtained from USGS database. Detail about the model is given in Appendix A.

Economics Model

The data requirements for economics model include elevation data, soil data, census data and road data. Additionally, parcel data from Roanoke County is required. GIS data layers like USGS DEM's, NRCS STATSGO soils, U.S. Census TIGER files, USGS DLG roads, and Roanoke County parcel map provide the data to the economics model. Detail about the model is provided in Appendix A.

Fish Health Model

The Fisheries group collect data for calculating mean metric scores (MMS) for fish habitat. The MMS is a statistic that rates the quality of health for the general fish population. The team sampled 43 sites in the URRW and these sites were incorporated into the GIS using coordinates from maps and GPS units. Small portions of the watersheds were buffered as the zones of influence in correlating land use characteristics to the mean metric score. Detail about the model is given in Appendix A.

3.3 Construction of a Development Framework

3.3.1 Construction of a Development Grid

The spatial resolution required for each individual model is different. While HSPF considers each land segment or sub watershed, varying in size from 3.13 square miles to 8.96 square miles, as a unit area for modeling, the economics model performs simulation with each parcel of size 300 meters by 300 meters as a unit for development. The fish health model considers the buffer zones of radii 30, 60, 90, and 150 meters as a unit area for simulation. Also an intuitive and easy-to-use interface was required for WebL2W to be useful. Therefore, the GIS group in the EPA/NSF project developed gridded form of input interface. The development grid is the template upon which the user alters the landscape by adding development tracts (Figure 3.3). The grid layer template for Back Creek subwatershed consists of 1,607 squares, each of which is 300 meters by 300 meters (9 hectares). Out of 1,607 squares, 830 are suitable for development. The total area obtained from 1,607 grid squares is 144.497 km^2, which is 0.503 km^2 less than the total watershed area of 145 km^2. The loss is due to the edge effects of the grid squares.

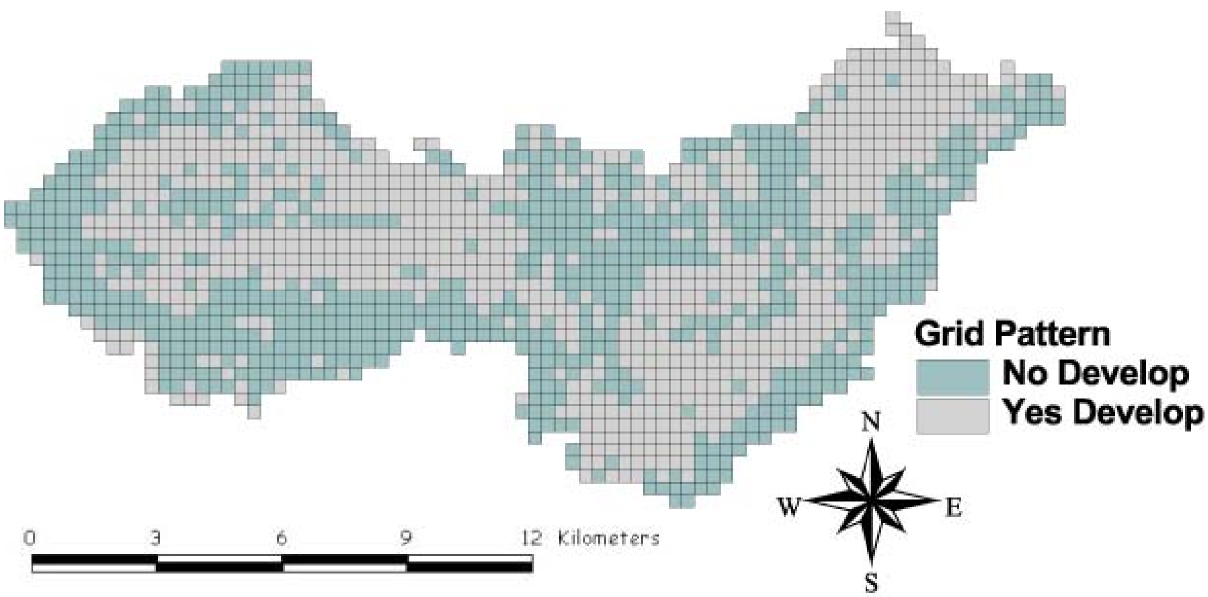

Figure 3.3. Development grids for WebL2W

The development criterion was determined with the raster overlay of four spatial data layers: slope, land use, preservation status, and flood plain location. In the overlay, the pixels in each of the four layers are reclassified with a value of either 0 or 1 (Dietz 2000). Pixels meeting the developable criteria for a particular layer were assigned value 0 and rest of the pixels was assigned value 1. Values assigned for each of the four layers were summed up and a pixel was considered to be developable if the reclassified values for all four layers sum to zero, otherwise the pixel is considered undevelopable. The method of raster overlay is summarized in Table 3.1.

GIS LAYER	CRITERIA	VALUE
Slope	>20%	1
	<20%	0
Land Use	Disturbed and Water	1
	Forest and Herb/Ag	0
Preservation Status	Preserved	1
	Unpreserved	0
Flood Plain Location	Inside Flood Plain	1
	Outside Flood Plain	0
Raster Overlay	**Sum of Values:**	0 = Developable >0 = Undevelopable

Table 3.1. Method of raster overlay for determining developable grid squares (adapted from Dietz 2000)

3.3.2 Construction of a Development Tract

A development tract is defined as a residential development tract of sufficient size to accommodate 50 residential dwelling units (approximately 125 people). Four residential development tracts have been identified to accommodate these 50 dwelling units. They are 1) High Density Residential Tract; 2) Medium Density Cluster Residential Tract; 3) Medium Density Conventional Residential Tract; 4) Low Density Residential Tract. The physical characteristics of each type of tract are given in Figure 3.4 (Stephenson 2001).

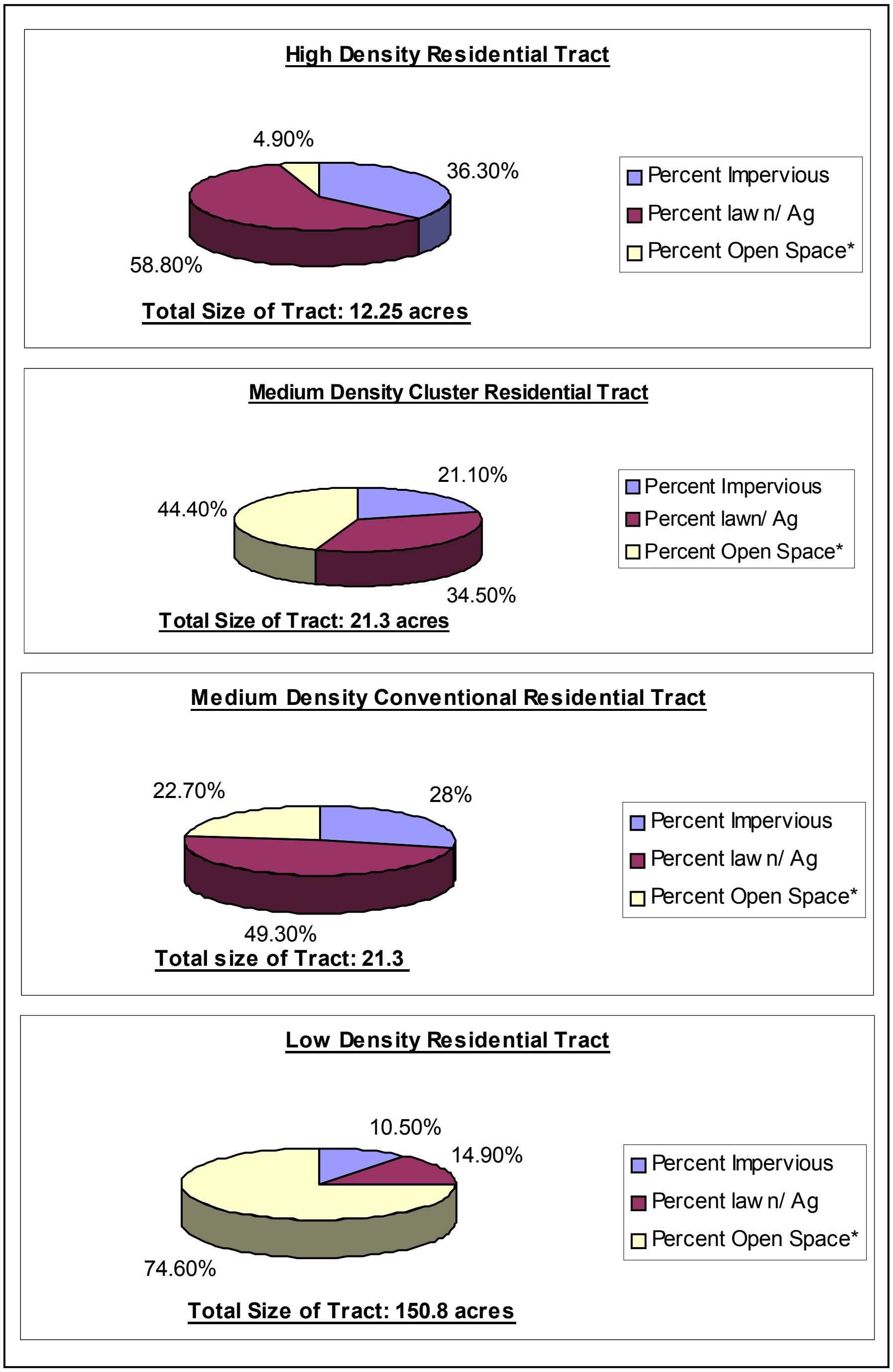

Figure 3.4. Land use distribution in each development tract[9]

*Percent Open Space can reflect predevelopment land cover (forest, herbaceous/agriculture, or mixed), or development preference (forest or lawn).

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[9] *Percent Open Space can reflect predevelopment land cover (forest, herbaceous/agriculture, or mixed), or development preference (forest or lawn).

Above land use patterns for each of the four types of tracts include primary and secondary roads (beyond intra-tract roads) that would be needed to serve a given increase in population).

The development tracts, which were used for previous studies like Dietz (2000), did not include primary and secondary roads as part of their land use distribution. In new tract construction additional impervious surfaces from secondary and primary roads were added to each development tract and a land use distribution was obtained as shown in Figure 3.4. A statistical approach was used to estimate the additional primary and secondary roads required by new development tracts. Using GIS data layers, the total population, miles of primary and secondary roads, and total land area for 12 census tracts in Roanoke County were obtained. These data were used to derive the relationship between population density and primary and secondary road density, which is given below.

$$I = 0.048P^{0.4279}$$

where, I = primary and secondary road density (road miles per square mile)

P = population density (persons per square mile)

The miles of road were then converted in the miles of road per tract. Primary and secondary were assumed to have an average width of 40 feet to calculate the area of new roads created.

3.4 Integration of Discipline Specific Models

Web-L2W encapsulates models from hydrology, economics, and fisheries into an integrated shell for evaluating responses owing to land development activity. It may be mentioned that these models were first calibrated and validated as standalone applications by different study groups of the EPA/ NSF project. Once the performance of standalone applications was considered satisfactory, then these were integrated into WebL2W. In the following sections, a brief description of the discipline specific modeling efforts is given.

3.4.1 Hydrology

The hydrology group of the EPA/ NSF project used HSPF (Hydrology Simulation Program FORTRAN) (Bicknell et al. 1997) for simulating hydrologic responses to land use change. Application of HSPF requires subdivision of the watershed into hydrologically homogeneous land segments, which become the units of spatial resolution for the model. In order to maximize the spatial resolution of the model, the Back Creek subwatershed was divided into 10 land segments (Figure 3.5). The model was first calibrated and validated as a standalone application using hourly data for four water years (1995-98). Land use for each of these segments was summarized from data supplied by the Gap Analysis Program of the U.S. Geological Survey for the Commonwealth of Virginia. In order to facilitate the process of creating 'what if' scenarios of land development and retrieval of output, a scenario generator was developed. The simulation results include effects of land use changes on annual runoff volume, storm peaks, and ground water recharge. Detailed analysis of hydrologic modeling is given in Lohani et al. (2002). An additional detail of hydrologic model is discussed in Appendix A. The capability of the scenario generator was integrated into WebL2W using GIS database and web programming, which will be described in the following section.

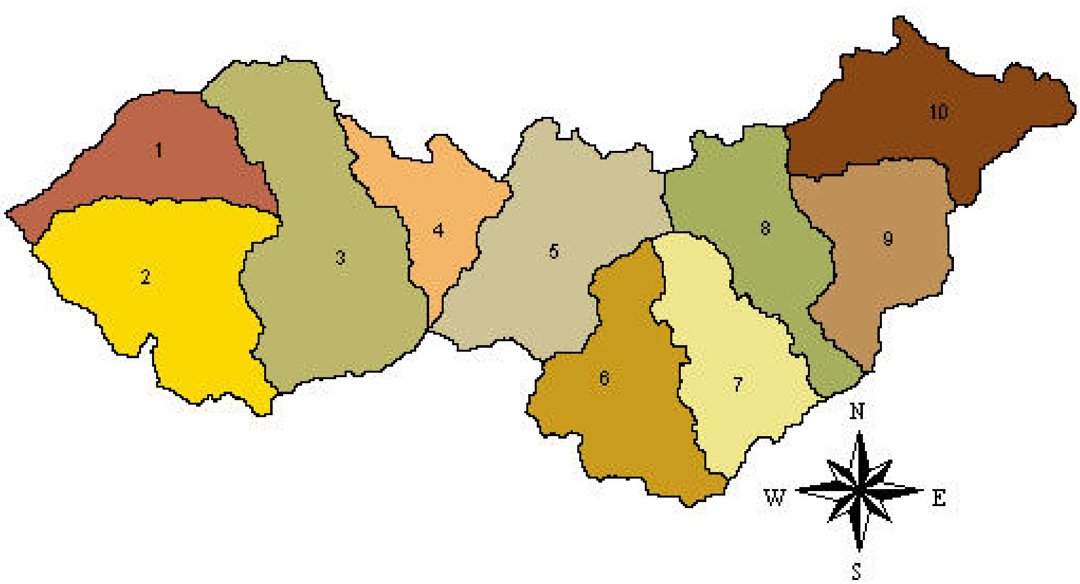

Figure 3.5. Back Creek sub watershed with ten land segments.

3.4.2 Economics[10]

The economics models estimate the effects of land use changes on land values, public expenditures, and tax revenues. The land value model, which estimates the effects of development on land values, specifies a regression equation for estimating land values, which requires a great deal of input from spatial data layers (Kaltsas 2000). Variables related to land ownership parcels that are utilized by the economics model include parcel size, coordinates, elevation, taxonomic soil order, population density, distance to landscape features, and road attachment. These variables are all attributes or derived features of the ownership parcels for Roanoke County. Additional data layers involved in specifying these variables include USGS DEMs, NRCS STATSGO soils, U.S. Census TIGER files, and USGS DLG roads (Dymond et al. 2002).

Standard GIS algorithms calculate the area and UTM coordinates of each parcel from the parcels layer. A GIS summarization process calculates mean elevation and predominant soil type for each parcel. Population density is estimated for each Census block group, and the block group layer is converted to a grid. A summarization process is again employed to obtain mean block group population density for each parcel. Distance calculation algorithms provide a set of grid cells of distances from a particular landscape feature, such as a mall or the city center. The average value of the grid cells that fall within each parcel provides the distance from that parcel to the feature. The Boolean variable of road attachment (true if a major road is attached to a parcel and false if it is not) is assigned for each parcel simply by selecting those parcels that touch a major road, and updating their attribute data accordingly.

Another economic modeling task that uses GIS functions is the calculation of public expenditures associated with development of new tracts (Spier 2000). The public expenditures that are evaluated are sewer and water line construction and connection costs and cost incurred in developing new public schools to serve the increased population. The GIS uses range-finding algorithms to estimate the distance from potential tracts to existing sewer and water lines.

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[10] The development of economics model was part of graduate thesis works done at Virginia Tech. For details refer Kaltsas (2000) and Spier (2000).

Distance values are a key input in determining the costs to developers and the public for hooking new developments to utility lines. Refer Appendix A for additional discussion about the models.

3.4.3 Fish Health[11]

The fish health model relates the land use in zones of influence to the health of fish populations in those areas. A statistic called the *mean metric score* rates the quality of health for fish populations. The mean metric score represents the estimated integrity of the fish community at each sampling site by examining its taxonomic structure and ecological function. Streams with high integrity contain a large number of native species as well as species with specialized ecological characteristics. Streams with low integrity contain few native species, and the species that are present are tolerant of degraded conditions. The mean metric score combines values for 13 different metrics commonly used in applications of the Index of Biotic Integrity, such as number of native species and proportion of tolerant individuals. The actual score for a zone of influence is a real number that can range from 0 (worst) to 1 (best). Additional detail about the model is given in Appendix A.

3.5 Design and Construction of WebL2W

The development of WebL2W has been carried out in two phases: i) Standalone Model, ii) Web-enabled Model.

3.5.1 DesktopL2W

Dietz (2000) has discussed the design and development of the user interface, land use change module, fish health module, and economics module of the desktop software, named DesktopL2W. DesktopL2W was developed using ESRI's MapObjects 2.0, and Microsoft Visual Basic 6.0. MapObjects (an ESRI control that is added to Visual Basic) provided map display and GIS functionalities as well as connectivity to the spatial database. The controls available in the Visual Basic programming environment were used to create forms that served as the skeletal structure for the interface. The modules that are operational in this version of DesktopL2W were

[11] The development of fish health model was a part of a master's thesis at Virginia Tech. For details refer Stancil (2000).

i) a module to calculate change in land use, ii) an economics model, and iii) a fish health model. This early version of the software was not capable of running HSPF from within the software shell.

The functionality of DesktopL2W was further extended with the addition of a module to perform hydrologic simulation, and a tabular display of HSPF simulation report using Crystal Report 7.0 as the development tool. The hydrology module in the software creates a pass file called UCI file for input in HSPF. The program runs HSPF with the help of a script written in Perl. The outputs of HSPF simulation are summarized to generate a form showing the original and changed land use distribution for the watershed, and a tabular display in Crystal Reports of the hydrologic effects including changes in annual runoff volume, storm peaks, and ground water recharge due to land development. The simulation results of HSPF have been thoroughly tested by running sample scenario outside the SDSS software using an Excel macro based application called Scenario Generator (Lohani et al. 2002) and the results have compared satisfactorily.

Upon start up, Desktop L2W displays the scenario input screen (Figure 3.6). The input screen consists of a watershed map interface showing the development grids in the sub watershed. The interface is provided with an interactive legend and command buttons with common GIS functionalities like pan, zoom in, zoom out, zoom to extent, and add data layers. Further, there are four command buttons to create new scenarios of land development using four pre-defined land development patterns – high density residential development, medium density cluster residential development, medium density conventional development, and low density residential development. A user can create a development scenario using one or more land development patterns. After creating the "what-if" scenario, the user clicks the "Accept Input and Run Model(s)" button on the input screen to access the model selection interface (Figure 3.7). The model selection interface allows the user to choose which models to run. The user has an option to select one or more models for evaluating the effects of the scenario and depending upon the selection made, discipline specific models will execute and provide results. Output interfaces for hydrologic, economic, and fish health simulations are shown in Figures 3.8 through 3.11.

