From Landscapes to Waterscapes: A PSE for Landuse Change Analysis

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Abstract

We describe the design and implementation of L2W - a problem-solving environment for land use change analysis. L2W organizes and unifies the diverse collection of software typically associated with ecosystem models (hydrological, economic, and biological). Our system provides a web-based interface for potential watershed managers and users to explore meaningful alternative land development and management scenarios and view their hydrological, ecological, and economic impacts. A prototype implementation for the Upper Roanoke River Watershed in Southwest Virginia, USA is described.

1 Introduction

Effective watershed management requires that decision-makers receive input about, and balance consideration of, a number of competing factors. The fundamental drivers of change on a watershed are modifications to land use and settlement patterns. These changes affect surface and groundwater flows, water quality, wildlife habitat, economic value of the land and infrastructure (directly due to the change itself such as building a housing development, and indirectly due to the effects of the change, such as increased flooding), and cause economic effects on municipalities (taxes raised versus services provided).

Modeling the effects of land use and settlement changes in a problem-solving environment (PSE) requires, at a minimum, the ability to integrate algorithms related to surface and subsurface hydrology, economics, and biology. At the same time, the users of the system are likely to have diverse backgrounds and levels of expertise, and are certain not to be experts in all of the domains that must be modeled.

The Landscapes to Waterscapes (L2W) project seeks to integrate the simulations and models necessary to provide support for policy planners seeking to determine the effects of land use and settlement pattern changes on the local watershed. This paper describes the interface and underlying architecture for our initial prototype system, along with a description of our immediate plans for future work.

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2 Design Principles

PSEs for watershed management are typically centered on physically-based conceptual models which delineate a watershed into multiple classifications based on land use and drainage connectivity. For example, Berry et al. describe their LUCAS PSE (Land Use Change Analysis System) [1] primarily from this perspective. The LUCAS system is designed on a probabilistic model that attempts to capture the influence of market economics (ownership characteristics), transportation networks (access and routing costs), human institutions (population density) and ecological behavior on landscape properties. The primary motivation is socioeconomic modeling which uses a transition matrix to assess spatial variations in land use which, in turn, is used for assessing a given set of impact factors.

In contrast, the design of the L2W PSE embodies modeling procedures for the assessment of the hydrologic and economic impacts of alternative landscape scenarios in an integrated framework. Geographic information system (GIS) data and techniques merge both the hydrologic and economic models with an intuitive web-based user interface. Incorporation of the GIS techniques into the PSE produces a more realistic, site-specific application where a user can create a land use change scenario based on local spatial characteristics. Design of the PSE/GIS follows the model developed by Fedra [3] and Goodchild [4] in which one user interface interacts with the GIS and the models employed by the application. Another advantage of using a GIS with the PSE, as described by [5], is that the GIS can obtain necessary parameters for hydrologic and other modeling processes through analysis of terrain, land cover, and other features.

Our current prototype seeks to (i) provide seamless web-based access to our PSE, (ii) receive input about, and assess the impact on, a number of distinct physical systems, and (iii) explicitly accommodate disparate abilities on the part of the users. In the following discussion, we specifically emphasize the models adapted for analysis of surface hydrology and economic impacts.

3 System Architecture and Implementation

The architecture of the L2W PSE is based on leveraging existing software tools into one integrated system. The surface hydrology model used is the HSPF (Hydrological Simulation Program FORTRAN) V11.0 system [2] that incorporates a watershed scale ARM (Agricultural Runoff Management Model) and NPS (Nonpoint Source Pollutant Loading Model) models into a basin-scale framework. HSPF models hydrological processes mathematically as flows and storages and uses a spatially lumped model for each *subarea* for a watershed (referred to as a subwatershed). In contrast, fully distributed, physically based models use a gridded rectangular cell as the building block and attempt to provide greater resolution in the modeling process. However, this enhancement in modeling power is not accompanied by corresponding spatial detail in the various input data (such as precipitation) and hence does not necessarily translate into improved hydrological forecasts. Furthermore, HSPF poses no topographic limits on the size of the subareas, is capable of modeling the hydrological processes on a continual basis, and supports the analysis of various scenarios where the user changes land use.

The hydrologist's interface to HSPF that we provide allows users to specify the percentage of basic land use types to be applied within specified sub-watersheds, which are selected from a map. These percentage figures reflect introduction of various land settlement patterns in a subwatershed. Land use changes are also provided to the economic model for analysis of economic impacts. The back-end prototype is written as a Visual BASIC (chosen because it supports the MapObjects system) application and the simulations for watershed runoff are accessed via Perl scripts wrapped around HSPF. Postprocessing tools are provided by Matlab and operating system utilities. The specification of spatial input is achieved by ESRI's MapObjects — a GIS programming tool that allows implementors to add map features and other GIS functions quickly without writing a lot of code in-house. By combining HSPF, Matlab, and MapObjects into one integrated system, we provide a way for the user to experiment with various hydrologic scenarios within the watershed.

The economic model estimates the effects of residential developments on water and sewer costs, prop-