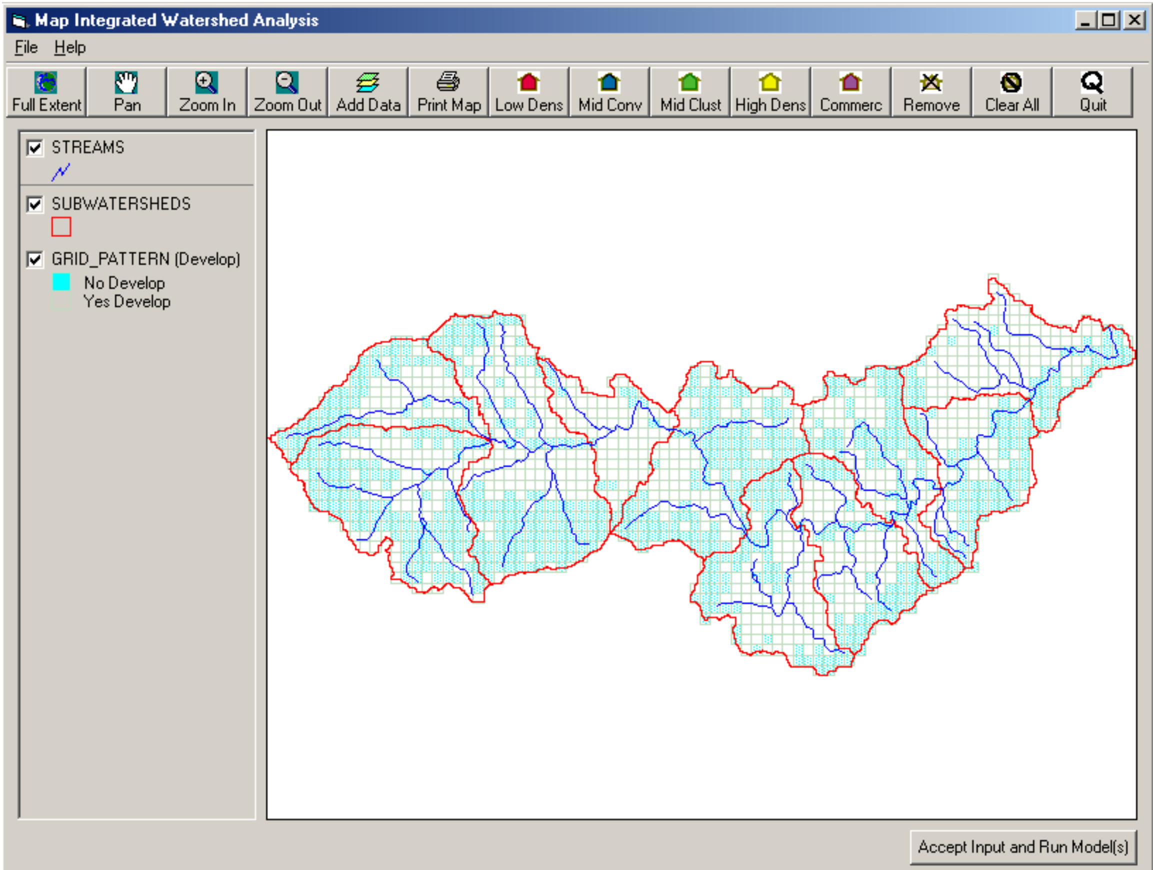


Figure 3.6. Scenario input screen of Desktop L2W

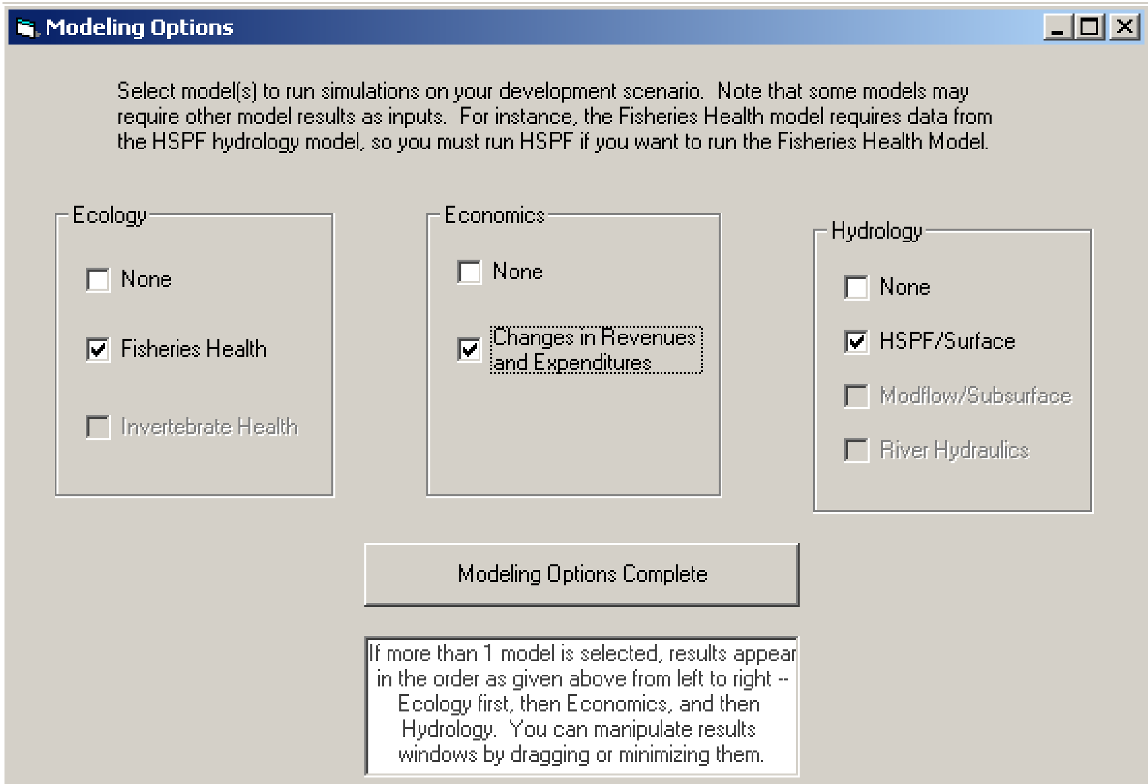


Figure 3.7. Model selection screen of Desktop L2W

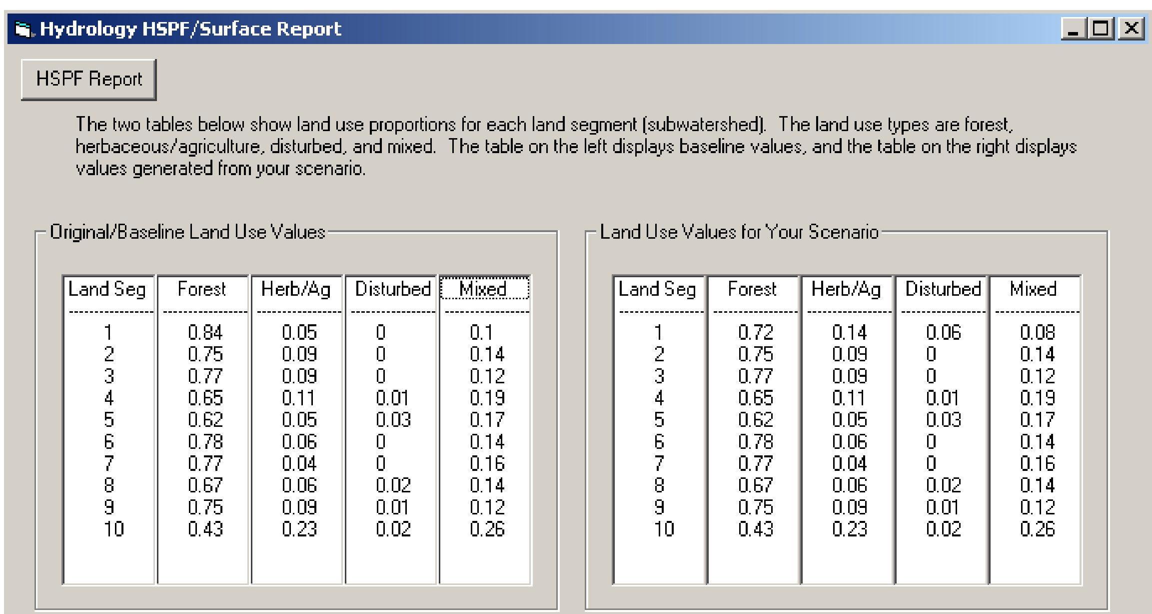
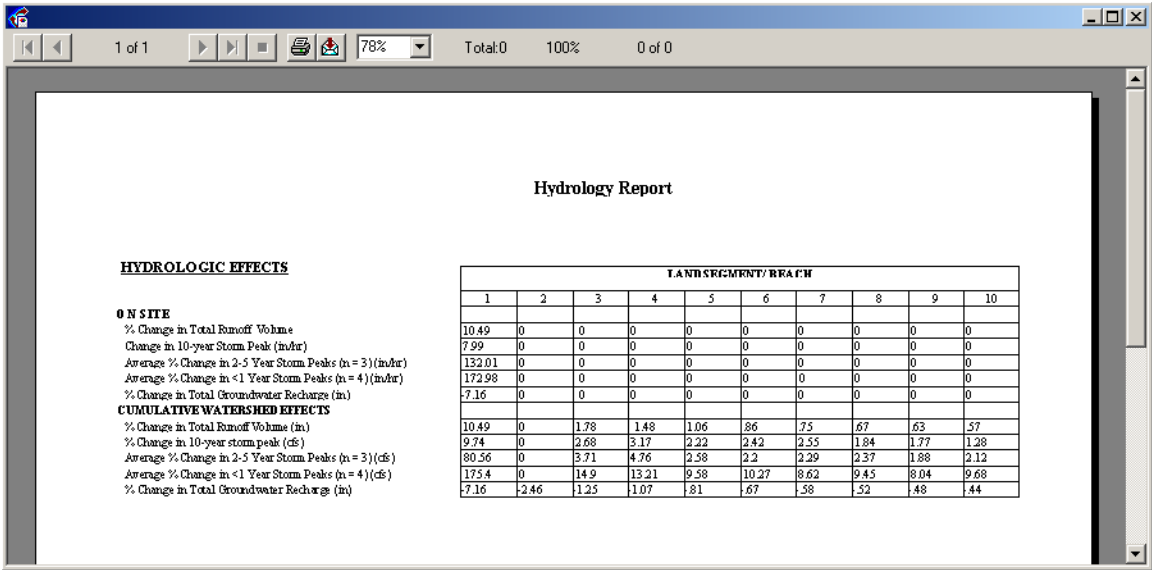


Figure 3.8. Land use distribution report from DesktopL2W.



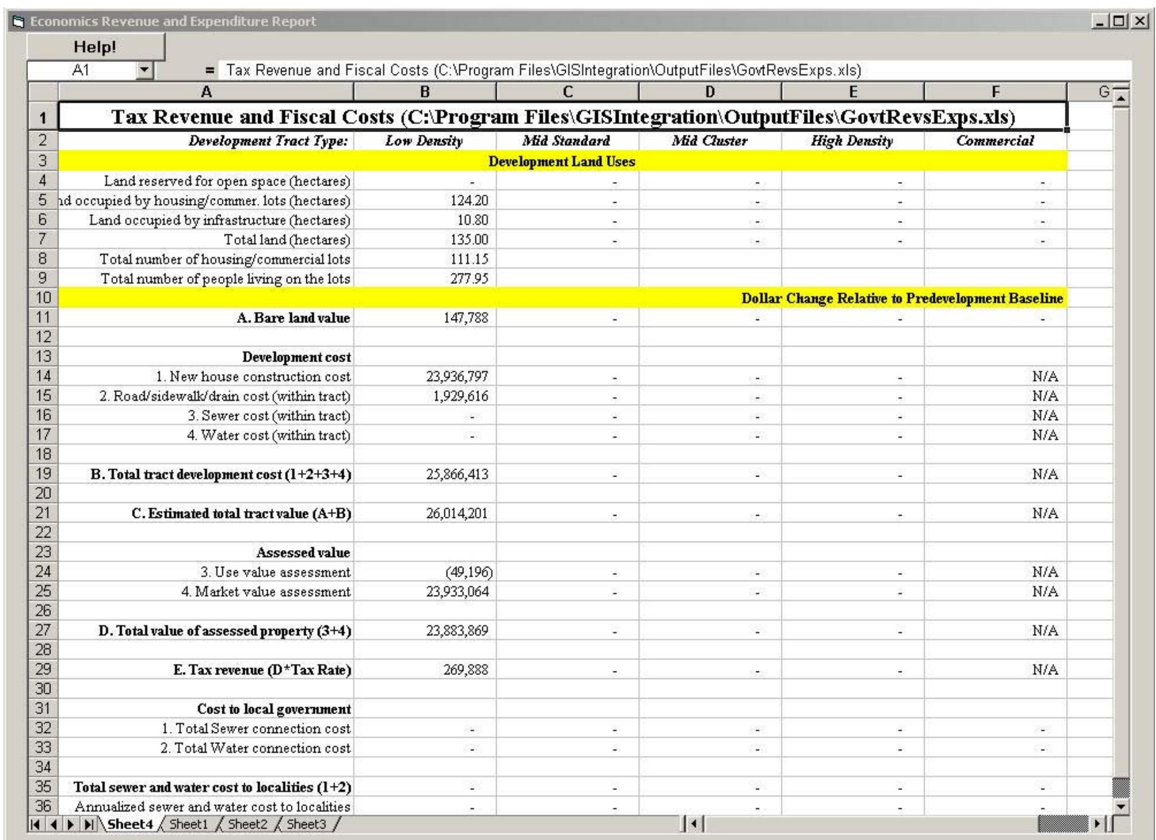
1 of 1 Total:0 100% 0 of 0

Hydrology Report

HYDROLOGIC EFFECTS

	LANDSEGMENT/ REACH									
	1	2	3	4	5	6	7	8	9	10
ON SITE										
% Change in Total Runoff Volume	10.49	0	0	0	0	0	0	0	0	0
Change in 10-year Storm Peak (in/hr)	7.99	0	0	0	0	0	0	0	0	0
Average % Change in 2-5 Year Storm Peaks (n = 3) (in/hr)	132.01	0	0	0	0	0	0	0	0	0
Average % Change in <1 Year Storm Peaks (n = 4) (in/hr)	172.98	0	0	0	0	0	0	0	0	0
% Change in Total Groundwater Recharge (in)	-7.16	0	0	0	0	0	0	0	0	0
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume (in)	10.49	0	1.78	1.48	1.06	.86	.75	.67	.63	.57
% Change in 10-year storm peak (cfs)	9.74	0	2.68	3.17	2.22	2.42	2.55	1.84	1.77	1.28
Average % Change in 2-5 Year Storm Peaks (n = 3) (cfs)	80.56	0	3.71	4.76	2.58	2.2	2.29	2.37	1.88	2.12
Average % Change in <1 Year Storm Peaks (n = 4) (cfs)	175.4	0	14.9	13.21	9.58	10.27	8.62	9.45	8.04	9.68
% Change in Total Groundwater Recharge (in)	-7.16	-2.46	-1.25	-1.07	-.81	-.67	-.58	-.52	-.48	-.44

Figure 3.9. Hydrology report from Desktop L2W



Economics Revenue and Expenditure Report

Help!

A1 = Tax Revenue and Fiscal Costs (C:\Program Files\GISIntegration\OutputFiles\GovtRevsExps.xls)

	A	B	C	D	E	F
1	**Tax Revenue and Fiscal Costs (C:\Program Files\GISIntegration\OutputFiles\GovtRevsExps.xls)**					
2	*Development Tract Type:*	*Low Density*	*Mid Standard*	*Mid Cluster*	*High Density*	*Commercial*
3			**Development Land Uses**			
4	Land reserved for open space (hectares)	-	-	-	-	-
5	nd occupied by housing/commer. lots (hectares)	124.20	-	-	-	-
6	Land occupied by infrastructure (hectares)	10.80	-	-	-	-
7	Total land (hectares)	135.00	-	-	-	-
8	Total number of housing/commercial lots	111.15				
9	Total number of people living on the lots	277.95				
10				**Dollar Change Relative to Predevelopment Baseline**		
11	**A. Bare land value**	147,788	-	-	-	-
12						
13	**Development cost**					
14	1. New house construction cost	23,936,797	-	-	-	N/A
15	2. Road/sidewalk/drain cost (within tract)	1,929,616	-	-	-	N/A
16	3. Sewer cost (within tract)	-	-	-	-	N/A
17	4. Water cost (within tract)	-	-	-	-	N/A
18						
19	**B. Total tract development cost (1+2+3+4)**	25,866,413	-	-	-	N/A
20						
21	**C. Estimated total tract value (A+B)**	26,014,201	-	-	-	N/A
22						
23	**Assessed value**					
24	3. Use value assessment	(49,196)	-	-	-	N/A
25	4. Market value assessment	23,933,064	-	-	-	N/A
26						
27	**D. Total value of assessed property (3+4)**	23,883,869	-	-	-	N/A
28						
29	**E. Tax revenue (D*Tax Rate)**	269,888	-	-	-	N/A
30						
31	**Cost to local government**					
32	1. Total Sewer connection cost	-	-	-	-	-
33	2. Total Water connection cost	-	-	-	-	-
34						
35	**Total sewer and water cost to localities (1+2)**	-	-	-	-	-
36	Annualized sewer and water cost to localities	-	-	-	-	-

Sheet4 / Sheet1 / Sheet2 / Sheet3

Fig 3.10. Economics report from DesktopL2W

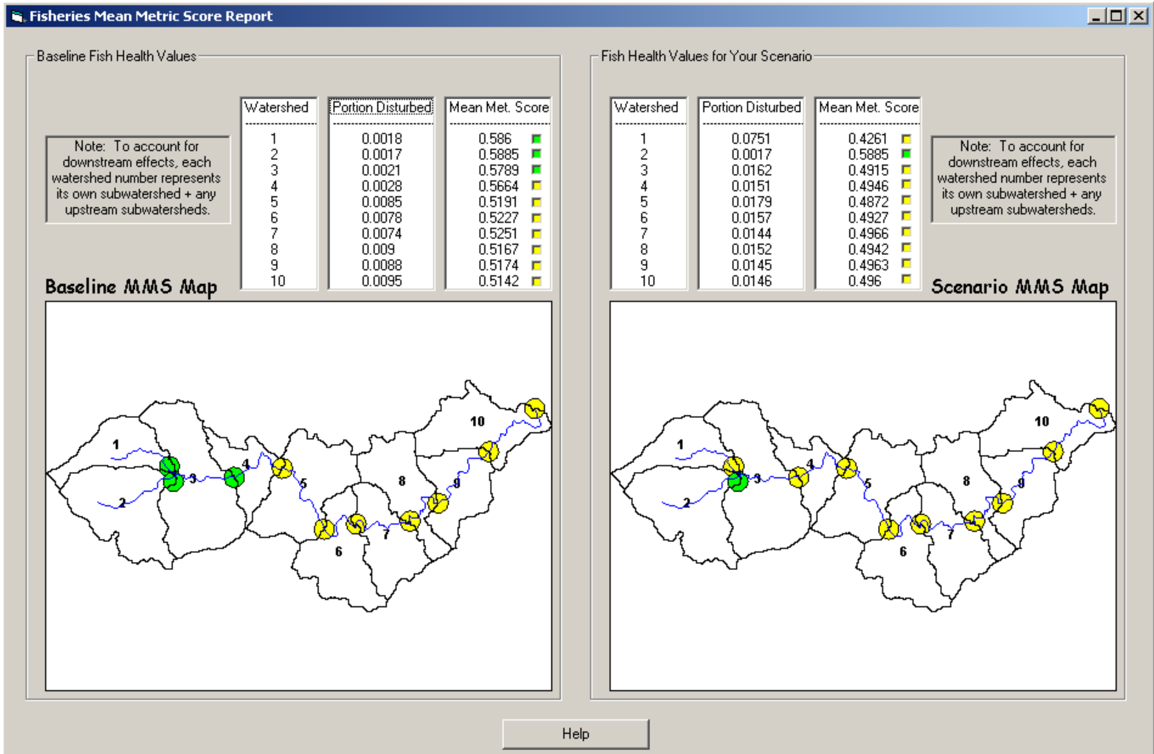


Figure 3.11. Fish health report from DesktopL2W

3.5.2 WebL2W

WebL2W is developed based on the concept of the desktop model, except the application is a client/ server application that runs in the internet. The input interface of WebL2W consists of a gridded map of Back Creek sub watershed and four types of tract development buttons (Figure 3.12). The buttons allow the user to create the four types of development tracts (high density residential, medium density cluster, medium density conventional, low density residential) clicking the button of desired tract type and then clicking on the developable grid square on the map. Once the user defines the desired scenario and presses the "Submit" button at the bottom of the interface, the scenario is compiled and submitted to the Microsoft Access database in the server. The user is then presented with a model selection interface (Figure 3.13), which allows the user to select one or more models to run. Output reports are generated in HTML format and returned to the client when the model runs are complete. A 'Help" link available at the top right corner of the interface gives novice users a quick summary of the steps necessary to create scenario and run models. A 'Standard Scenario' link just below the 'Help' link in the interface enables the user to view simulation results from twelve different types of common scenarios.

Details about these scenarios are covered in Chapter 4. An additional scenario has been developed and the link named 'Test Scenario' to the results from this scenario is provided at the top right corner of the interface near 'Help' link. This scenario can be used as a sample for testing of the software and user feedback can be submitted online through a form which can be accessed through 'Feedback" link at the upper right corner of the main interface. The user interface of WebL2W is designed to allow users from all backgrounds to use the system easily. This is especially important as the software is intended to serve as a decision making tool for watershed managers and planners from various backgrounds who may not know the specialized knowledge of underlying hardware and software, and the modeling techniques.

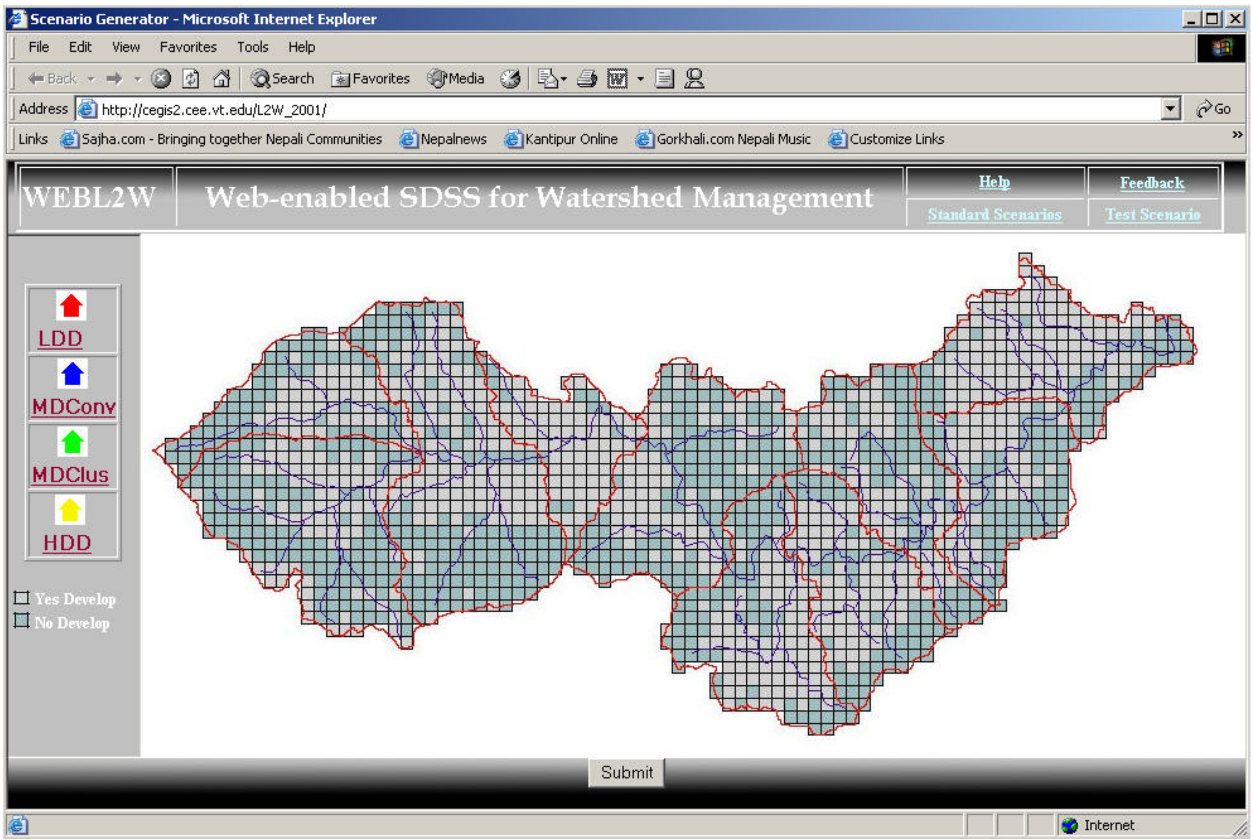


Figure 3.12. WebL2W scenario creation interface

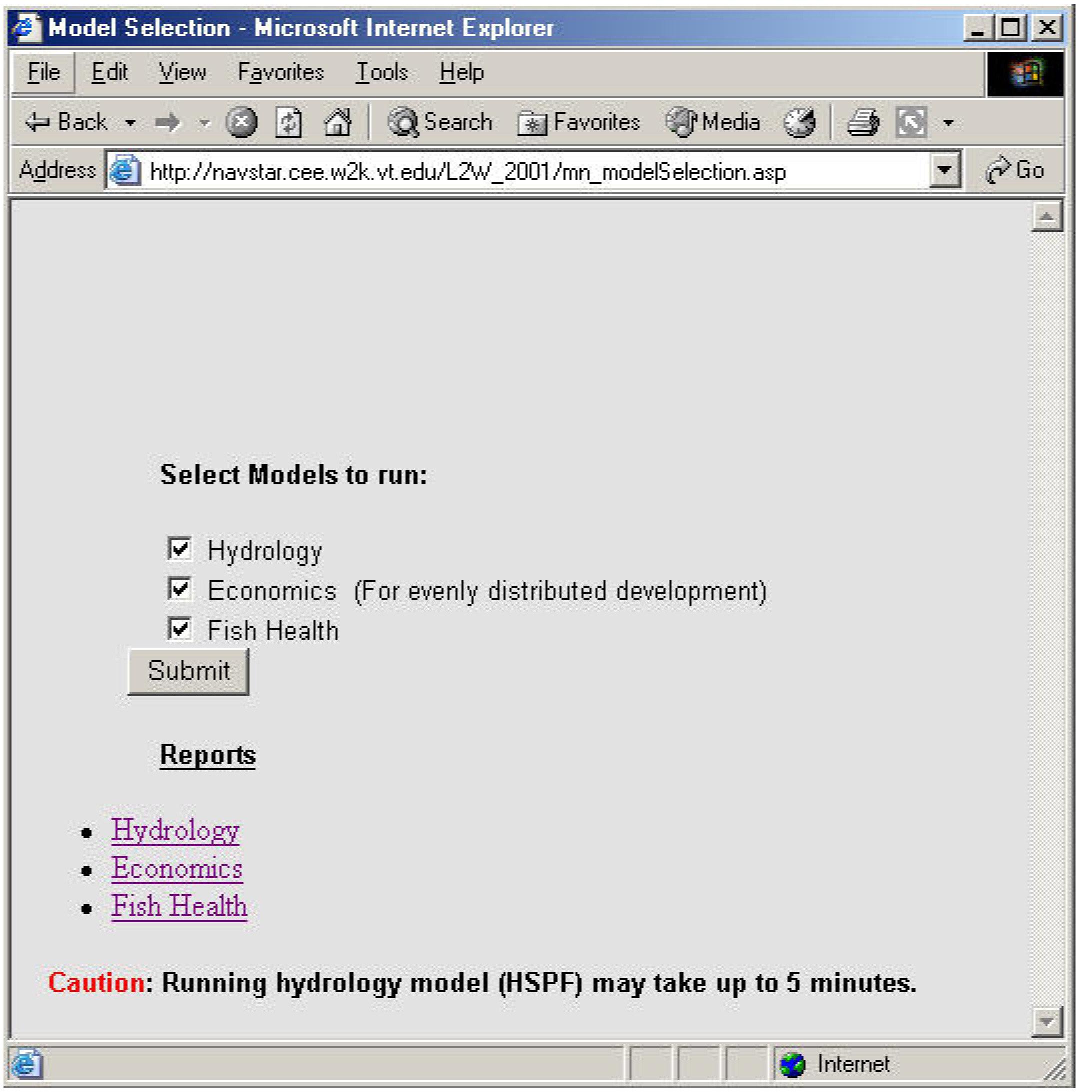


Figure 3.13. WebL2W model selection interface

System Architecture

WebL2W is based on the state-of-art client/server computing technology. The overall flow diagram of the computing environment is shown in Figure 3.14. The system is based on multi-tiered architecture, which can be divided into following main layers.

1. Client
2. Web Server
3. Application
4. Database

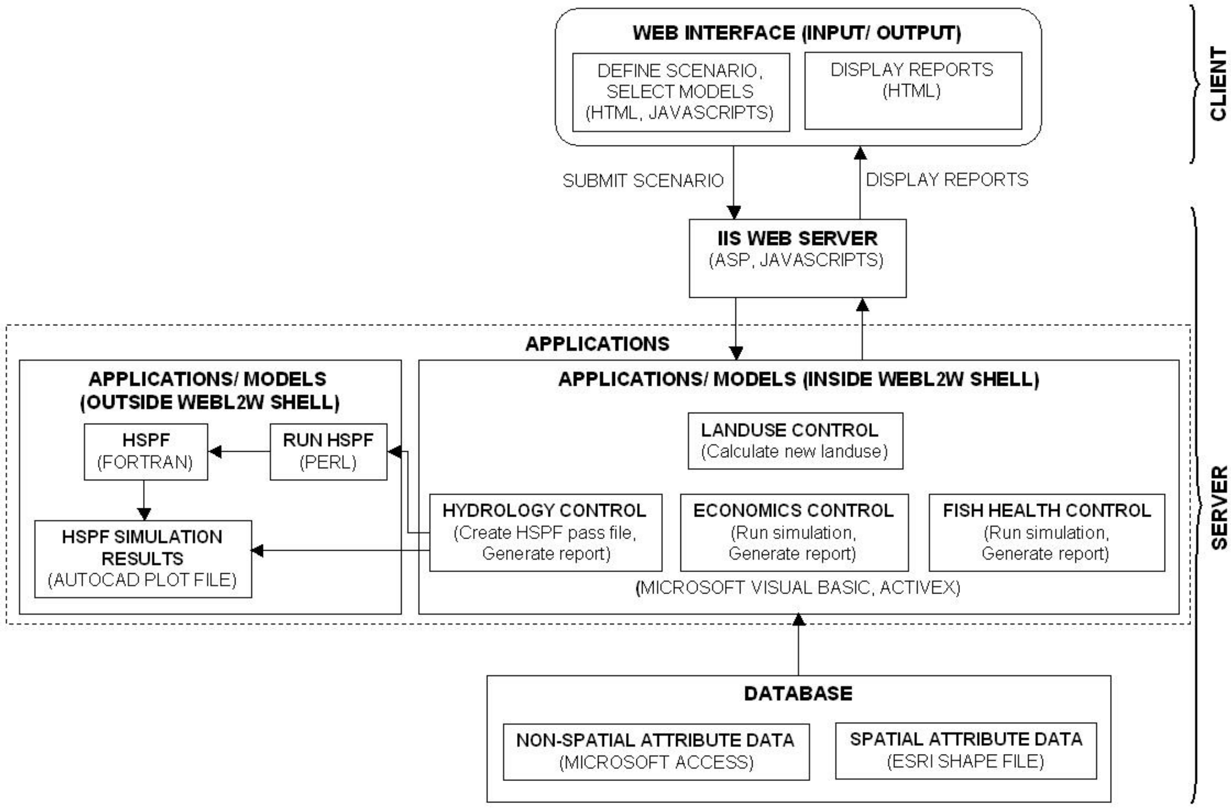


Figure 3.14. Process flow diagram for WebL2W

1. Client

The client application is the web browser in the user's computer through which the user interface is accessed. Interface management and scenario creation tasks are performed in the client, thus leaving the client free from more resource consuming tasks like database management, application logic, simulation, and report generation.

One of the early problems while developing the interface for WebL2W was in allowing users to build the scenario with point and click capability similar to DesktopL2W. The ArcIMS application, which was initially used to regenerate a new image to the client in each user click, was found to be inconvenient as the ArcIMS product maintained constant client/server communications to perform the task. This slowed down the entire modeling process to an unbearable pace. Various technologies including ActiveX control, Java Viewer of ArcIMS etc. were considered to solve the issue. The optimum solution was to perform an image capture of the watershed map and utilize client side JavaScript for the user to define the scenario in the map interface. A custom image painting routine developed in JavaScript was used to paint the grids with various colors as user points and clicks on the map with different types of development tract. This method enabled the client portion of the software to perform interface management including map painting as well as scenario compiling before submission to the server without compromising the performance of the overall system. The implementation code for client interface is given in Appendix B.

An alternate client interface is also included with WebL2W, which allows a user to perform general GIS functions like pan, zoom in, zoom out in Back Creek sub watershed map and also query attribute data of the features in the map (Figure 3.15). The interface is created using the HTML viewer in ArcIMS.

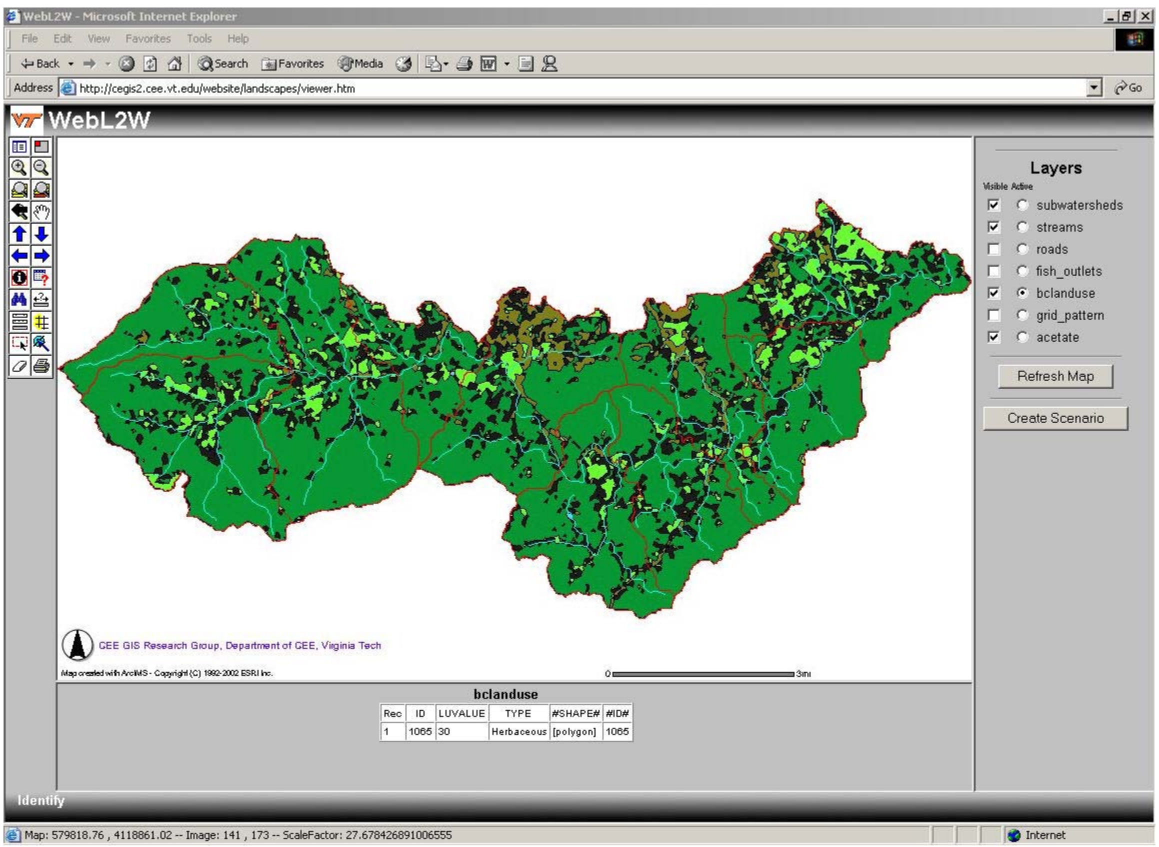


Figure 3.15. ArcIMS map of Back Creek sub watershed.

2. Web Server

   Microsoft Internet Information Service 5.0 (IIS) is used as the web server. The web server provides an interface between the client application and server processes thus allowing the user to access the application, run the models and obtain the results of the run. Active Server Pages (ASP) are used to connect the client with the modeling applications and database, which are housed in the application layer and the database layer, respectively.

3. Application

   The application layer includes applications to perform various modeling tasks in the software. These applications are the ActiveX controls developed in Visual Basic programming environment. The implementation code for each of the controls is given in Appendix B. Following are the applications housed within the application layer.

   a. Land use control

      The land use control evaluates the new land use distribution in the watershed once the user submits the new scenario to the database.

   b. Hydrology control

      The hydrology control creates a pass file (UCI file) from the new land use distribution, which is the input file for HSPF. It then calls a subroutine written in the Perl scripting language, which runs HSPF shell with the pass file as input. Once an HSPF run is complete, the hydrology control compiles the simulation results and creates a hydrology report in an HTML table. The scenario development interface in Figure 3.16 shows a development at land segment 3 with 263 acres of medium density conventional development and 263 acres of low density residential development. The hydrology simulation report generated due to this scenario is shown in Figure 3.17.

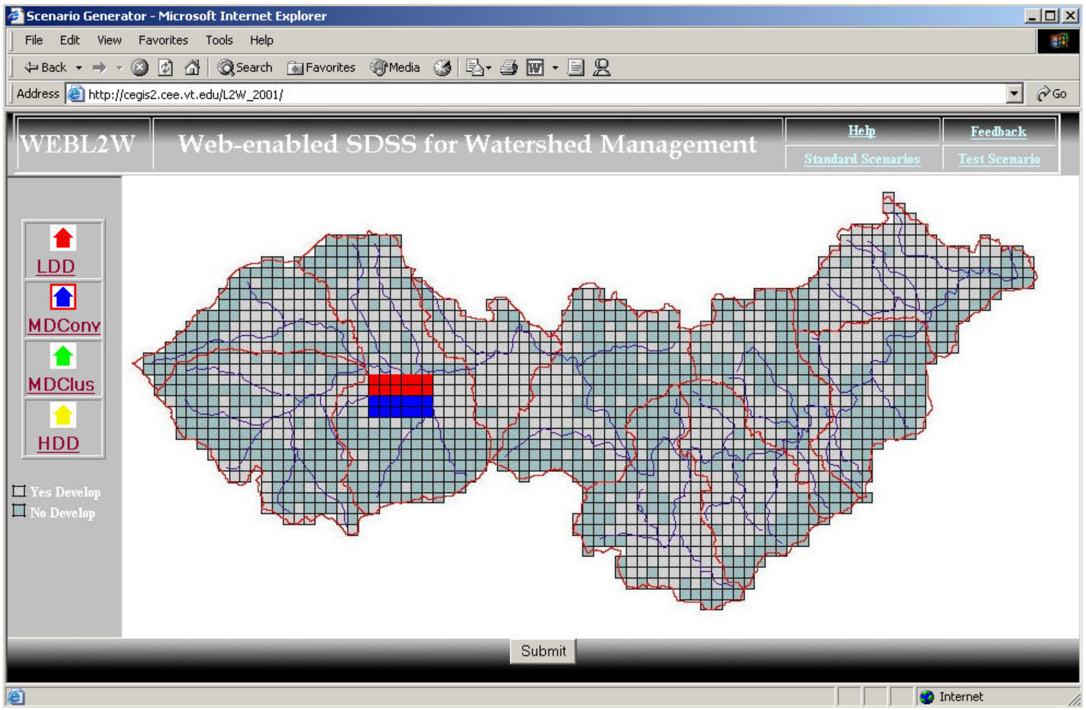
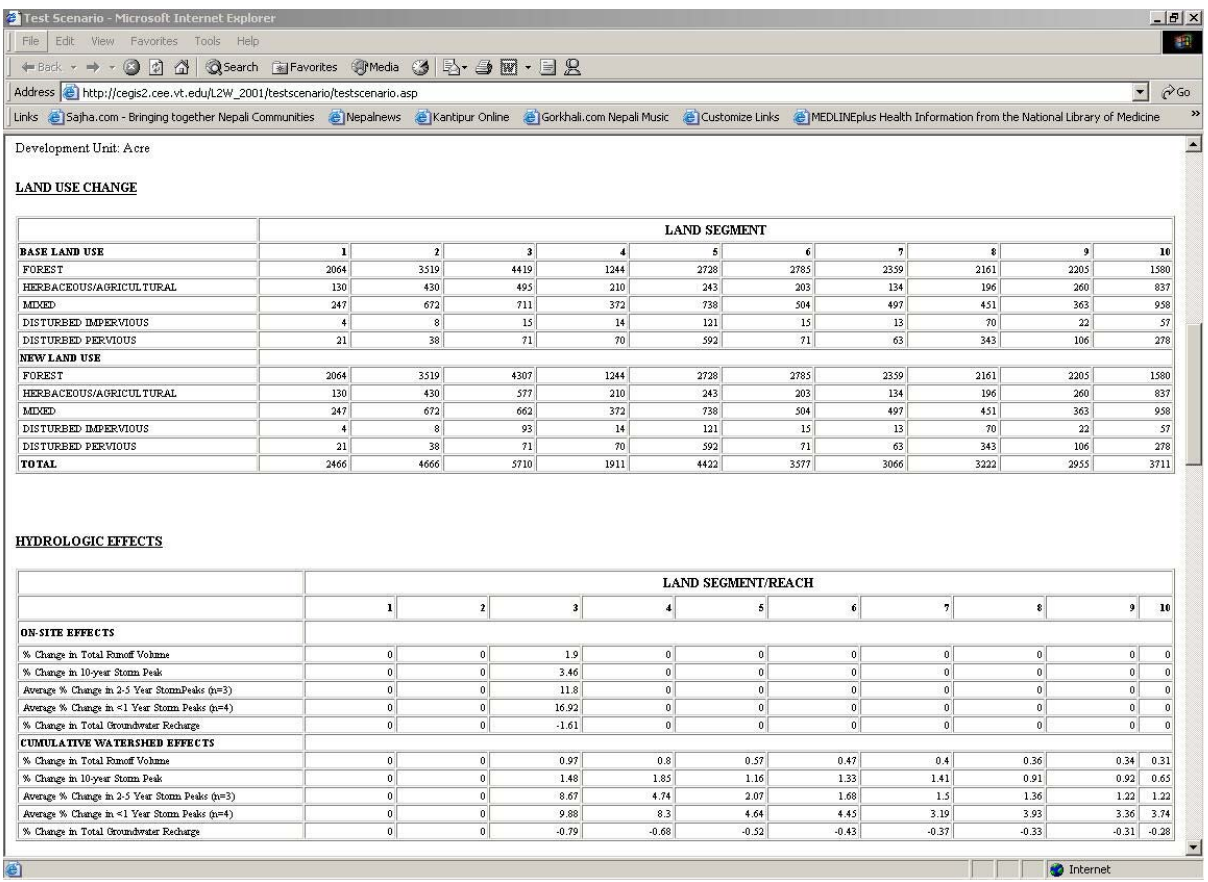


Figure 3.16. WebL2W interface with development scenario


Development Unit: Acre

LAND USE CHANGE

	LAND SEGMENT									
BASE LAND USE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGRICULTURAL	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	2064	3519	4307	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGRICULTURAL	130	430	577	210	243	203	134	196	260	837
MIXED	247	672	662	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	93	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

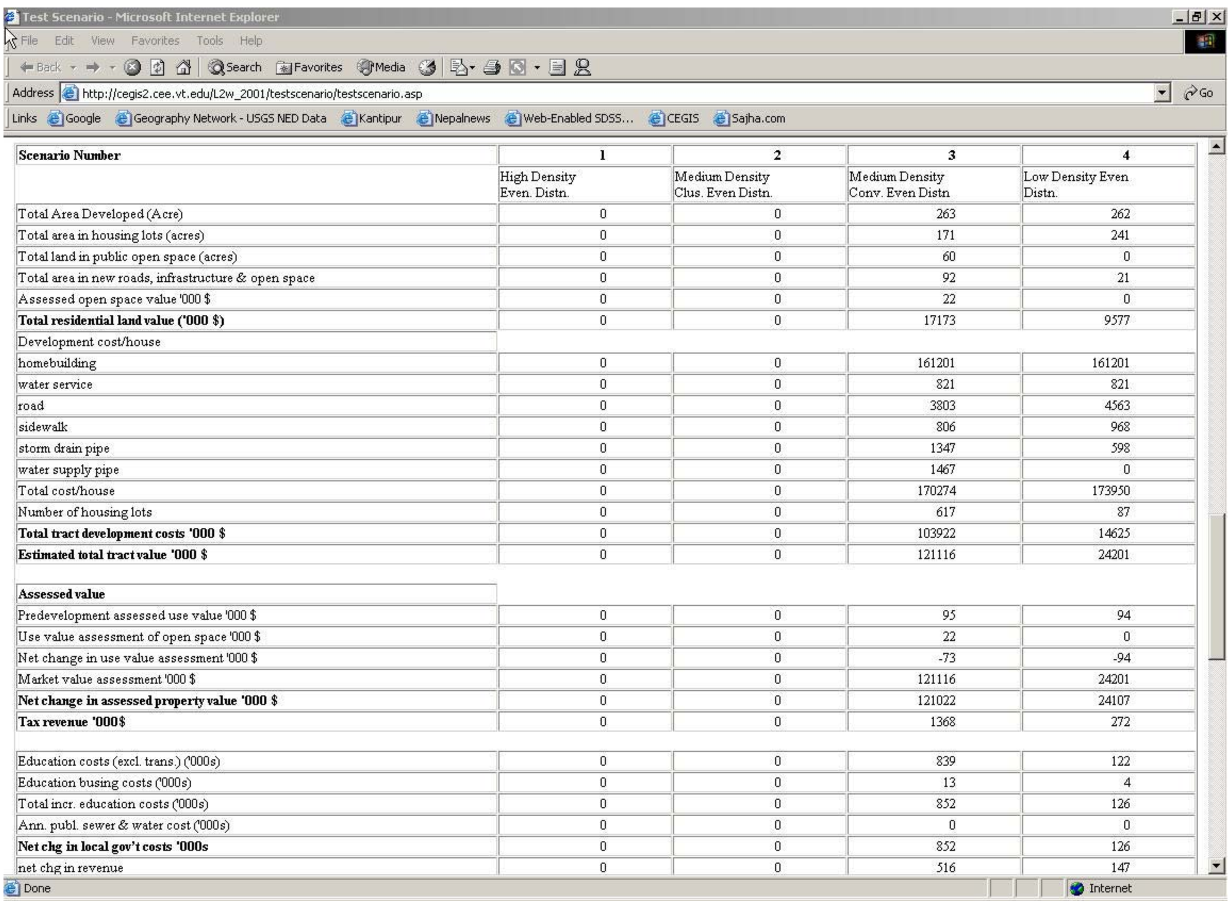
HYDROLOGIC EFFECTS

	LAND SEGMENT/REACH									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ON-SITE EFFECTS										
% Change in Total Runoff Volume	0	0	1.9	0	0	0	0	0	0	0
% Change in 10-year Storm Peak	0	0	3.46	0	0	0	0	0	0	0
Average % Change in 2-5 Year StormPeaks (n=3)	0	0	11.8	0	0	0	0	0	0	0
Average % Change in <1 Year Storm Peaks (n=4)	0	0	16.92	0	0	0	0	0	0	0
% Change in Total Groundwater Recharge	0	0	-1.61	0	0	0	0	0	0	0
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	0	0	0.97	0.8	0.57	0.47	0.4	0.36	0.34	0.31
% Change in 10-year Storm Peak	0	0	1.48	1.85	1.16	1.33	1.41	0.91	0.92	0.65
Average % Change in 2-5 Year Storm Peaks (n=3)	0	0	8.67	4.74	2.07	1.68	1.5	1.36	1.22	1.22
Average % Change in <1 Year Storm Peaks (n=4)	0	0	9.88	8.3	4.64	4.45	3.19	3.93	3.36	3.74
% Change in Total Groundwater Recharge	0	0	-0.79	-0.68	-0.52	-0.43	-0.37	-0.33	-0.31	-0.28

Figure 3.17. Hydrology report from WebL2W

c. Economics control

The economics control runs the model for economics simulation to evaluate total residential land value, the development cost involved with home building, road, sidewalk, sewer, storm drainage, and water supply system construction as well as the tax revenue and other public expenditures related to educational costs and busing costs for new residents. The current version of WebL2W can only evaluate the economic impacts for evenly distributed development in the watershed. The control generates an economics report in tabular form. A sample economics simulation report generated while executing the scenario in Figure 3.16 is shown below in Figure 3.18.

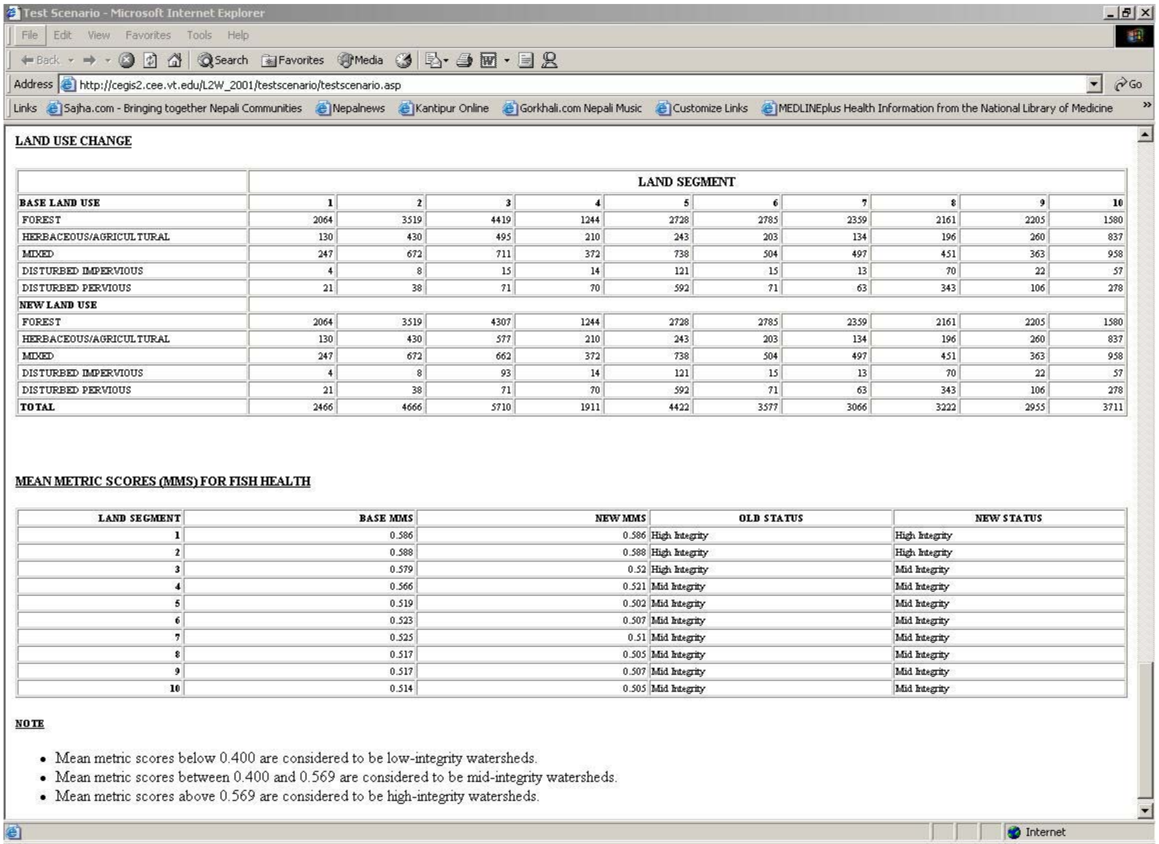


Scenario Number	1	2	3	4
	High Density Even. Distn.	Medium Density Clus. Even Distn.	Medium Density Conv. Even Distn	Low Density Even Distn.
Total Area Developed (Acre)	0	0	263	262
Total area in housing lots (acres)	0	0	171	241
Total land in public open space (acres)	0	0	60	0
Total area in new roads, infrastructure & open space	0	0	92	21
Assessed open space value '000 $	0	0	22	0
Total residential land value ('000 $)	0	0	17173	9577
Development cost/house				
homebuilding	0	0	161201	161201
water service	0	0	821	821
road	0	0	3803	4563
sidewalk	0	0	806	968
storm drain pipe	0	0	1347	598
water supply pipe	0	0	1467	0
Total cost/house	0	0	170274	173950
Number of housing lots	0	0	617	87
Total tract development costs '000 $	0	0	103922	14625
Estimated total tract value '000 $	0	0	121116	24201
Assessed value				
Predevelopment assessed use value '000 $	0	0	95	94
Use value assessment of open space '000 $	0	0	22	0
Net change in use value assessment '000 $	0	0	-73	-94
Market value assessment '000 $	0	0	121116	24201
Net change in assessed property value '000 $	0	0	121022	24107
Tax revenue '000$	0	0	1368	272
Education costs (excl. trans.) ('000s)	0	0	839	122
Education busing costs ('000s)	0	0	13	4
Total incr. education costs ('000s)	0	0	852	126
Ann. publ. sewer & water cost ('000s)	0	0	0	0
Net chg in local gov't costs '000s	0	0	852	126
net chg in revenue	0	0	516	147

Figure 3.18. Economics report from WebL2W

d. Fish health control

The model for evaluating the effect in the quality of fish health due to land development is programmed in fish health control. This application takes new land use as input data and evaluates the change in mean metric scores (MMS) at the zones of influence due to the change in land use. It then generates a fish health report in tabular form showing the habitat condition before and after land development. A sample report from fish health simulation is shown in Figure 3.19. This report is generated as the result of the scenario in Figure 3.16.


Test Scenario - Microsoft Internet Explorer

Address http://cegis2.cee.vt.edu/L2W_2001/testscenario/testscenario.asp

LAND USE CHANGE

	LAND SEGMENT									
BASE LAND USE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGRICULTURAL	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	2064	3519	4307	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGRICULTURAL	130	430	577	210	243	203	134	196	260	837
MIXED	247	672	662	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	93	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

MEAN METRIC SCORES (MMS) FOR FISH HEALTH

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.586	High Integrity	High Integrity
2	0.588	0.588	High Integrity	High Integrity
3	0.579	0.52	High Integrity	Mid Integrity
4	0.566	0.521	Mid Integrity	Mid Integrity
5	0.519	0.502	Mid Integrity	Mid Integrity
6	0.523	0.507	Mid Integrity	Mid Integrity
7	0.525	0.51	Mid Integrity	Mid Integrity
8	0.517	0.505	Mid Integrity	Mid Integrity
9	0.517	0.507	Mid Integrity	Mid Integrity
10	0.514	0.505	Mid Integrity	Mid Integrity

NOTE

- Mean metric scores below 0.400 are considered to be low-integrity watersheds.
- Mean metric scores between 0.400 and 0.569 are considered to be mid-integrity watersheds.
- Mean metric scores above 0.569 are considered to be high-integrity watersheds.

Figure 3.19. Fish health report from WebL2W

e. External Model

WebL2W uses HSPF for hydrologic simulation. HSPF is an application external to the application layer of the software architecture. This application is invoked by a subroutine written in Perl script once the subroutine receives the input pass file information from the hydrology control in the application layer.

4. Database

Database layer houses spatial data as well as non-spatial attribute data inside its shell. The spatial data are stored in ESRI's shapefile format. The attribute data for each grid square are stored in Microsoft Access database format. The tables in the attribute database are related to each other with a unique ID assigned for each grid square. An independent table stores the values of static parameters for the economics model. Further, shape file related to the grid pattern in the sub watershed is associated with its attribute table in Access database through the unique ID assigned for each grid square. The entire process is explained in the following paragraph. An entity relationship diagram of the overall database layer is shown in Figure 3.20.

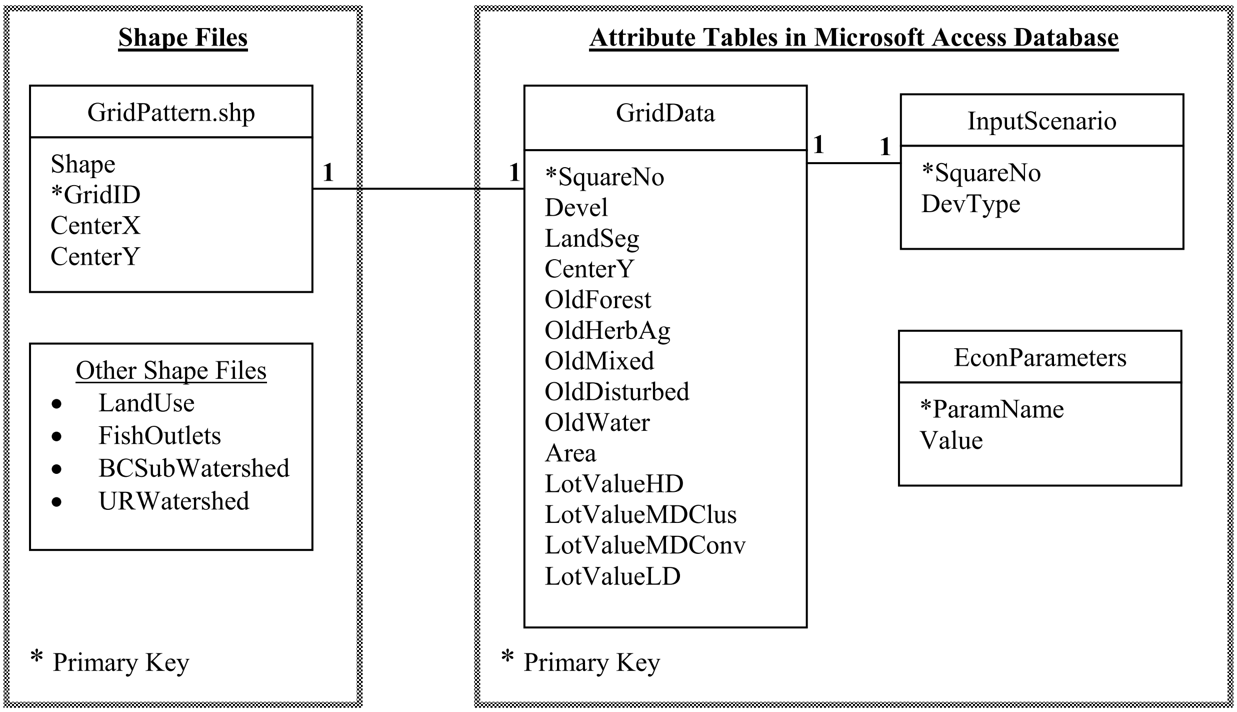
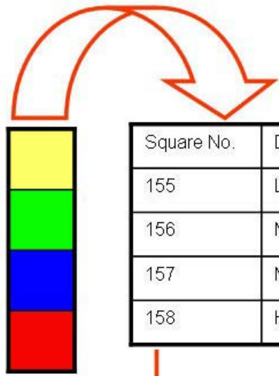


Figure 3.20. Database structure of WebL2W

When the user loads the map in the web browser, the web document assigns a unique value to each of the grids in the image, which matches with the grid's unique ID assigned in the server database. This operation is performed with the program written client side JavaScript. Once the user defines the scenario and submits it by pressing the 'Submit' button, a table named 'Input Scenario' in the server is populated with the grid ID numbers and development types of each of the developed grids in the scenario. Selected server applications then retrieve necessary attribute data required for the models from the database. An example for the overall process of database operation is given in Figure 3.21.



InputScenario

Square No.	Development Type
155	LDD
156	MDConv
157	MDClus
158	HDD

GridPattern.shp

GridID	CenterX	CenterY
155	579360.843644	4118001.383057
156	579360.843644	4118301.383057
157	579360.843644	4118601.383057
158	579360.843644	4118901.383057

GridData

Square No	Devel	Land Seg	Old Forest	Old HerbAg	Old Mixed	Old Disturbed	Old Water	Land ValueHD	LandValue MDClus	LandValue MDConv	Land ValueLD
155	1	1	71933.923	8092.566	9890.914	0	0	46.78	46.61	42.41	30.14
156	1	1	69236.401	1798.348	18882.655	0	0	48.40	48.21	43.87	31.18
157	1	1	88119.056	899.174	899.174	0	0	48.75	48.56	44.19	31.41
158	1	1	72833.097	3596.696	13487.611	0	0	48.15	47.97	43.65	31.02

Figure 3.21. Database process in WebL2W

4.0 CASE STUDY

WebL2W is designed to evaluate the multi-disciplinary impacts of watershed development. The following sets of case studies have been presented to demonstrate the potential of WebL2W.

<u>All developable grids in the watershed developed</u>

All the developable grids in the watershed are using high density, medium density cluster, medium density conventional, and low density development types respectively (Case I, Case II, Case III, Case IV). The main objective of these scenarios is to show the impacts on hydrologic, economic, and fish health parameters due to extreme development conditions.

<u>All developable grids in the most upstream sub watersheds developed</u>

All developable grids in the most upstream sub watersheds (land segments 1 and 2) are developed using high density, medium density cluster, medium density conventional, and low density development types respectively (Case V, Case VI, Case VII, Case VIII). These scenarios show the multi-disciplinary impacts in the entire watershed when headwater portion of the watershed is developed with different types of developments.

<u>All developable grids in the most downstream sub watershed developed</u>

All developable grids in the most downstream sub watershed (land segment 10) are developed using high density, medium density cluster, medium density conventional, and low density development types respectively (Case IX, Case X, Case XI, Case XII). The primary objective of these scenarios is to show the multi-disciplinary impacts on the entire watershed when the outlet portion is developed.

All the three models included in WebL2W *viz.* hydrology, economics, and fish health, are executed for each scenario and the results from each simulation are provided.

4.1 Entire Watershed Developed

Development scenarios covering all the developable grids in the sub watershed are created using a high density residential pattern, a medium density cluster pattern, a medium density conventional pattern, and a high density pattern, respectively. Each of these development scenarios covers 17,609 acres of developable land. The land use distributions in the developable area are summarized in Table 4.1. It can be seen that land segment 1 has about 791 acre developable land covered by forest, 112 acre under agriculture, and about 179 acre as mixed land.

LANDSEG	FOREST	HERBAG	MIXED	TOTAL
1	790.55	111.76	178.42	1080.73
2	1098.73	354.84	457.93	1911.50
3	1883.28	387.72	530.59	2801.59
4	1019.41	193.08	318.62	1531.11
5	1014.96	108.87	456.82	1580.66
6	1428.24	158.87	368.84	1955.94
7	1229.60	113.09	424.83	1767.52
8	889.65	132.65	292.18	1314.48
9	859.87	183.75	247.52	1291.15
10	797.44	783.66	793.66	2374.77
TOTAL	11011.73	2528.30	4069.41	17609.44

Table 4.1. Development scenario land use when entire watershed is developed (area in acres)

Case I: High Density Development

Figure 4.1 shows a high density residential pattern full build out scenario. The reports from this scenario run are shown in Tables 4.2 through 4.6. Table 4.2 shows the comparative land use distribution before and after development in the watershed. Tables 4.3 through 4.5 show effects on hydrology, economics, and fish habitat due to land use change respectively.

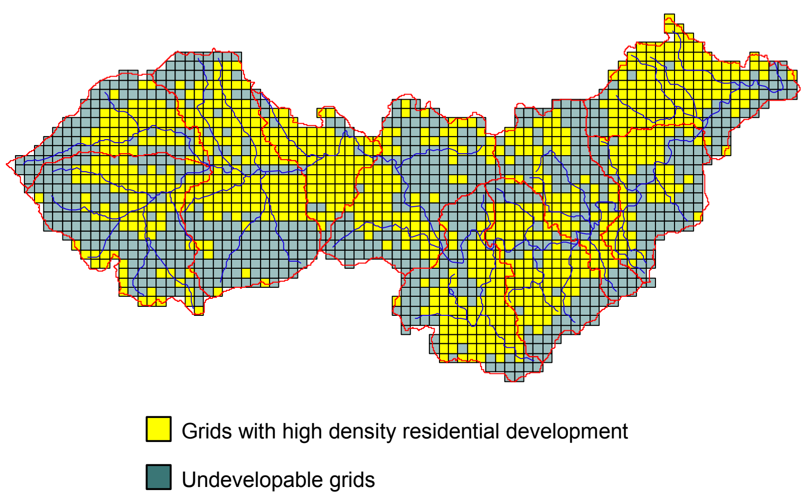


Figure 4.1. High density development in the entire watershed (Development Scenario I)[12]

[12] Note: One yellow grid represents 9 hectares of land developed using the high-density residential pattern.

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1313	2475	2630	276	1764	1428	1191	1316	1388	823
HERBACEOUS/AGR	673	1240	1807	945	1088	1226	1087	858	860	1517
MIXED	77	237	207	69	304	153	94	174	128	204
DISTURBED IMPERVIOUS	383	677	995	550	674	699	632	530	474	888
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.2. Change in land use due to development scenario I (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	28.78	26.34	24.42	35.22	15.18	24.33	25.76	21.73	29.87	35.72
% Change in 10-year Storm Peak	21.9	19.76	45.57	79.83	31.39	56.74	60.01	17.47	37.02	13.92
Average % Change in 2-5 Year Storm Peaks	369.28	301.69	156.16	89.11	31.94	61.34	62.24	52.63	134.51	79
Average % Change in <1 Year Storm Peaks	508.67	473.68	316.08	494.67	138.03	311.25	372.91	264.87	505.18	561.73
% Change in Total Groundwater Recharge	-19.44	-17.49	-21.01	-35.74	-16.43	-24.52	-25.71	-17.8	-18.54	-25.89
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	28.78	26.34	25.78	27.37	23.86	23.94	24.19	23.94	24.34	25.4
% Change in 10-year Storm Peak	26.02	23.42	37.87	60.2	68.85	78.35	84.47	71.36	58.99	50.25
Average % Change in 2-5 Year Storm Peaks	232.91	181.89	161.24	139.43	106.09	97.82	97.16	93.74	112.93	114.47
Average % Change in <1 Year Storm Peaks	500.86	467.13	376.89	316.82	243.95	230.31	231.38	238.38	249.27	259.98
% Change in Total Groundwater Recharge	-19.44	-18.16	-19.57	-21.79	-20.47	-21.17	-21.75	-21.34	-21.12	-21.56

Table 4.3. Hydrologic effects due to development scenario I

Economic Effects (Development: High Density)	Values
Total Area Developed (acre)	17609
Total area in housing lots (acre)	14317
Total land in public open space (acre)	880
Total area in new roads, infrastructure & open space (acre)	3292
Assessed open space value ('000 $)	260
Total residential land value ('000 $)	1680251
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	987
Water supply pipe ($)	1200
Total cost/house ($)	168402
Number of housing lots	71852
Total tract development costs ('000 $)	12100070
Estimated total tract value ('000 $)	13780581
Assessed value	
Predevelopment assessed use value ('000 $)	6343
Use value assessment of open space ('000 $)	260
Net change in use value assessment ('000 $)	-6083
Market value assessment ('000 $)	13780581
Net change in assessed property value ('000 $)	13774238
Tax revenue ('000$)	155649
Education costs (excl. trans.) ('000 $)	97778
Education busing costs ('000 $)	735
Total incr. education costs ('000 $)	98514
Ann. publ. sewer & water cost ('000 $)	12
Net change in local government costs ('000 $)	98526
Net change in revenue ('000 $)	
	57123
Number of new students	29407
Cost per student (local share) ($)	3325
Per student busing cost ($)	50

Table 4.4. Economic effects due to development scenario I

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.395	High Integrity	Low Integrity
2	0.588	0.398	High Integrity	Low Integrity
3	0.579	0.394	High Integrity	Low Integrity
4	0.566	0.390	Mid Integrity	Low Integrity
5	0.519	0.391	Mid Integrity	Low Integrity
6	0.523	0.390	Mid Integrity	Low Integrity
7	0.525	0.389	Mid Integrity	Low Integrity
8	0.517	0.390	Mid Integrity	Low Integrity
9	0.517	0.390	Mid Integrity	Low Integrity
10	0.514	0.388	Mid Integrity	Low Integrity

Table 4.5. Effects on fish habitat due to development scenario I

NOTE
Mean metric scores below 0.400 are considered to be low-integrity watersheds.
Mean metric scores between 0.400 and 0.569 are considered to be mid-integrity watersheds.
Mean metric scores above 0.569 are considered to be high-integrity watersheds.

<u>Case II: Medium Density Cluster Development</u>

Figure 4.2 shows the development scenario with medium density cluster pattern where grids with green color represent developed grids. The reports from this scenario run are shown in Tables 4.6 through 4.9. Table 4.6 shows the comparative land use distribution before and after development in the watershed. Table 4.7, Table 4.8, and Table 4.9 show effects on hydrology, economics, and fish habitat in the watershed.

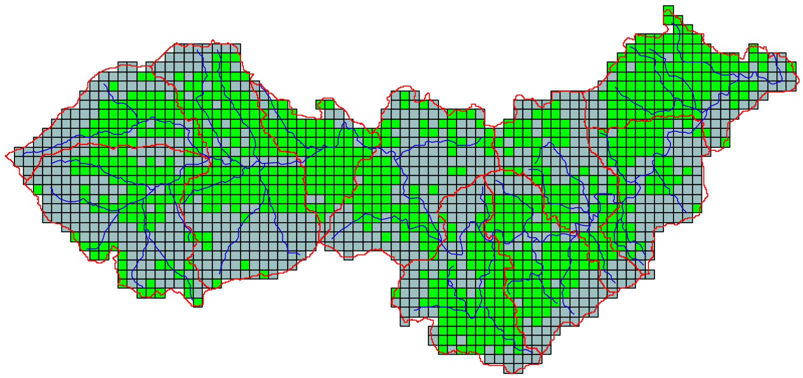


Figure 4.2. Medium density cluster development in the entire watershed (Development Scenario II)[13]

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1455	2673	2969	460	1947	1685	1412	1476	1543	966
HERBACEOUS/AGR	585	1112	1597	827	949	1059	930	751	764	1421
MIXED	109	319	302	126	386	220	170	226	172	347
DISTURBED IMPERVIOUS	296	524	771	428	548	543	490	425	370	698
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.6. Change in land use due to development scenario II (area in acres)

[13] Note: One green grid represents 9 hectare of land developed using the medium-density cluster pattern.

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	22.26	20.38	18.91	27.37	11.77	18.89	19.88	16.84	23.05	27.64
% Change in 10-year Storm Peak	17.01	15.35	35.65	62.04	24.37	44.06	46.45	13.72	28.67	10.91
Average % Change in 2-5 Year Storm Peaks	288.55	236.1	122.37	70.68	25.29	48.66	49.2	41.69	106.64	62.02
Average % Change in <1 Year Storm Peaks	388	361.25	239.48	373.7	105.55	232.57	280.28	204.9	389.32	434.14
% Change in Total Groundwater Recharge	-15.28	-13.72	-16.46	-28.01	-12.9	-19.24	-20.22	-13.94	-14.52	-20.2
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	22.25	20.38	19.95	21.2	18.48	18.56	18.74	18.54	18.85	19.67
% Change in 10-year Storm Peak	20.31	18.22	29.65	46.88	53.3	60.48	64.61	55.08	46.32	39.27
Average % Change in 2-5 Year Storm Peaks	177.37	139.88	124.83	110.64	84	76.29	74.95	75.2	89.93	89.2
Average % Change in <1 Year Storm Peaks	383.93	359.34	285.4	233.88	182.79	168.34	171.71	184.19	188.09	198
% Change in Total Groundwater Recharge	-15.28	-14.26	-15.35	-17.09	-16.06	-16.6	-17.07	-16.74	-16.57	-16.9

Table 4.7. Hydrologic effects due to development scenario II

Economic Effects (Development: Mid. Density Cluster)	Values
Total Area Developed (acre)	17609
Total area in housing lots (acre)	8333
Total land in public open space (acre)	7924
Total area in new roads, infrastructure & open space (acre)	9276
Assessed open space value ('000 $)	2854
Total residential land value ('000 $)	972369
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	808
Water supply pipe ($)	1200
Total cost/house ($)	168223
Number of housing lots	41327
Total tract development costs ('000 $)	6959624
Estimated total tract value ('000 $)	7934847
Assessed value	
Predevelopment assessed use value ('000 $)	6343
Use value assessment of open space ('000 $)	2854
Net change in use value assessment ('000 $)	-3489
Market value assessment ('000 $)	7934847
Net change in assessed property value ('000 $)	7928504
Tax revenue ('000$)	89592
Education costs (excl. trans.) ('000 $)	56208
Education busing costs ('000 $)	634
Total incr. education costs ('000 $)	56842
Ann. publ. sewer & water cost ('000 $)	7
Net change in local government costs ('000 $)	56849
Net change in revenue ('000 $)	
	32743
Number of new students	16905
Cost per student (local share) ($)	3325
Per student busing cost ($)	75

Table 4.8. Economic effects due development scenario II

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.406	High Integrity	Mid Integrity
2	0.588	0.409	High Integrity	Mid Integrity
3	0.579	0.405	High Integrity	Mid Integrity
4	0.566	0.401	Mid Integrity	Mid Integrity
5	0.519	0.401	Mid Integrity	Mid Integrity
6	0.523	0.401	Mid Integrity	Mid Integrity
7	0.525	0.400	Mid Integrity	Low Integrity
8	0.517	0.400	Mid Integrity	Low Integrity
9	0.517	0.400	Mid Integrity	Mid Integrity
10	0.514	0.399	Mid Integrity	Low Integrity

Table 4.9. Effects on fish habitat due to development scenario II

Case III: Medium Density Conventional Development

Figure 4.3 shows the WebL2W interface for development scenario with medium density conventional pattern in the entire watershed. Table 4.10 shows the comparative land use distribution before and after development in the watershed. Tables 4.11 through 4.13 show results from hydrologic, economics, fish health simulations.

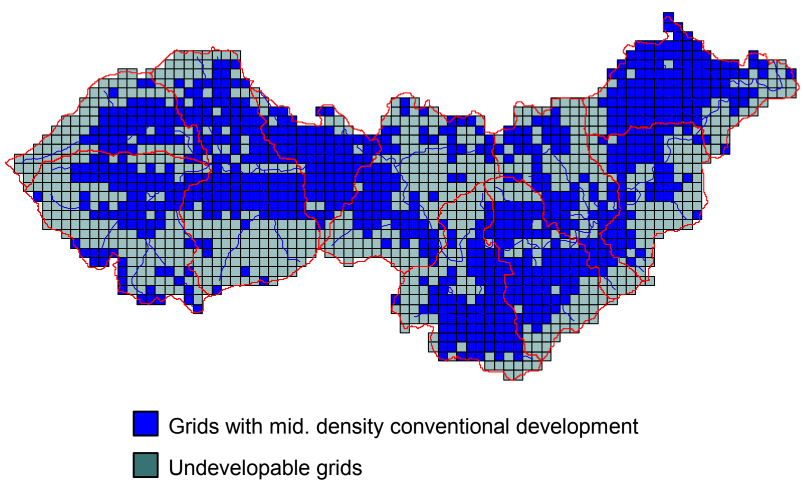


Figure 4.3. Medium density conventional development in the entire watershed (Development Scenario III)[14]

[14] Note: One blue grid represents 9 hectare of land developed using the medium-density conventional pattern.

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1629	2915	3383	684	2170	1999	1682	1672	1732	1142
HERBACEOUS/AGR	447	904	1262	639	736	801	690	583	611	1237
MIXED	149	420	419	196	487	301	264	291	227	522
DISTURBED IMPERVIOUS	220	390	575	321	437	406	366	333	280	532
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.10. Change in land use due to development scenario III (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	16.41	15.06	13.96	20.19	8.68	13.94	14.66	12.47	17.07	20.46
% Change in 10-year Storm Peak	12.49	11.31	26.13	45.78	17.96	32.5	34.23	10.06	21.17	8.01
Average % Change in 2-5 Year Storm Peaks	209.23	172.95	89.6	51.32	18.37	35.34	35.71	30.33	77.41	45.36
Average % Change in <1 Year Storm Peaks	281.65	262.12	169.79	266.61	76.42	163.13	198.25	150.49	285.63	321.25
% Change in Total Groundwater Recharge	-11.16	-10.03	-12.06	-20.54	-9.43	-14.07	-14.78	-10.19	-10.63	-14.81
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	16.4	15.06	14.73	15.65	13.64	13.7	13.83	13.69	13.92	14.53
% Change in 10-year Storm Peak	14.99	13.38	21.97	34.26	38.77	44.06	46.44	40.24	34.55	29.14
Average % Change in 2-5 Year Storm Peaks	126.32	99.15	88.9	81.26	61.19	53.96	51.76	55.85	66.05	63.47
Average % Change in <1 Year Storm Peaks	280.45	263.68	202.13	166.95	127.75	116.37	128	133.86	136.88	141.9
% Change in Total Groundwater Recharge	-11.16	-10.42	-11.23	-12.51	-11.75	-12.15	-12.49	-12.25	-12.12	-12.37

Table 4.11. Hydrologic effects due to development scenario III

Economic Effects (Development: Mid. Density Conventional)	Values
Total Area Developed (acre)	17609
Total area in housing lots (acre)	11458
Total land in public open space (acre)	4050
Total area in new roads, infrastructure & open space (acre)	6151
Assessed open space value ('000 $)	1459
Total residential land value ('000 $)	1150044
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	3803
Sidewalk ($)	806
Storm drain pipe ($)	1347
Water supply pipe ($)	1467
Total cost/house ($)	170274
Number of housing lots	41327
Total tract development costs ('000 $)	6959624
Estimated total tract value ('000 $)	8111127
Assessed value	
Predevelopment assessed use value ('000 $)	6343
Use value assessment of open space ('000 $)	1459
Net change in use value assessment ('000 $)	-4884
Market value assessment ('000 $)	8111127
Net change in assessed property value ('000 $)	8104784
Tax revenue ('000$)	91584
Education costs (excl. trans.) ('000 $)	56208
Education busing costs ('000 $)	845
Total incr. education costs ('000 $)	57053
Ann. publ. sewer & water cost ('000 $)	7
Net change in local government costs ('000 $)	57060
Net change in revenue ('000 $)	
	34524
Number of new students	16905
Cost per student (local share) ($)	3325
Per student busing cost ($)	100

Table 4.12. Economic effects due to development scenario III

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.419	High Integrity	Mid Integrity
2	0.588	0.422	High Integrity	Mid Integrity
3	0.579	0.417	High Integrity	Mid Integrity
4	0.566	0.413	Mid Integrity	Mid Integrity
5	0.519	0.413	Mid Integrity	Mid Integrity
6	0.523	0.413	Mid Integrity	Mid Integrity
7	0.525	0.412	Mid Integrity	Mid Integrity
8	0.517	0.412	Mid Integrity	Mid Integrity
9	0.517	0.412	Mid Integrity	Mid Integrity
10	0.514	0.411	Mid Integrity	Mid Integrity

Table 4.13. Effects on fish habitat due to development scenario III

Case IV: Low Density Development

Figure 4.4 shows the WebL2W interface with low density residential pattern where the red grids are area developed. Table 4.14 shows the comparative land use distribution before and after development in the watershed. Tables 4.15 through 4.17 show results from hydrologic, economics, and fish health simulations.

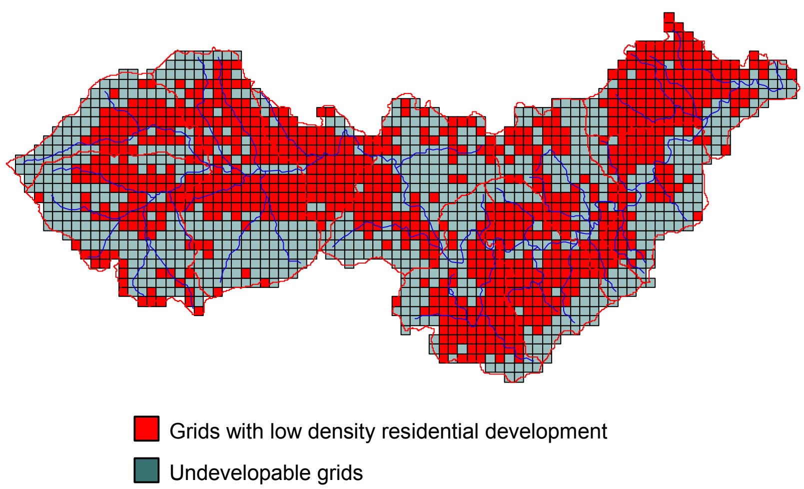


Figure 4.4. Low density development in the entire watershed (Development Scenario IV)[15]

[15] Note: One red grid represents 9 hectare of land developed using the low-density residential pattern.

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1866	3244	3948	990	2475	2428	2051	1939	1990	1381
HERBACEOUS/AGR	265	628	818	391	453	457	371	360	407	997
MIXED	202	557	578	292	624	411	391	378	301	760
DISTURBED IMPERVIOUS	112	199	295	168	279	210	190	202	151	294
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.14. Change in land use due to development scenario IV (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	8.13	7.45	6.92	10.1	4.33	6.87	7.3	6.22	8.44	10.14
% Change in 10-year Storm Peak	6.14	5.54	12.72	22.79	8.91	16.02	17	4.9	10.42	3.88
Average % Change in 2-5 Year Storm Peaks	98.54	84.13	43.5	24.52	8.78	16.73	17.05	14.49	36.56	21.88
Average % Change in <1 Year Storm Peaks	130.73	121.21	71.42	118.64	35.81	74.61	89.27	73.4	139.84	159.72
% Change in Total Groundwater Recharge	-5.41	-4.89	-5.87	-9.93	-4.55	-6.82	-7.16	-4.95	-5.2	-7.26
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	8.13	7.45	7.3	7.77	6.78	6.79	6.86	6.8	6.91	7.21
% Change in 10-year Storm Peak	7.54	6.53	10.97	16.55	18.52	21.04	21.18	19.84	17.21	14.74
Average % Change in 2-5 Year Storm Peaks	60.55	48.63	38.46	39.73	29.11	23.35	25.54	27.4	31.71	28.22
Average % Change in <1 Year Storm Peaks	135.07	128.13	92.18	74.33	59.73	56.64	63.46	61.67	65.43	62.23
% Change in Total Groundwater Recharge	-5.41	-5.07	-5.46	-6.08	-5.7	-5.89	-6.06	-5.94	-5.88	-6.01

Table 4.15. Hydrologic effects due to development scenario IV

Economic Effects (Development: Low Density)	Values
Total Area Developed (acre)	17609
Total area in housing lots (acre)	16168
Total land in public open space (acre)	0
Total area in new roads, infrastructure & open space (acre)	1441
Assessed open space value ('000 $)	0
Total residential land value ('000 $)	643785
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	4563
Sidewalk ($)	968
Storm drain pipe ($)	598
Water supply pipe ($)	0
Total cost/house ($)	173950
Number of housing lots	5838
Total tract development costs ('000 $)	983146
Estimated total tract value ('000 $)	1626931
Assessed value	
Predevelopment assessed use value ('000 $)	6343
Use value assessment of open space ('000 $)	0
Net change in use value assessment ('000 $)	-6343
Market value assessment ('000 $)	1626931
Net change in assessed property value ('000 $)	1620588
Tax revenue ('000$)	18313
Education costs (excl. trans.) ('000 $)	8197
Education busing costs ('000 $)	247
Total incr. education costs ('000 $)	8444
Ann. publ. sewer & water cost ('000 $)	1
Net change in local government costs ('000 $)	8445
Net change in revenue ('000 $)	
	9868
Number of new students	2465
Cost per student (local share) ($)	3325
Per student busing cost ($)	200

Table 4.16. Economic effects due to development scenario IV

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.447	High Integrity	Mid Integrity
2	0.588	0.450	High Integrity	Mid Integrity
3	0.579	0.446	High Integrity	Mid Integrity
4	0.566	0.441	Mid Integrity	Mid Integrity
5	0.519	0.439	Mid Integrity	Mid Integrity
6	0.523	0.439	Mid Integrity	Mid Integrity
7	0.525	0.438	Mid Integrity	Mid Integrity
8	0.517	0.438	Mid Integrity	Mid Integrity
9	0.517	0.438	Mid Integrity	Mid Integrity
10	0.514	0.437	Mid Integrity	Mid Integrity

Table 4.17. Effects on fish habitat due to development scenario IV

4.2 Headwater developed

Development scenarios covering all the developable grids in land segments 1 and 2 are created using a high density residential pattern, a medium density cluster pattern, a medium density conventional pattern, and a high density pattern respectively. Each of these development scenarios covers 2992 acres of developable land. The land use distribution of the developable areas prior to development is summarized in Table 4.18.

LANDSEG	FOREST	HERBAG	MIXED	TOTAL
1	790.55	111.76	178.42	1080.73
2	1098.73	354.84	457.93	1911.50
TOTAL	1889.28	466.60	636.35	2992.23

Table 4.18. Development scenario land use when headwater is developed (area in acres)

Case V: High Density Development

Full development of the most upstream sub watersheds with a high density residential pattern is shown in Figure 4.5. Table 4.19 shows the comparative land use distribution before and after development in the watershed, and Tables 4.20 through 4.22 show effects on hydrology, economics, and fish health simulations respectively.

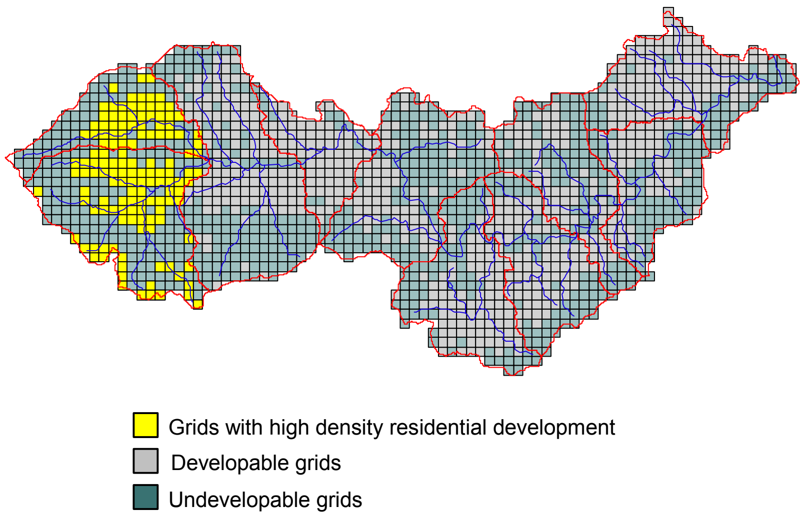


Figure 4.5. High density development in the headwater (Development Scenario V)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1313	2475	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	673	1240	495	210	243	203	134	196	260	837
MIXED	77	237	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	383	677	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.19. Change in land use due to development scenario V (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	28.78	26.34								
% Change in 10-year Storm Peak	21.9	19.76								
Average % Change in 2-5 Year Storm Peaks	369.28	301.69								
Average % Change in <1 Year Storm Peaks	508.67	473.68								
% Change in Total Groundwater Recharge	-19.44	-17.49								
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	28.78	26.34	13.4	11.14	7.93	6.49	5.61	5.04	4.7	4.26
% Change in 10-year Storm Peak	26.02	23.42	19.26	23.2	21.67	20.46	18.43	13.94	13.22	9.64
Average % Change in 2-5 Year Storm Peaks	232.91	181.89	44.97	29.64	24.64	14.88	14.68	16.04	18.27	14.35
Average % Change in <1 Year Storm Peaks	500.86	467.13	167.24	114.71	81.54	68.89	75.73	71.55	72.03	71.73
% Change in Total Groundwater Recharge	-19.44	-18.16	-9.19	-7.92	-5.97	-4.94	-4.3	-3.85	-3.56	-3.23

Table 4.20. Hydrologic effects due to development scenario V

Economic Impacts (Development: High Density)	Values
Total Area Developed (acre)	2992
Total area in housing lots (acre)	2433
Total land in public open space (acre)	150
Total area in new roads, infrastructure & open space (acre)	559
Assessed open space value ('000 $)	44
Total residential land value ('000 $)	285527
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	987
Water supply pipe ($)	1200
Total cost/house ($)	168402
Number of housing lots	12210
Total tract development costs ('000 $)	2056181
Estimated total tract value ('000 $)	2341752
Assessed value	
Predevelopment assessed use value ('000 $)	1078
Use value assessment of open space ('000 $)	44
Net change in use value assessment ('000 $)	-1033
Market value assessment ('000 $)	2341752
Net change in assessed property value ('000 $)	2340674
Tax revenue ('000$)	26450
Education costs (excl. trans.) ('000 $)	16616
Education busing costs ('000 $)	125
Total incr. education costs ('000 $)	16741
Ann. publ. sewer & water cost ('000 $)	2
Net change in local government costs ('000 $)	16743
Net change in revenue ('000 $)	
	9707
Number of new students	4997
Cost per student (local share) ($)	3325
Per student busing cost ($)	50

Table 4.21. Economic effects due to development scenario V

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.395	High Integrity	Low Integrity
2	0.588	0.398	High Integrity	Low Integrity
3	0.579	0.422	High Integrity	Mid Integrity
4	0.566	0.427	Mid Integrity	Mid Integrity
5	0.519	0.434	Mid Integrity	Mid Integrity
6	0.523	0.44	Mid Integrity	Mid Integrity
7	0.525	0.445	Mid Integrity	Mid Integrity
8	0.517	0.448	Mid Integrity	Mid Integrity
9	0.517	0.451	Mid Integrity	Mid Integrity
10	0.514	0.454	Mid Integrity	Mid Integrity

Table 4.22. Effects on fish habitat due to development scenario V

<u>Case VI: Medium Density Cluster Development</u>

Figure 4.6 shows the upstream sub watersheds developed with a medium density cluster pattern. The comparative land uses distribution before and after development in the watershed is given in Table 4.23. Tables 4.24 through 4.26 show hydrologic effects, economic effects, and effects on fish habitat due to land use change respectively.

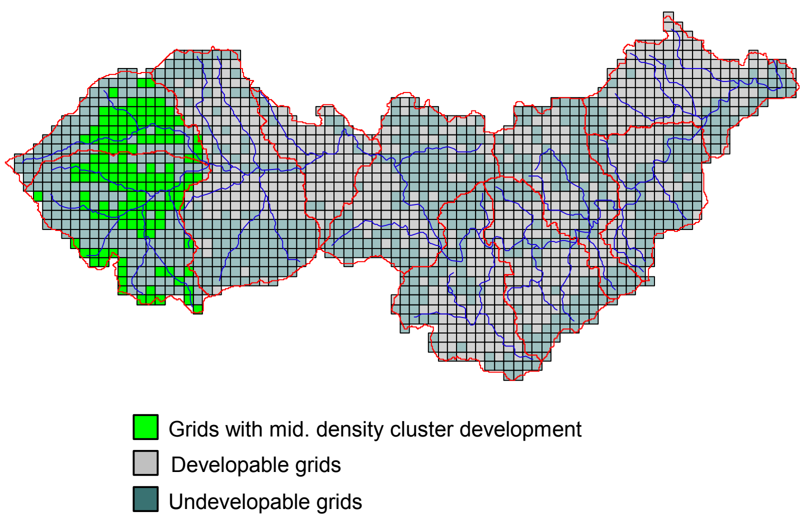


Figure 4.6. Medium density cluster development in the headwater (Development Scenario VI)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1455	2673	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	585	1112	495	210	243	203	134	196	260	837
MIXED	109	319	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	296	524	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.23. Change in land use due to development scenario VI (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	22.26	20.38								
% Change in 10-year Storm Peak	17.01	15.35								
Average % Change in 2-5 Year Storm Peaks	288.55	236.1								
Average % Change in <1 Year Storm Peaks	388	361.25								
% Change in Total Groundwater Recharge	-15.28	-13.72								
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	22.25	20.38	10.36	8.62	6.14	5.02	4.34	3.9	3.64	3.3
% Change in 10-year Storm Peak	20.31	18.22	15.1	17.85	16.54	15.52	14.32	10.74	10.22	7.44
Average % Change in 2-5 Year Storm Peaks	177.37	139.88	33.75	23.88	19.48	10.97	11.92	12.94	14.31	11.6
Average % Change in <1 Year Storm Peaks	383.93	359.34	124.94	87.34	63.28	53.64	59.36	53.85	56.74	52.69
% Change in Total Groundwater Recharge	-15.28	-14.26	-7.21	-6.22	-4.69	-3.88	-3.38	-3.02	-2.79	-2.54

Table 4.24. Hydrologic effects due to development scenario VI

Economic Impacts (Develop: Mid. Density Cluster)	Values
Total Area Developed (acre)	2992
Total area in housing lots (acre)	1416
Total land in public open space (acre)	1347
Total area in new roads, infrastructure & open space (acre)	1576
Assessed open space value ('000 $)	485
Total residential land value ('000 $)	165236
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	808
Water supply pipe ($)	1200
Total cost/house ($)	168223
Number of housing lots	7023
Total tract development costs ('000 $)	1182658
Estimated total tract value ('000 $)	1348379
Assessed value	
Predevelopment assessed use value ('000 $)	1078
Use value assessment of open space ('000 $)	485
Net change in use value assessment ('000 $)	-593
Market value assessment ('000 $)	1348379
Net change in assessed property value ('000 $)	1347301
Tax revenue ('000$)	15225
Education costs (excl. trans.) ('000 $)	9551
Education busing costs ('000 $)	108
Total incr. education costs ('000 $)	9659
Ann. publ. sewer & water cost ('000 $)	1
Net change in local government costs ('000 $)	9660
Net change in revenue ('000 $)	
	5564
Number of new students	2873
Cost per student (local share) ($)	3325
Per student busing cost ($)	75

Table 4.25. Economic effects due to development scenario VI

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.406	High Integrity	Mid Integrity
2	0.588	0.409	High Integrity	Mid Integrity
3	0.579	0.432	High Integrity	Mid Integrity
4	0.566	0.437	Mid Integrity	Mid Integrity
5	0.519	0.443	Mid Integrity	Mid Integrity
6	0.523	0.45	Mid Integrity	Mid Integrity
7	0.525	0.454	Mid Integrity	Mid Integrity
8	0.517	0.457	Mid Integrity	Mid Integrity
9	0.517	0.46	Mid Integrity	Mid Integrity
10	0.514	0.462	Mid Integrity	Mid Integrity

Table 4.26. Effects on fish habitat due development scenario VI

Case VII: Medium Density Conventional Development

Figure 4.8 shows the upstream sub watersheds developed with a medium density conventional pattern at the headwater portion of the watershed. Table 4.27 shows the comparative land use distribution before and after development. Hydrologic effects, effects on economic parameters, and effects on fish habitat due to land use change respectively are summarized in Tables 4.28 through 4.30.

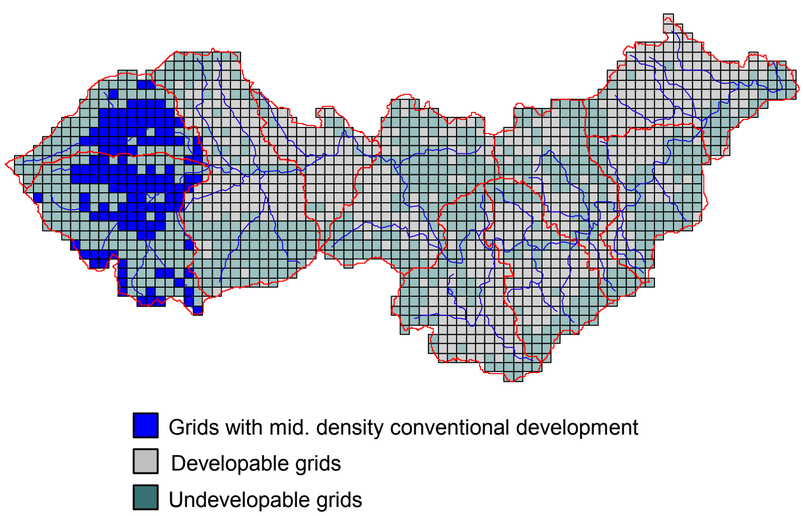


Figure 4.7. Medium density conventional development in the headwater (Development Scenario VII)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1629	2915	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	447	904	495	210	243	203	134	196	260	837
MIXED	149	420	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	220	390	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.27. Change in land use due to development scenario VII (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	16.41	15.06								
% Change in 10-year Storm Peak	12.49	11.31								
Average % Change in 2-5 Year Storm Peaks	209.23	172.95								
Average % Change in <1 Year Storm Peaks	281.65	262.12								
% Change in Total Groundwater Recharge	-11.16	-10.03								
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	16.4	15.06	7.65	6.36	4.53	3.71	3.21	2.88	2.69	2.43
% Change in 10-year Storm Peak	14.99	13.38	11.21	13.22	12.03	11.16	10.65	7.92	7.57	5.5
Average % Change in 2-5 Year Storm Peaks	126.32	99.15	21.8	17.94	14.04	8.34	8.93	9.61	10.13	8.61
Average % Change in <1 Year Storm Peaks	280.45	263.68	88.93	61.69	46.37	40.59	43.63	37.38	41.67	39.46
% Change in Total Groundwater Recharge	-11.16	-10.42	-5.27	-4.54	-3.42	-2.83	-2.47	-2.21	-2.04	-1.85

Table 4.28. Hydrologic effects due to development scenario VII

Economic Impacts (Development: Mid. Density Conventional)	Values
Total Area Developed (acre)	2992
Total area in housing lots (acre)	1947
Total land in public open space (acre)	688
Total area in new roads, infrastructure & open space (acre)	1045
Assessed open space value ('000 $)	248
Total residential land value ('000 $)	195428
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	3803
Sidewalk ($)	806
Storm drain pipe ($)	1347
Water supply pipe ($)	1467
Total cost/house ($)	170274
Number of housing lots	7023
Total tract development costs ('000 $)	1182658
Estimated total tract value ('000 $)	1378334
Assessed value	
Predevelopment assessed use value ('000 $)	1078
Use value assessment of open space ('000 $)	248
Net change in use value assessment ('000 $)	-830
Market value assessment ('000 $)	1378334
Net change in assessed property value ('000 $)	1377256
Tax revenue ('000$)	15563
Education costs (excl. trans.) ('000 $)	9551
Education busing costs ('000 $)	144
Total incr. education costs ('000 $)	9695
Ann. publ. sewer & water cost ('000 $)	1
Net change in local government costs ('000 $)	9696
Net change in revenue ('000 $)	
	5867
Number of new students	2873
Cost per student (local share) ($)	3325
Per student busing cost ($)	100

Table 4.29. Economic effects due to development scenario VII

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.419	High Integrity	Mid Integrity
2	0.588	0.422	High Integrity	Mid Integrity
3	0.579	0.445	High Integrity	Mid Integrity
4	0.566	0.449	Mid Integrity	Mid Integrity
5	0.519	0.453	Mid Integrity	Mid Integrity
6	0.523	0.46	Mid Integrity	Mid Integrity
7	0.525	0.464	Mid Integrity	Mid Integrity
8	0.517	0.466	Mid Integrity	Mid Integrity
9	0.517	0.469	Mid Integrity	Mid Integrity
10	0.514	0.471	Mid Integrity	Mid Integrity

Table 4.30. Effects on fish habitat due to development scenario VII

Case VIII: Low Density Development

Figure 4.8 shows the upstream sub watersheds developed with a low density residential pattern. The comparative land use distribution before and after development is summarized in Table 4.31. Tables 4.32 through 4.34 show effects on hydrologic, economic, and fish health parameters due to the development respectively.

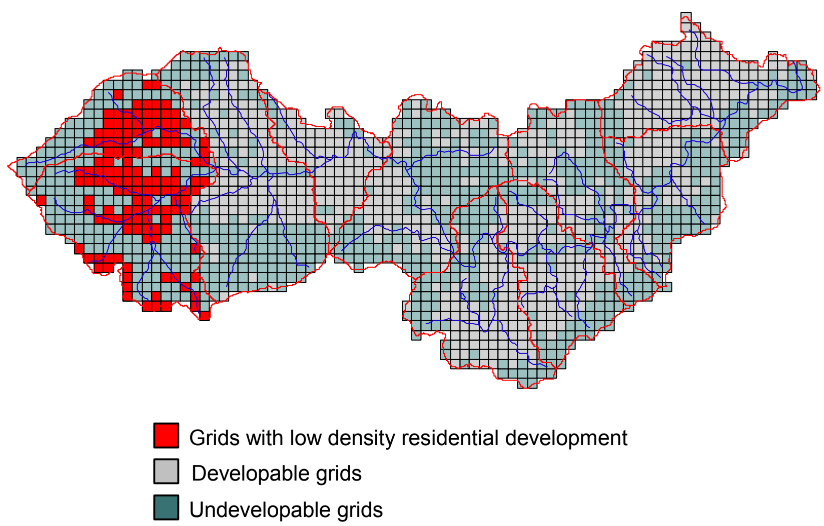


Figure 4.8. Low density development in the headwater (Development Scenario VIII)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	1866	3244	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	265	628	495	210	243	203	134	196	260	837
MIXED	202	557	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	112	199	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.31. Change in land use due to development scenario VIII (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume	8.13	7.45								
% Change in 10-year Storm Peak	6.14	5.54								
Average % Change in 2-5 Year Storm Peaks	98.54	84.13								
Average % Change in <1 Year Storm Peaks	130.73	121.21								
% Change in Total Groundwater Recharge	-5.41	-4.89								
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume	8.13	7.45	3.79	3.15	2.24	1.83	1.59	1.43	1.33	1.21
% Change in 10-year Storm Peak	7.54	6.53	5.54	6.58	5.49	5	5.3	3.96	3.77	2.74
Average % Change in 2-5 Year Storm Peaks	60.55	48.63	6.95	9.07	6.18	4.21	4.45	4.69	4.16	4.2
Average % Change in <1 Year Storm Peaks	135.07	128.13	40.72	27.43	22.25	21.09	20.4	19.27	19.11	20.45
% Change in Total Groundwater Recharge	-5.41	-5.07	-2.56	-2.21	-1.66	-1.38	-1.2	-1.07	-0.99	-0.9

Table 4.32. Hydrologic effects due to development scenario VIII

Economic Impacts (Development: Low Density)	Values
Total Area Developed (acre)	2992
Total area in housing lots (acre)	2747
Total land in public open space (acre)	0
Total area in new roads, infrastructure & open space (acre)	245
Assessed open space value ('000 $)	0
Total residential land value ('000 $)	109399
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	4563
Sidewalk ($)	968
Storm drain pipe ($)	598
Water supply pipe ($)	0
Total cost/house ($)	173950
Number of housing lots	992
Total tract development costs ('000 $)	167067
Estimated total tract value ('000 $)	276466
Assessed value	
Predevelopment assessed use value ('000 $)	1078
Use value assessment of open space ('000 $)	0
Net change in use value assessment ('000 $)	-1078
Market value assessment ('000 $)	276466
Net change in assessed property value ('000 $)	275389
Tax revenue ('000$)	3112
Education costs (excl. trans.) ('000 $)	1393
Education busing costs ('000 $)	42
Total incr. education costs ('000 $)	1435
Ann. publ. sewer & water cost ('000 $)	0
Net change in local government costs ('000 $)	1435
Net change in revenue ('000 $)	
	1677
Number of new students	419
Cost per student (local share) ($)	3325
Per student busing cost ($)	200

Table 4.33. Economic effects due to development scenario VIII

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
1	0.586	0.447	High Integrity	Mid Integrity
2	0.588	0.450	High Integrity	Mid Integrity
3	0.579	0.472	High Integrity	Mid Integrity
4	0.566	0.476	Mid Integrity	Mid Integrity
5	0.519	0.475	Mid Integrity	Mid Integrity
6	0.523	0.481	Mid Integrity	Mid Integrity
7	0.525	0.485	Mid Integrity	Mid Integrity
8	0.517	0.484	Mid Integrity	Mid Integrity
9	0.517	0.487	Mid Integrity	Mid Integrity
10	0.514	0.487	Mid Integrity	Mid Integrity

Table 4.34. Effects on fish habitat due to development scenario VIII

4.3 Outlet developed

Development scenarios covering all the developable grids in the most downstream sub watershed (land segment 10) are created using a high density residential pattern, a medium density cluster pattern, a medium density conventional pattern, and a low density pattern respectively. Each of these development scenarios covers 2375 acres of developable land with land use distribution prior to development as shown in Table 4.35.

LANDSEG	FOREST	HERBAG	MIXED	TOTAL
10	797.44	783.66	793.66	2374.77

Table 4.35. Development Scenario Land Use when outlet is developed (area in acres)

Case IX: High Density Development

Figure 4.9 shows the watershed development scenario with high density residential pattern at land segment 10 at the outlet of the watershed. Table 4.36 shows the comparative land use distribution before and after development in the watershed. Tables 4.37 through 4.39 show effects on hydrology, economic parameters, and fish habitat due to land use change respectively.

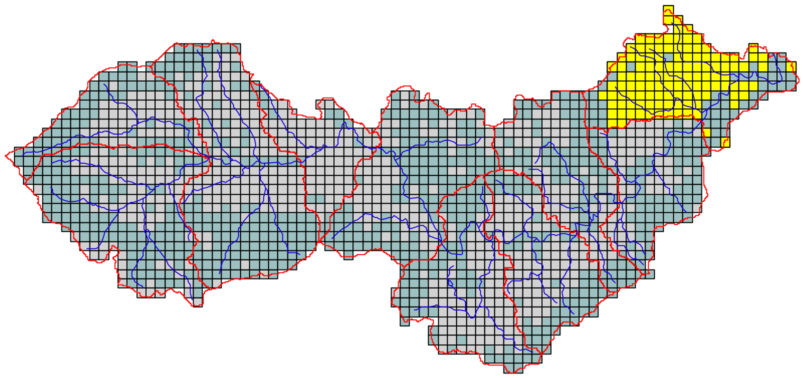


Figure 4.9. High density development at the outlet (Development Scenario IX)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	823
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	1517
MIXED	247	672	711	372	738	504	497	451	363	204
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	888
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.36. Change in land use due to development scenario IX (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume										35.72
% Change in 10-year Storm Peak										13.92
Average % Change in 2-5 Year Storm Peaks										79
Average % Change in <1 Year Storm Peaks										561.73
% Change in Total Groundwater Recharge										-25.89
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume										3.34
% Change in 10-year Storm Peak										2.98
Average % Change in 2-5 Year Storm Peaks										4.59
Average % Change in <1 Year Storm Peaks										16.28
% Change in Total Groundwater Recharge										-2.37

Table 4.37. Hydrologic effects due to development scenario IX

Economic Impacts (Development: High Density)	Values
Total Area Developed (acre)	2374
Total area in housing lots (acre)	1931
Total land in public open space (acre)	119
Total area in new roads, infrastructure & open space (acre)	443
Assessed open space value ('000 $)	35
Total residential land value ('000 $)	226571
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	987
Water supply pipe ($)	1200
Total cost/house ($)	168402
Number of housing lots	9689
Total tract development costs ('000 $)	1631617
Estimated total tract value ('000 $)	1858223
Assessed value	
Predevelopment assessed use value ('000 $)	855
Use value assessment of open space ('000 $)	35
Net change in use value assessment ('000 $)	-820
Market value assessment ('000 $)	1858223
Net change in assessed property value ('000 $)	1857368
Tax revenue ('000$)	20988
Education costs (excl. trans.) ('000 $)	13185
Education busing costs ('000 $)	99
Total incr. education costs ('000 $)	13284
Ann. publ. sewer & water cost ('000 $)	2
Net change in local government costs ('000 $)	13286
Net change in revenue ('000 $)	
	7703
Number of new students	3965
Cost per student (local share) ($)	3325
Per student busing cost ($)	50

Table 4.38. Economic effects due to development scenario IX

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
10	0.514	0.461	Mid Integrity	Mid Integrity

Table 4.39. Effects on fish habitat due to development scenario IX

Case X: Medium Density Cluster Development

Figure 4.10 shows the most downstream watershed developed with a medium density cluster pattern. The comparative land use distribution before and after development in the watershed is given in Table 4.40. Tables 4.41 through 4.43 show hydrologic, economic, and ecological impacts due to the development respectively.

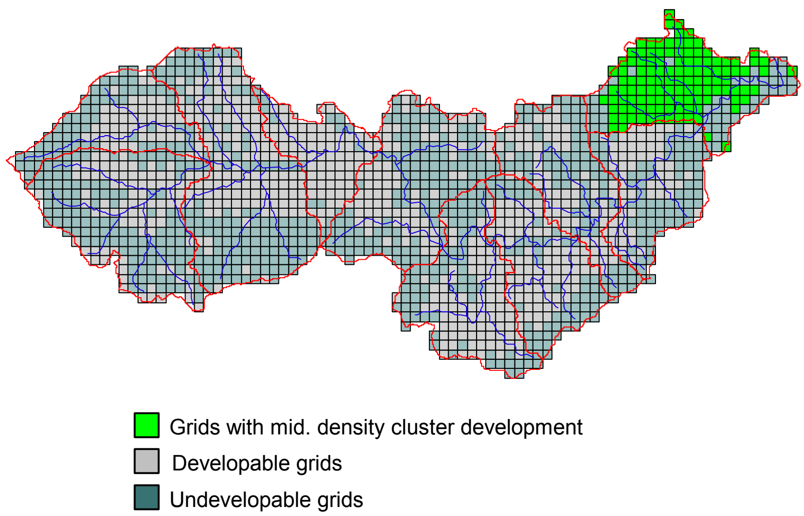


Figure 4.10. Medium density cluster development at the outlet (Development Scenario X)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
HERBACEOUS/AGR	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
MIXED	130	430	495	210	243	203	134	196	260	837
DISTURBED IMPERVIOUS	247	672	711	372	738	504	497	451	363	958
DISTURBED PERVIOUS	4	8	15	14	121	15	13	70	22	57
NEW LAND USE										
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	966
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	1421
MIXED	247	672	711	372	738	504	497	451	363	347
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	698
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.40. Change in land use due to development scenario X (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume										27.64
% Change in 10-year Storm Peak										10.91
Average % Change in 2-5 Year Storm Peaks										62.02
Average % Change in <1 Year Storm Peaks										434.14
% Change in Total Groundwater Recharge										-20.2
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume										2.59
% Change in 10-year Storm Peak										2.48
Average % Change in 2-5 Year Storm Peaks										3.54
Average % Change in <1 Year Storm Peaks										7.23
% Change in Total Groundwater Recharge										-1.85

Table 4.41. Hydrologic effects due to development scenario X

Economic Impacts (Development: Mid. Density Cluster)	Values
Total Area Developed (acre)	2374
Total area in housing lots (acre)	1124
Total land in public open space (acre)	1069
Total area in new roads, infrastructure & open space (acre)	1250
Assessed open space value ('000 $)	385
Total residential land value ('000 $)	131118
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	2855
Sidewalk ($)	660
Storm drain pipe ($)	808
Water supply pipe ($)	1200
Total cost/house ($)	168223
Number of housing lots	5573
Total tract development costs ('000 $)	938461
Estimated total tract value ('000 $)	1069963
Assessed value	
Predevelopment assessed use value ('000 $)	855
Use value assessment of open space ('000 $)	385
Net change in use value assessment ('000 $)	-470
Market value assessment ('000 $)	1069963
Net change in assessed property value ('000 $)	1069108
Tax revenue ('000$)	12081
Education costs (excl. trans.) ('000 $)	7579
Education busing costs ('000 $)	85
Total incr. education costs ('000 $)	7665
Ann. publ. sewer & water cost ('000 $)	1
Net change in local government costs ('000 $)	7666
Net change in revenue ('000 $)	
	4415
Number of new students	2279
Cost per student (local share) ($)	3325
Per student busing cost ($)	75

Table 4.42. Economic effects due to development scenario X

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
10	0.514	0.469	Mid Integrity	Mid Integrity

Table 4.43. Effects on fish habitat due to development scenario X

Case XI: Medium Density Conventional Development

The most downstream watershed development with a medium density conventional pattern at land segment 10 at the outlet of the watershed is shown in Figure 4.11. Table 4.44 shows the comparative land use distribution before and after development. Tables 4.45 through 4.47 show hydrologic effects, effects on economic parameters, and effects on fish habitat due to change in land use respectively.

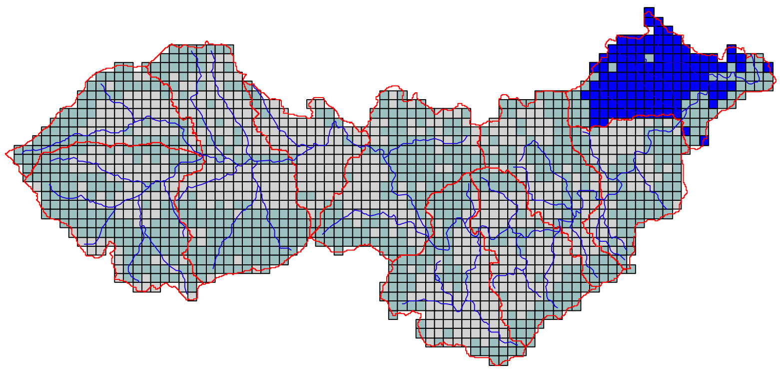


Figure 4.11. Medium density conventional development at the outlet (Development Scenario XI)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1142
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	1237
MIXED	247	672	711	372	738	504	497	451	363	522
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	532
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.44. Change in land use due to development scenario XI (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume										20.46
% Change in 10-year Storm Peak										8.01
Average % Change in 2-5 Year Storm Peaks										45.36
Average % Change in <1 Year Storm Peaks										321.25
% Change in Total Groundwater Recharge										-14.81
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume										1.91
% Change in 10-year Storm Peak										1.89
Average % Change in 2-5 Year Storm Peaks										2.61
Average % Change in <1 Year Storm Peaks										1.86
% Change in Total Groundwater Recharge										-1.36

Table 4.45. Hydrologic effects due to development scenario XI

Economic Impacts (Development: Mid. Density Conventional)	**Values**
Total Area Developed (acre)	2374
Total area in housing lots (acre)	1545
Total land in public open space (acre)	546
Total area in new roads, infrastructure & open space (acre)	829
Assessed open space value ('000 $)	197
Total residential land value ('000 $)	155076
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	3803
Sidewalk ($)	806
Storm drain pipe ($)	1347
Water supply pipe ($)	1467
Total cost/house ($)	170274
Number of housing lots	5573
Total tract development costs ('000 $)	938461
Estimated total tract value ('000 $)	1093733
Assessed value	
Predevelopment assessed use value ('000 $)	855
Use value assessment of open space ('000 $)	197
Net change in use value assessment ('000 $)	-659
Market value assessment ('000 $)	1093733
Net change in assessed property value ('000 $)	1092878
Tax revenue ('000$)	12350
Education costs (excl. trans.) ('000 $)	7579
Education busing costs ('000 $)	114
Total incr. education costs ('000 $)	7693
Ann. publ. sewer & water cost ('000 $)	1
Net change in local government costs ('000 $)	7694
Net change in revenue ('000 $)	
	4655
Number of new students	2279
Cost per student (local share) ($)	3325
Per student busing cost ($)	100

Table 4.46. Economic effects due to development scenario XI

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
10	0.514	0.477	Mid Integrity	Mid Integrity

Table 4.47. Effects on fish habitat due to development scenario XI

Case XII: Low Density Development

Figure 4.12 shows the most downstream watershed developed with a low density residential pattern. Table 4.48 shows the comparative land use distribution before and after development in the watershed. Effects on and fish health parameters due to the change in land use are given in tables 4.49 through 4.51 respectively.

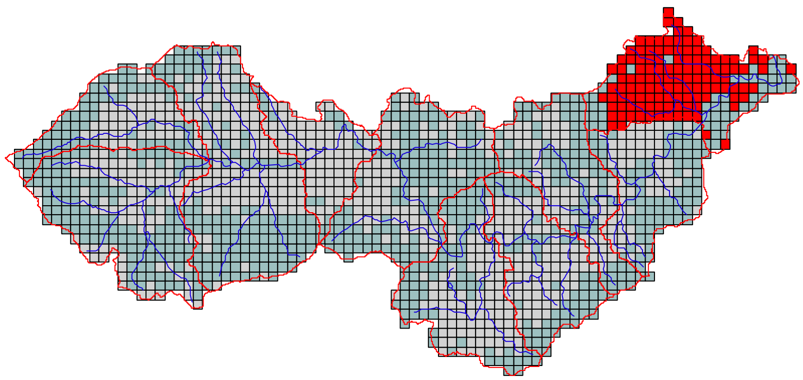


Figure 4.12. Low density development at the outlet (Development Scenario XII)

	LAND SEGMENT									
BASE LAND USE	1	2	3	4	5	6	7	8	9	10
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1580
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	837
MIXED	247	672	711	372	738	504	497	451	363	958
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	57
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
NEW LAND USE										
FOREST	2064	3519	4419	1244	2728	2785	2359	2161	2205	1381
HERBACEOUS/AGR	130	430	495	210	243	203	134	196	260	997
MIXED	247	672	711	372	738	504	497	451	363	760
DISTURBED IMPERVIOUS	4	8	15	14	121	15	13	70	22	294
DISTURBED PERVIOUS	21	38	71	70	592	71	63	343	106	278
TOTAL	2466	4666	5710	1911	4422	3577	3066	3222	2955	3711

Table 4.48. Change in land use due to development scenario XII (area in acres)

	LAND SEGMENT/REACH									
LOCAL EFFECTS	1	2	3	4	5	6	7	8	9	10
% Change in Total Runoff Volume										10.14
% Change in 10-year Storm Peak										3.88
Average % Change in 2-5 Year Storm Peaks										21.88
Average % Change in <1 Year Storm Peaks										159.72
% Change in Total Groundwater Recharge										-7.26
CUMULATIVE WATERSHED EFFECTS										
% Change in Total Runoff Volume										0.95
% Change in 10-year Storm Peak										0.92
Average % Change in 2-5 Year Storm Peaks										1.28
Average % Change in <1 Year Storm Peaks										0.29
% Change in Total Groundwater Recharge										-0.66

Table 4.49. Hydrologic effects due to development scenario XII

Economic Impacts (Development: Low Density)	Values
Total Area Developed (acre)	2374
Total area in housing lots (acre)	2180
Total land in public open space (acre)	0
Total area in new roads, infrastructure & open space (acre)	194
Assessed open space value ('000 $)	0
Total residential land value ('000 $)	86810
Development cost/house	
Homebuilding ($)	161201
Water service ($)	821
Road ($)	4563
Sidewalk ($)	968
Storm drain pipe ($)	598
Water supply pipe ($)	0
Total cost/house ($)	173950
Number of housing lots	787
Total tract development costs ('000 $)	132571
Estimated total tract value ('000 $)	219381
Assessed value	
Predevelopment assessed use value ('000 $)	855
Use value assessment of open space ('000 $)	0
Net change in use value assessment ('000 $)	-855
Market value assessment ('000 $)	219381
Net change in assessed property value ('000 $)	218526
Tax revenue ('000$)	2469
Education costs (excl. trans.) ('000 $)	1105
Education busing costs ('000 $)	33
Total incr. education costs ('000 $)	1139
Ann. publ. sewer & water cost ('000 $)	0
Net change in local government costs ('000 $)	1139
Net change in revenue ('000 $)	
	1331
Number of new students	332
Cost per student (local share) ($)	3325
Per student busing cost ($)	200

Table 4.50. Economic effects due to development scenario XII

LAND SEGMENT	BASE MMS	NEW MMS	OLD STATUS	NEW STATUS
10	0.514	0.492	Mid Integrity	Mid Integrity

Table 4.51. Effects on fish habitat due to development scenario XII

4.4 Analysis of Case Studies

A comparative analysis of the results from above sets of case studies is performed and graphs are generated to show relationships of the impacts related to hydrologic, economic and fish health modeling with the development types. These graphs are generated merely to show the overall pattern of change in watershed parameters due to change in development. A more rigorous analysis is needed to accurately represent the relationships among these parameters. All the graphs are obtained by post processing the WebL2W results.

Comparison of Cases I, II, III, and IV

With the results from cases I, II, III, and IV (entire watershed developed with high density residential, medium density cluster, medium density conventional, and low density residential tracts respectively), a set of graphs (Figures 4.13 - 4.15) has been generated to show the effects on watershed due to different types of development. Figure 4.13 shows the cumulative effects on hydrologic parameters at the outlet due to changing development types. Figure 4.14 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in development type from low density through high density. Figure 4.15 shows the relationship between the new MMS in fish habitats at land segments 1, 2, and 5 and the change in development type.

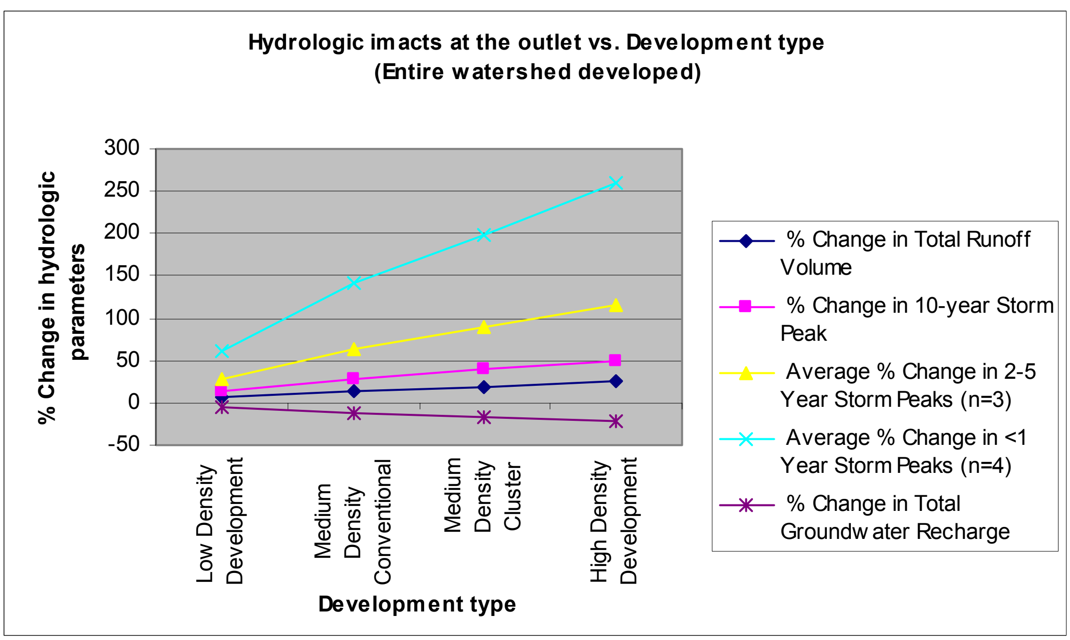


Figure 4.13. Relationship between the hydrologic parameters at the outlet and development types when entire watershed is developed.

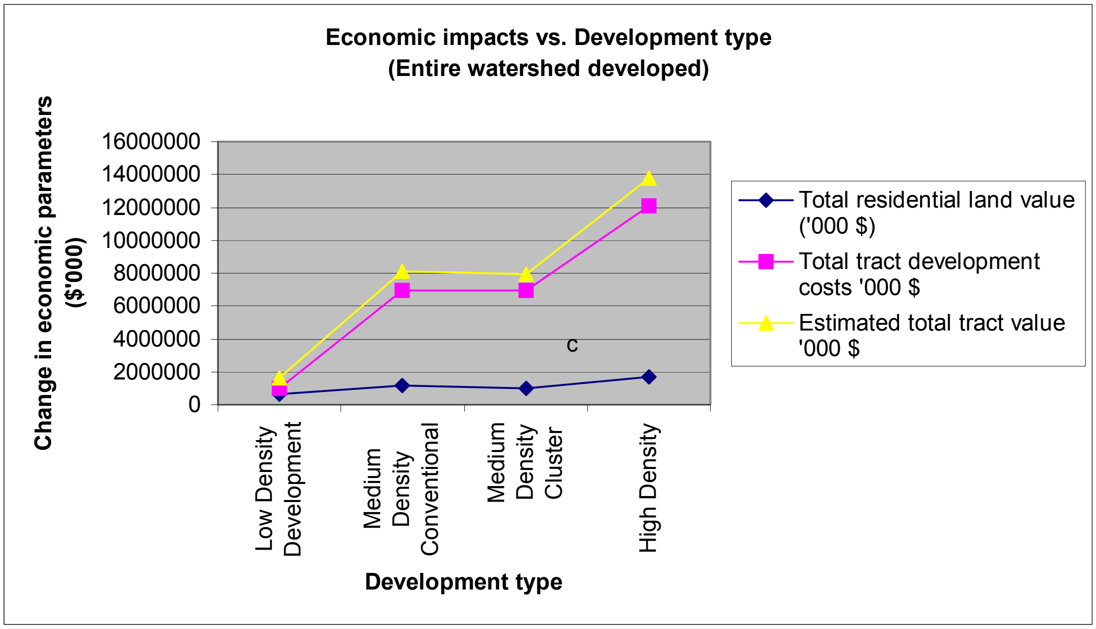


Figure 4.14. Relationship between economic parameters and development types when entire watershed is developed.

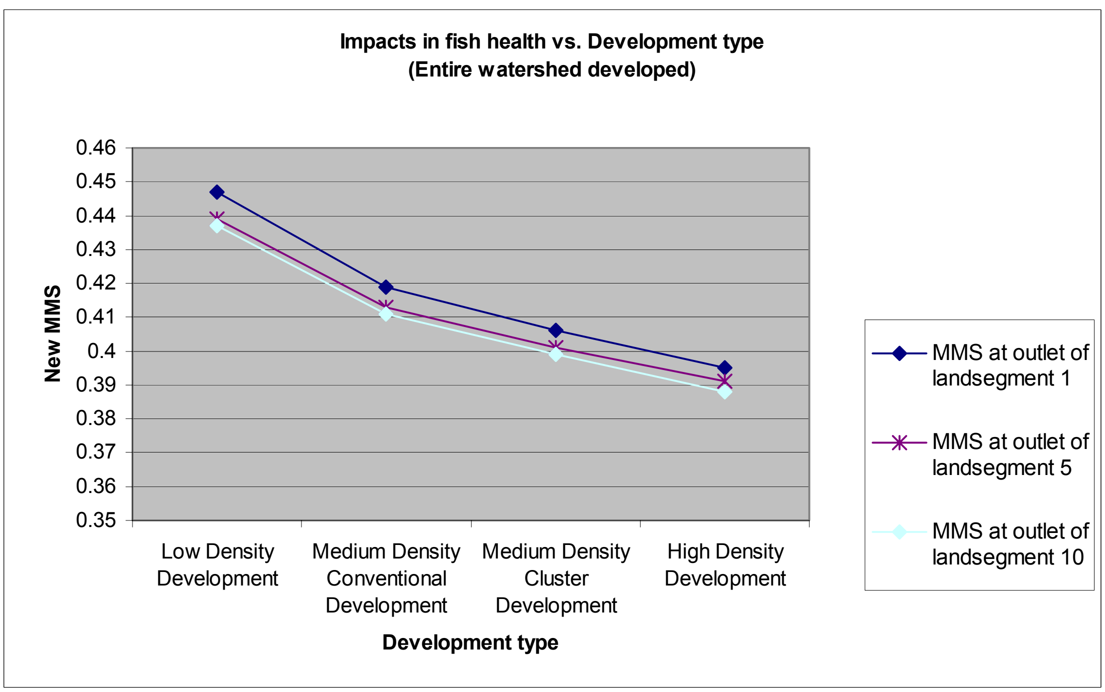


Figure 4.15. Relationship between change in MMS after development and development types when entire watershed is developed.

Comparison of Cases V, VI, VII, and VIII

With the results from cases V, VI, VII, and VIII (headwater portion of the watershed developed with high density residential, medium density cluster, medium density conventional, and low density residential tracts respectively), a set of graphs (Figures 4.16 – 4.18) have been generated to show how the hydrologic, economic, and fish health parameters varies with change in development pattern from low density residential through high density residential. Figure 4.16 shows how the changes in cumulative hydrologic effects at the outlet vary when development patterns are changed in the headwater portion of the watershed. Relationships between major economic parameters like land value, tract value, and tract development cost with development patterns is plotted in Figure 4.17. Figure 4.18 shows the relationship between the new MMS in fish habitats at land segments 1, 5, and 10 and the development types.

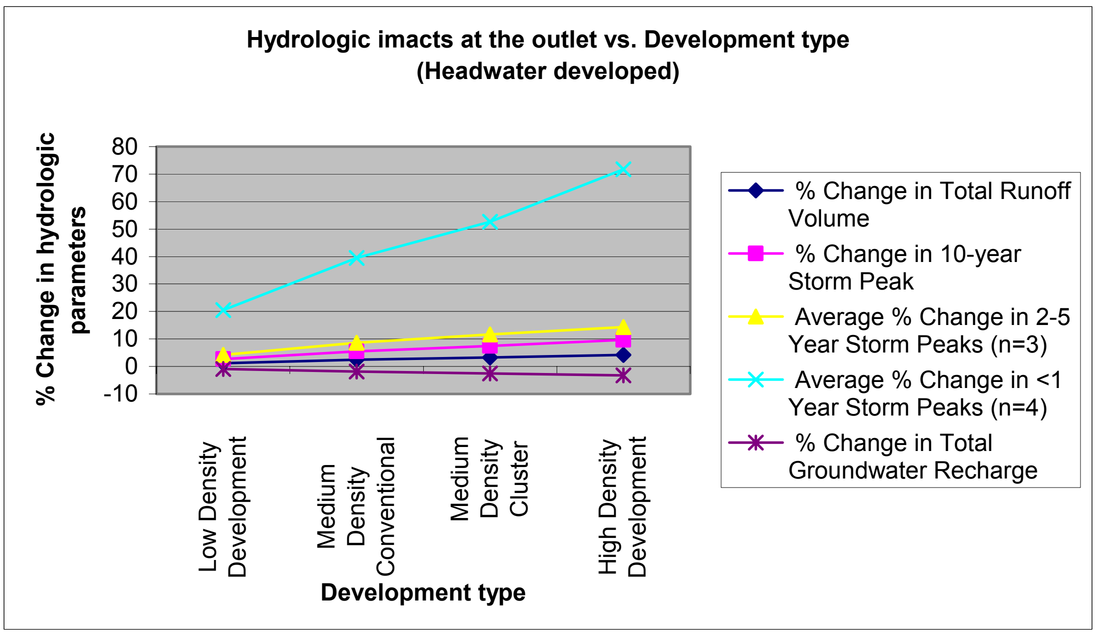


Figure 4.16. Relationship between the hydrologic parameters at the outlet and development types when headwater portion of the watershed is developed.

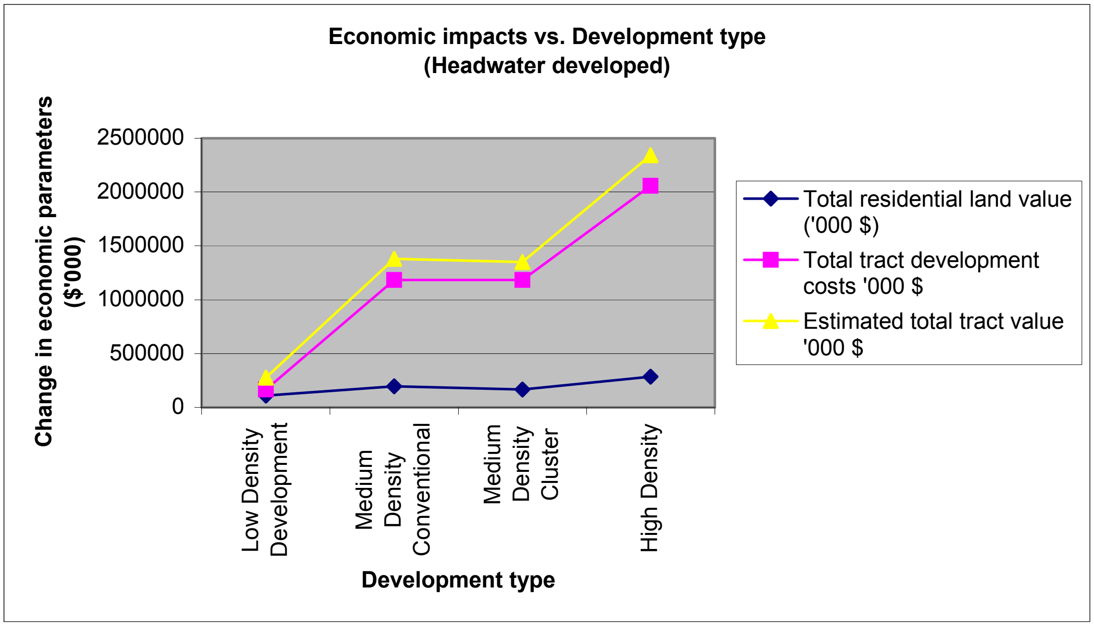


Figure 4.17. Relationship between economic parameters and development types when headwater portion of the watershed is developed.

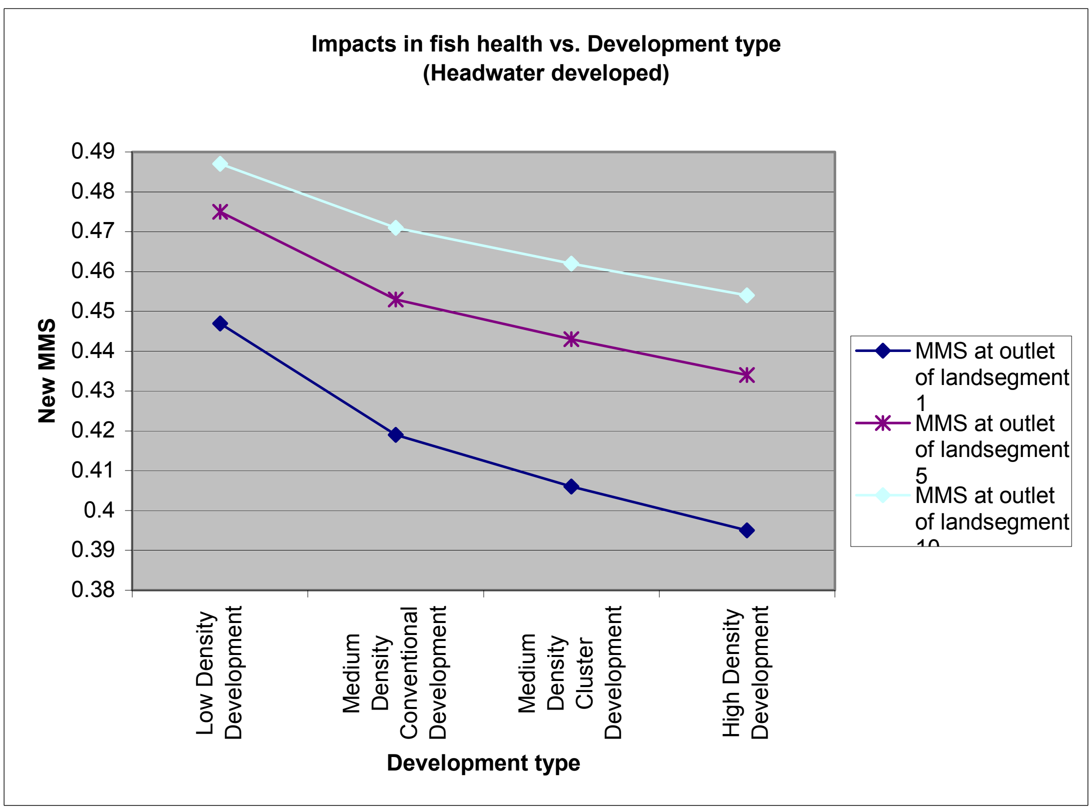


Figure 4.18. Relationship between change in MMS after development and development types when headwater portion of the watershed is developed.

Comparison of Cases IX, X, XI, and XII

With the results from cases IX, X, XI, and XII (outlet portion of the watershed developed with high density residential, medium density cluster, medium density conventional, and low density residential tracts respectively), a set of graphs (Figures 4.19 - 4.21) has been plotted to show how hydrologic, economic, and ecologic impacts change due to change in development pattern at the outlet of the watershed. Relationship between the changes in cumulative hydrologic parameters at the outlet with the change in development pattern is shown in Figure 4.19. Figure 4.20 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in development pattern near the outlet of the watershed. Relationship between the new MMS in the fish habitats at land segments 1, 5, and 10 and the change in development patterns near the outlet of the watershed is shown in Figure 4.21.

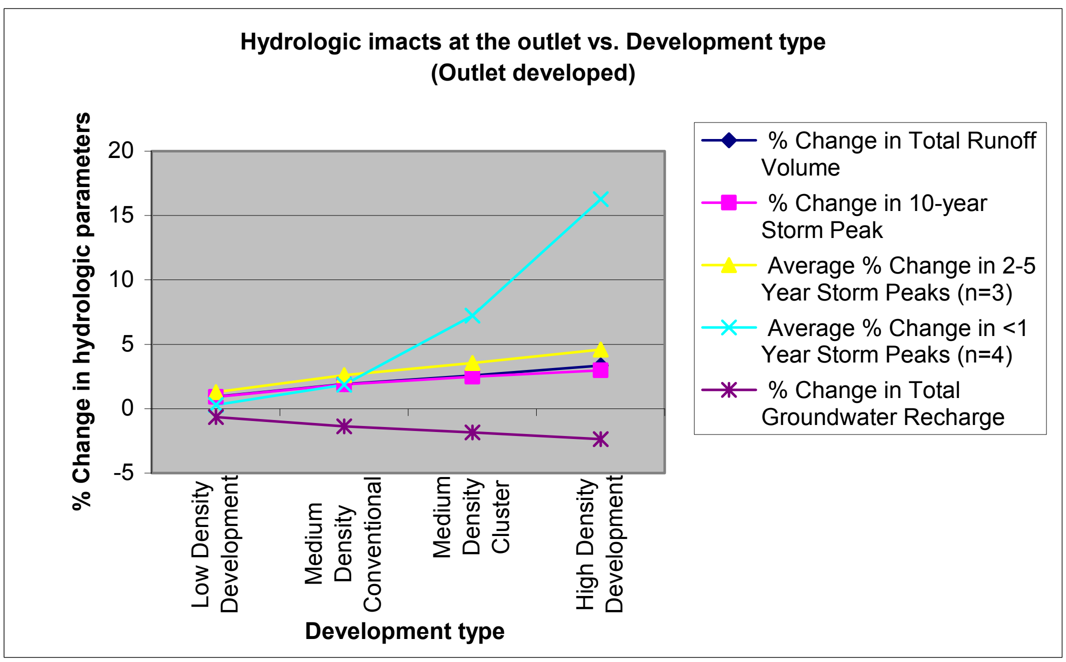


Figure 4.19. Relationship between the hydrologic parameters at the outlet and development types when outlet portion of the watershed is developed.

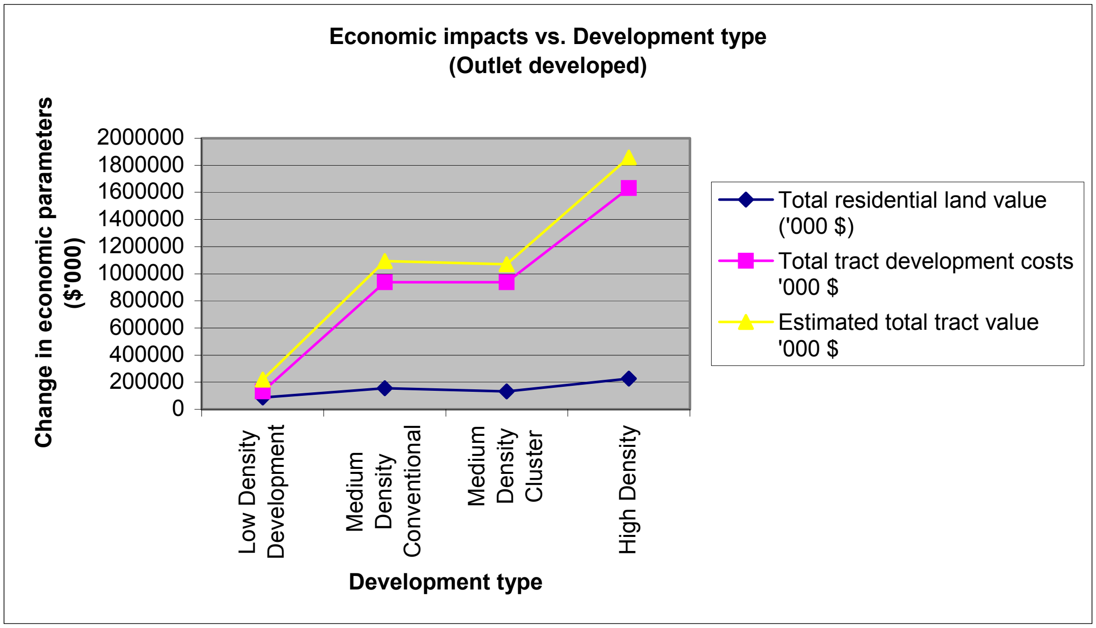


Figure 4.20. Relationship between economic parameters and development types when outlet portion of the watershed is developed.

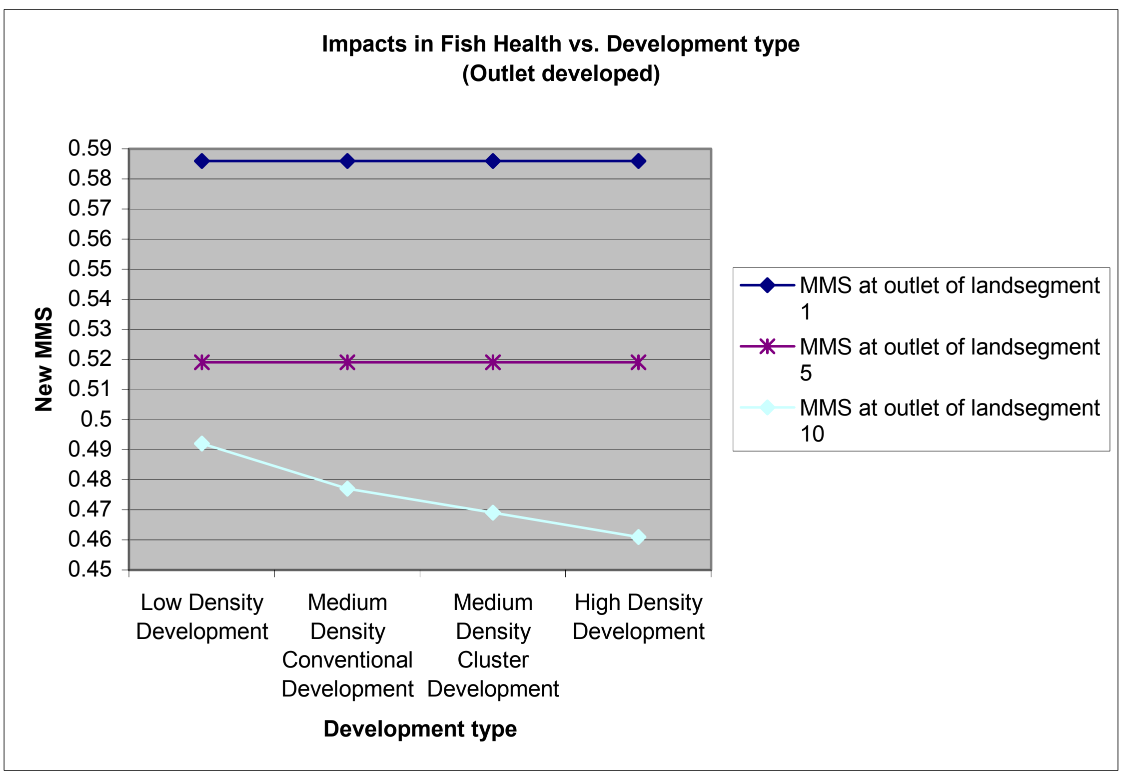


Figure 4.21. Relationship between change in MMS after development and development types when outlet portion of the watershed is developed.

Comparison of Cases I, V, and IX

With the results from cases I, V, and IX (high density residential development in the entire watershed, in the headwater, and in the outlet respectively), a set of graphs (Figures 4.22 - 4.24) has been generated to show the effects on watershed due to change in total developed area. Figure 4.22 shows the cumulative effects on hydrologic parameters at the outlet due to change in total developed area. Figure 4.23 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in total developed area. Figure 4.24 shows the relationship between the new MMS in fish habitats at land segments 1, 2, and 5 and the change in total developed area.

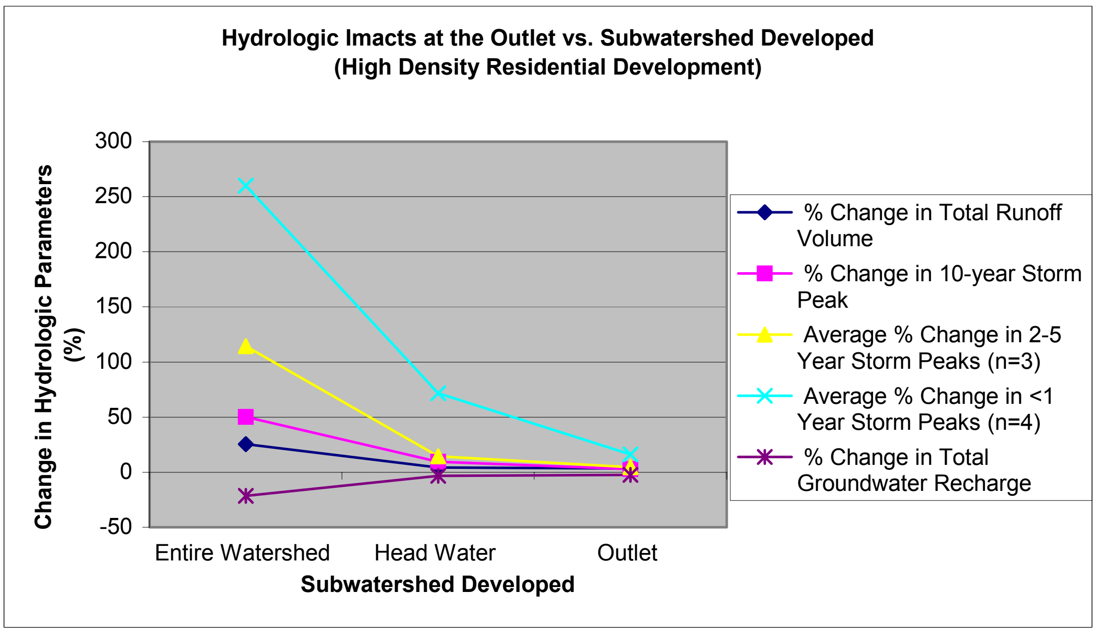


Figure 4.22. Relationship between the hydrologic parameters at the outlet and sub watershed area developed (High density development).

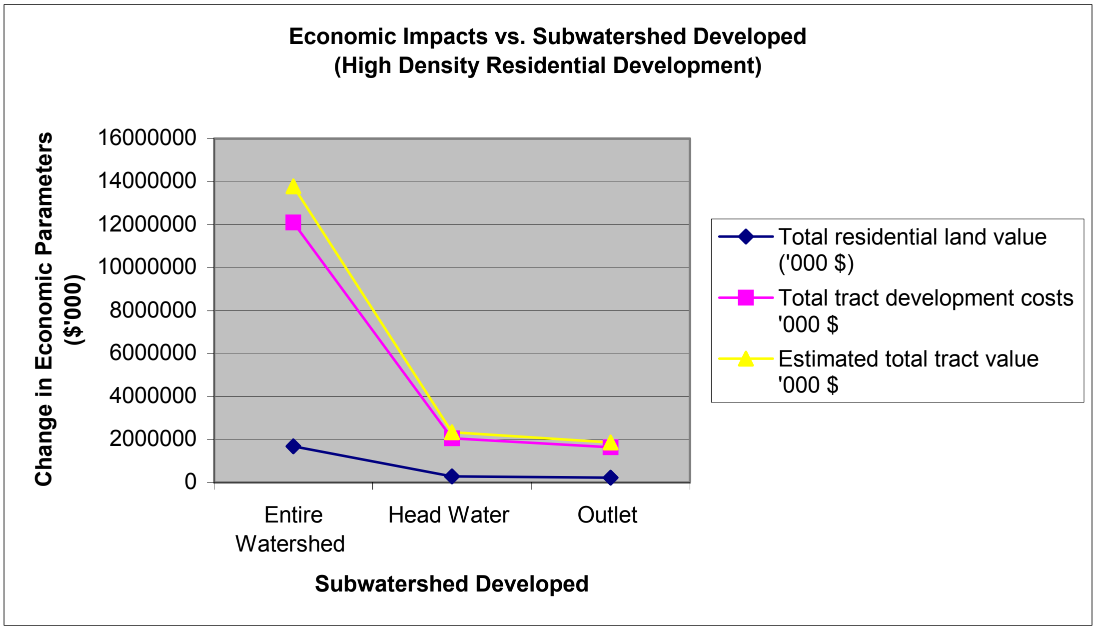


Figure 4.23. Relationship between the economic parameters and sub watershed area developed (High density development).

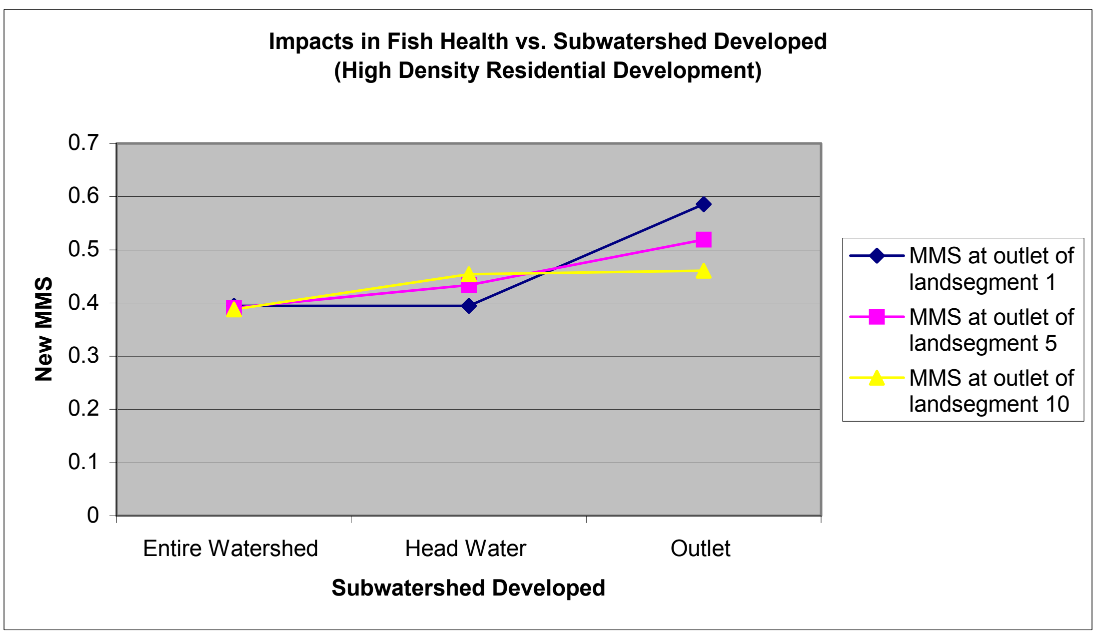


Figure 4.24. Relationship between change in MMS after development and sub watershed area developed (High density development).

Comparison of Cases II, VI, and X

With the results from cases II, VI, and X (medium density cluster development in the entire watershed, in the headwater, and in the outlet respectively), a set of graphs (Figures 4.25 - 4.27) has been generated to show the effects on watershed due to change in total developed area. Figure 4.25 shows the cumulative effects on hydrologic parameters at the outlet due to change in total developed area. Figure 4.26 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in total developed area. Figure 4.27 shows the relationship between the new MMS in fish habitats at land segments 1, 2, and 5 and the change in total developed area.

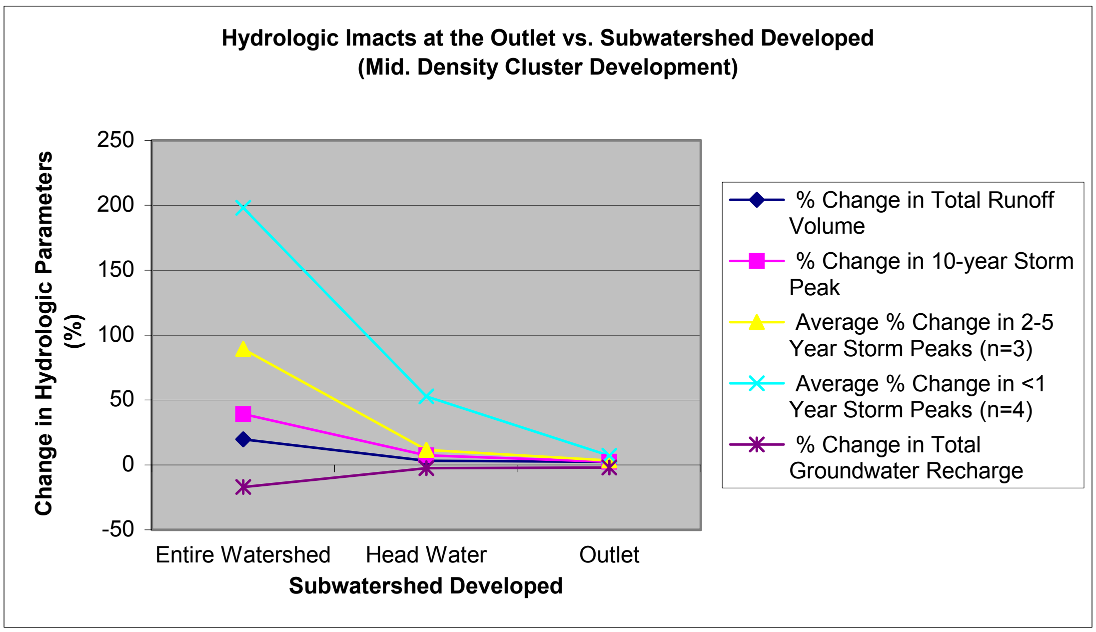


Figure 4.25. Relationship between the hydrologic parameters at the outlet and sub watershed area developed (Medium density cluster development).

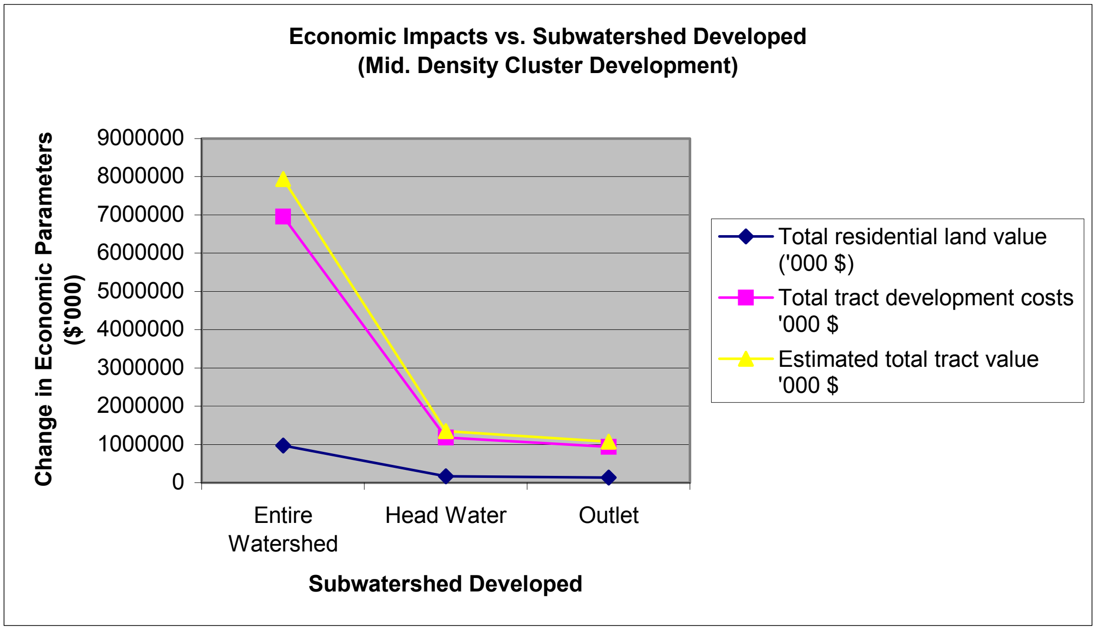


Figure 4.26. Relationship between the economic parameters and sub watershed area developed (Medium density cluster development).

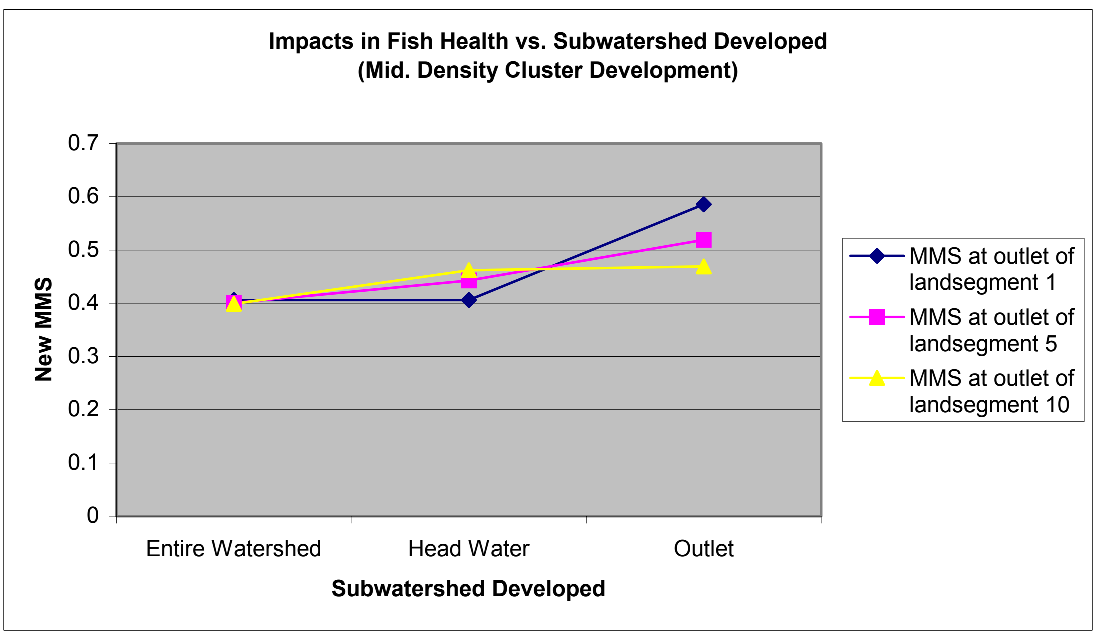


Figure 4.27. Relationship between change in MMS after development and sub watershed area developed (Medium density cluster development).

Comparison of Cases III, VII, and XI

With the results from cases III, VII, and XI (medium density conventional development in the entire watershed, in the headwater, and in the outlet respectively), a set of graphs (Figures 4.28 - 4.30) has been generated to show the effects on watershed due to change in total developed area. Figure 4.28 shows the cumulative effects on hydrologic parameters at the outlet due to change in total developed area. Figure 4.29 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in total developed area. Figure 4.30 shows the relationship between the new MMS in fish habitats at land segments 1, 2, and 5 and the change in total developed area.

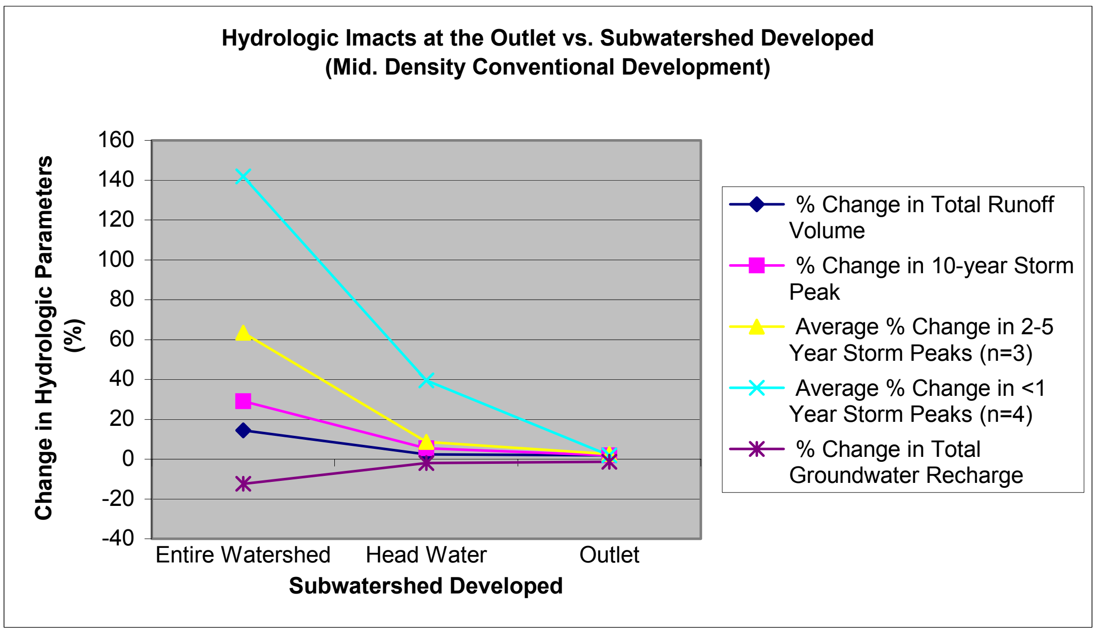


Figure 4.28. Relationship between the hydrologic parameters at the outlet and sub watershed area developed (Medium density conventional development).

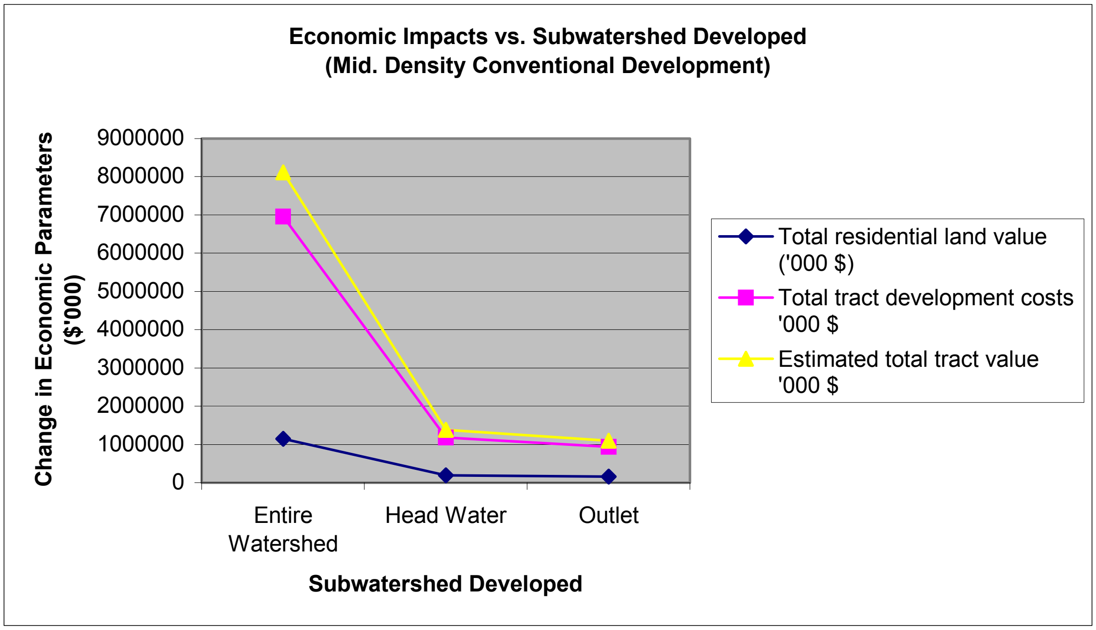


Figure 4.29. Relationship between the economic parameters and sub watershed area developed (Medium density conventional development).

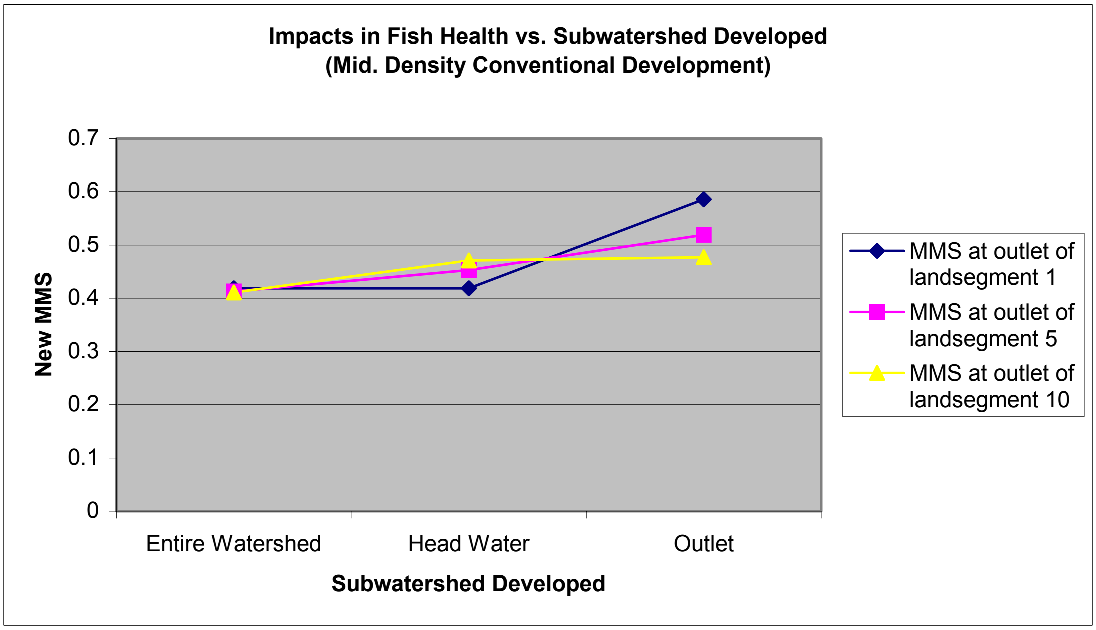


Figure 4.30. Relationship between change in MMS after development and sub watershed area developed (Medium density conventional development).

Comparison of Cases IV, VIII, and XII

With the results from cases IV, VIII, and XII (low density residential development in the entire watershed, in the headwater, and in the outlet respectively), a set of graphs (Figures 4.31 - 4.33) has been generated to show the effects on watershed due to change in total developed area. Figure 4.31 shows the cumulative effects on hydrologic parameters at the outlet due to change in total developed area. Figure 4.32 shows how the change in economic parameters like land value, tract value, and tract development cost vary due to change in total developed area. Figure 4.33 shows the relationship between the new MMS in fish habitats at land segments 1, 2, and 5 and the change in total developed area.

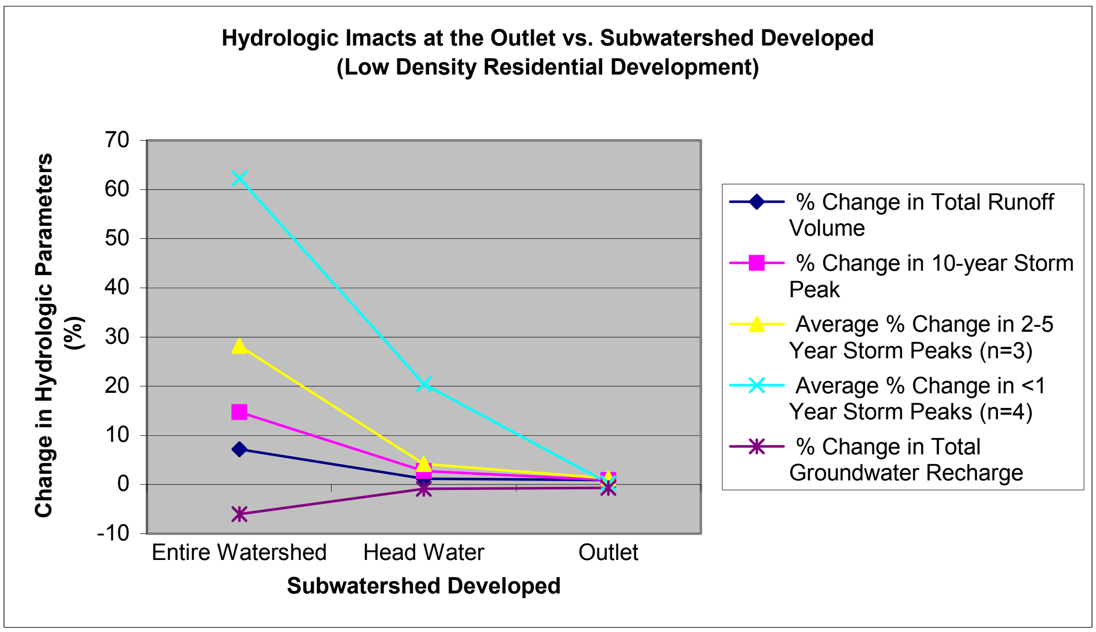


Figure 4.31. Relationship between the hydrologic parameters at the outlet and sub watershed area developed (Low density development).

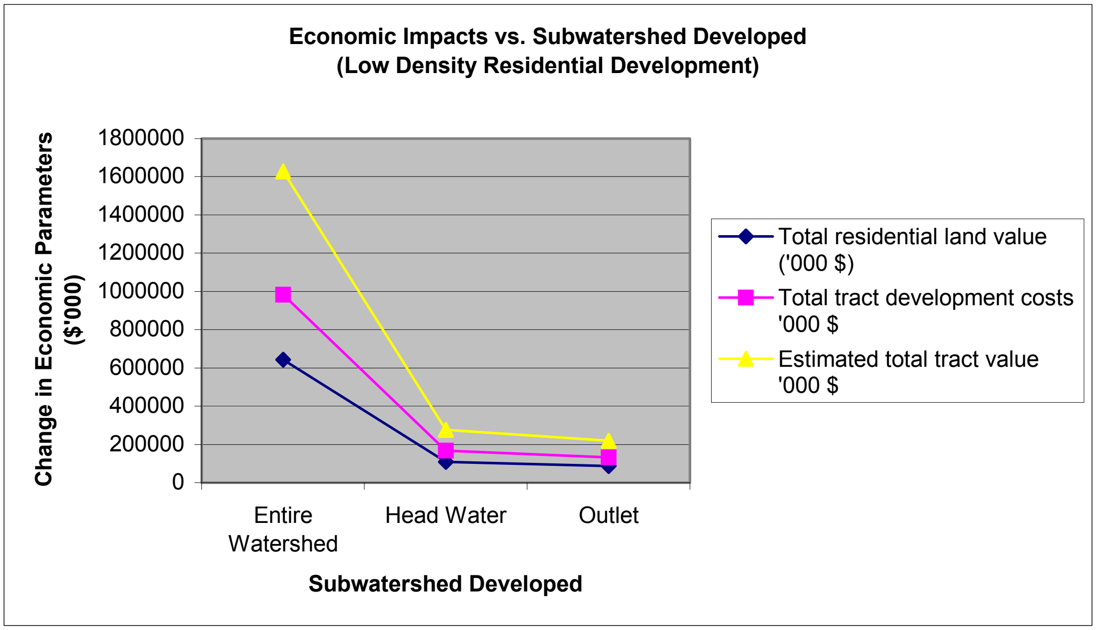


Figure 4.32. Relationship between the economic parameters and sub watershed area developed (Low density development).

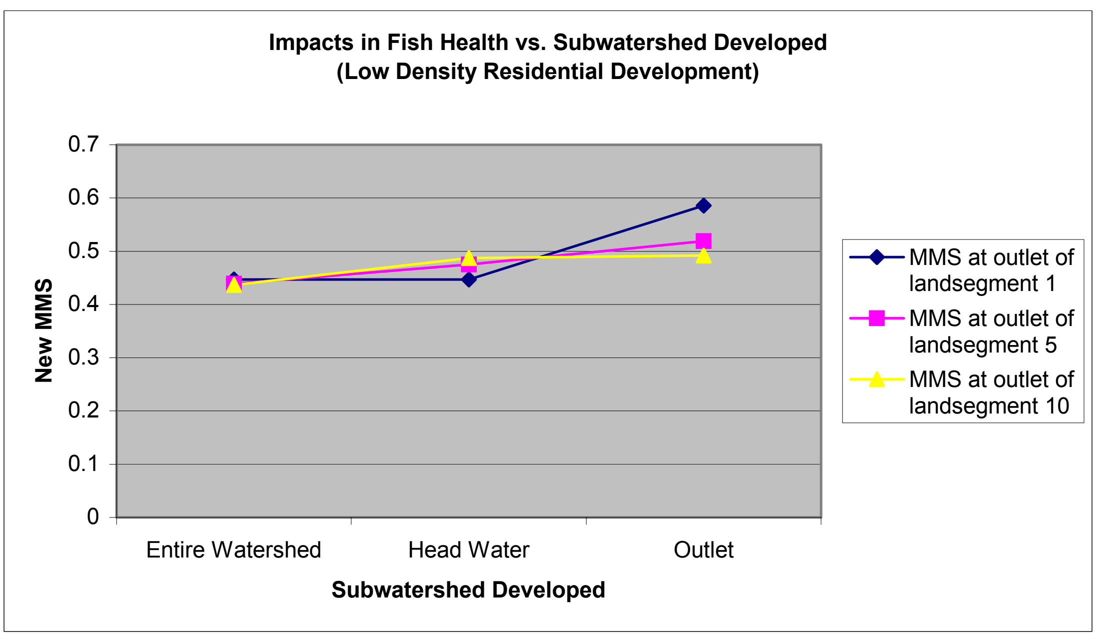


Figure 4.33. Relationship between change in MMS after development and sub watershed area developed (Low density development).

4.5 Software Testing

The hydrology module of WebL2W has been thoroughly tested running various sample scenarios in WebL2W as well as in Scenario Generator and DesktopL2W. Similarly, scenarios are run and tested independently in WebL2W and DesktopL2W for fish health module. The results for these modules have been compared satisfactorily. The economics module in WebL2W has been tested with the development scenario provided by the economics group of the EPA/NSF project. Additionally, a set of standard sample runs and a feedback form can be accessed from the WebL2W interface. Users can test the software using these sample scenarios and submit their comments in the feedback form.

5.0 DISCUSSION AND CONCLUSIONS

This chapter summarizes the contribution of this research, discusses limitations of WebL2W including future directions.

5.1 Contribution

A web-enabled SDSS for interdisciplinary watershed management, named WebL2W, is successfully developed and tested. Although there are some web-enabled hydrologic systems developed elsewhere (see section 2.5.2), none of these have the interdisciplinary potential comparable to WebL2W, which incorporates a relational database system, GIS support and visualization, thin client architecture, and multidisciplinary analytical models for hydrology, economics, and fish health into a single shell. It is web-based software that can be used in simulating the hydrologic, economic, and ecological consequences of land use change in Back Creek sub watershed in southwest Virginia.

Users of WebL2W can define development scenarios with four different types of predefined development pattern, once they access the user interface through web. These four types of develop patterns are i) low density residential, ii) medium density conventional, iii) medium density cluster, iv) high density residential. Once the scenario is defined, the user can select one or all three model(s) and then evaluate the scenario. All the computations works are done in the server and tabular reports from each of the simulations are displayed in the user's browser. An easy to use interface, a help file, and a set of standard scenario within the system make WebL2W usable to users from diverse background.

WebL2W can be used as a planning and decision making tool by watershed planners and managers. Figure 5.1 shows an example of result that can be derived from outputs generated by WebL2W. It shows how hydrologic, economic, and fish health related parameters get affected as a result of watershed development. It may be noted that the results obtained in Figure 5.1 are for a development scenario with high density development in the entire developable grids of Back Creek sub watershed.

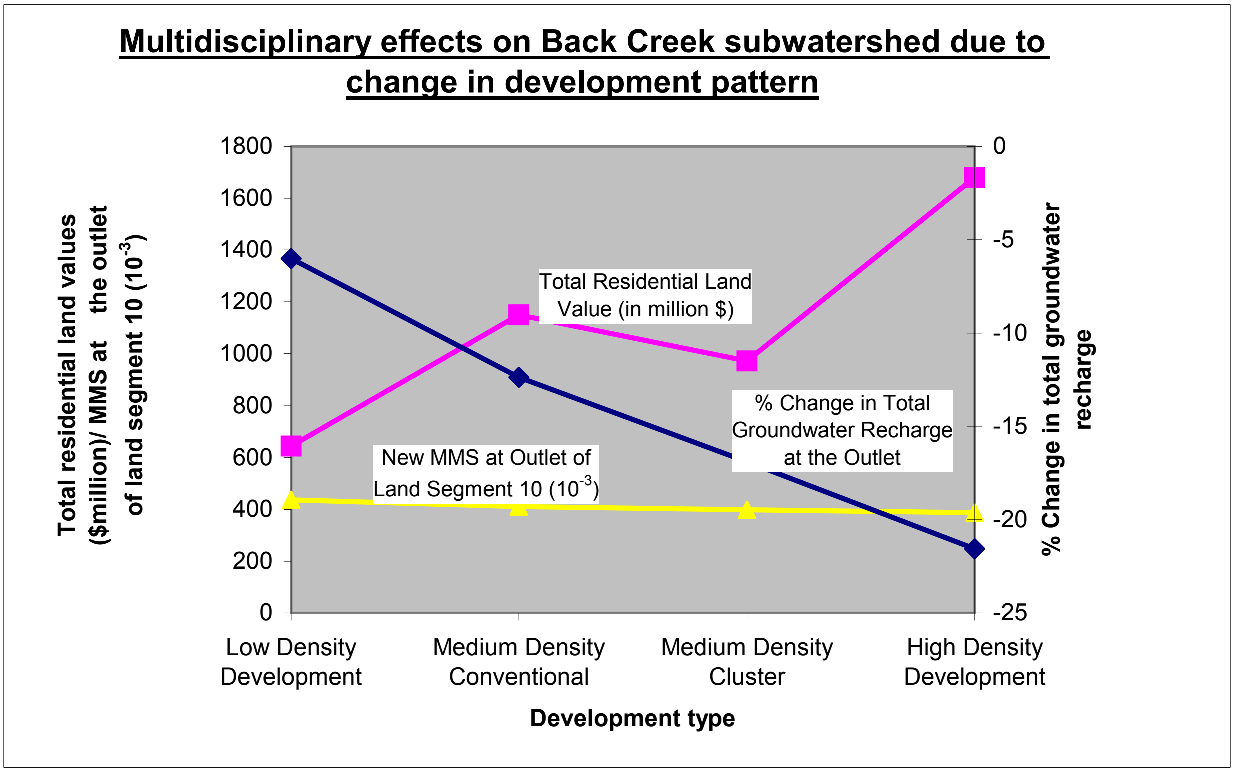


Figure 5.1. Multidisciplinary effects on Back Creek Sub watershed due to change in development pattern.

5.2 Limitations

The current version of WebL2W is site-specific software, which works only for Back Creek sub watershed in southwest Virginia. Some of the limitations of the current version of the software are given below.

The watershed model HSPF used in WebL2W was developed before the availability of new spatial technology and the internet. Integrating such a model into WebL2W poses many challenges. HSPF uses binary files as an input pass file and generates outputs as binary files also. Handling the huge amount of data involved in water resources analysis through these binary files is a rather cumbersome process. This has been the main cause for the slow performance of WebL2W. Secondly, as HSPF runs in DOS shell, a piping script is necessary to run the model from other applications, which makes the overall system more vulnerable to errors.

The economics model in the current version of WebL2W estimates land values for evenly developed expensive constructions only, though the economics model has the capability to estimate land values for clumped developments and inexpensive constructions too. This limitation is because of the fact that entire economics model could not be programmed and tested in WebL2W in limited time due to the complexity of the model.

The spatial resolution required for different models are different. The hydrology model HSPF treats each land segment within Back Creek sub watershed as a unit of development, whereas the economics model treats a parcel of size 300 meter by 300 meter as a unit of development. The fish health model further considers the buffer zone of influence as a spatial unit for modeling. A gridded pattern of development with each grid of size 300 meters by 300 meters (9 hectares) was therefore chosen to solve the issue with spatial resolution.

The main user interface of WebL2W does not have common GIS capabilities like pan, zoom in, zoom out, and query. The architecture of WebL2W is designed such that the color for each grid needs to be changed when a user clicks in the grid with a development pattern. The ArcIMS software, which is used for interface development, maintained continuous active connection with the server, thereby slowing down the performance of the software. A more intuitive method is thus developed which uses the image capture from the ArcIMS display. A map painting routine developed in client-side JavaScript processes the color change in the map when user clicks on a grid square with a development pattern. This frees the server from the interface management, thereby increasing the performance of the system. An alternate interface has been developed separately in ArcIMS, which allows user to perform common GIS operations and query of database.

Further, the current version of WebL2W lacks the capability of post processing the results and displaying them in graphical format.

5.3 Future Directions

The current version of WebL2W provides a basic framework for developing web-enabled SDSS in watershed management area. Some issues that will further enhance the potential of the system are listed below.

Integration of GIS interface with scenario interface: The scenario creation interface of WebL2W can be integrated with GIS functionalities of ArcIMS with additional programming. This will eliminate the need of a separate interface for GIS operations and query.

Development of expert interface: Current version of WebL2W has the basic interface that lets a user create a new development scenario by clicking on the developable grids. This capability can be further improved such that users can specify new developments in term of area or number of people moving into a certain section of the watershed.

Graphical reporting: The current version of WebL2W generates simulation reports in tabular form. The software can be extended to generate graphical reports to show effects of development on various parameters representing hydrologic, economic, and fish health models.

Extension of model base: More watershed-related models can be added to current version of WebL2W to increase the usability of such type of systems. Currently, the hydrology model HSPF only simulates water quantity related effects of development. The HSPF model also has the capability to model water quality related effects of development, which should be considered in future extension of WebL2W capabilities. Similarly, the economics models used in this study have the capability to model economic impacts due to expensive as well as inexpensive construction in the watershed. The economic model for expensive construction has been implemented in the current version of WebL2W. Future version of WebL2W can be extended with the capabilities of inexpensive construction model. Some other models that can be integrated with current version of WebL2W can be habitat models for other aquatic and non-aquatic animals etc.

Extension of application watersheds: The current version of WebL2W is limited to Back Creek sub watershed. It is difficult to extend the current version of WebL2W to other watersheds, as the models used in the software are very complex and need site-specific calibration and validation. However, the usability of WebL2W can be extended to other watersheds as well with the use of more generic models in future.

Performance improvement: Performance of the entire system can always be improved by remodeling the system with new innovations in modeling and programming areas.

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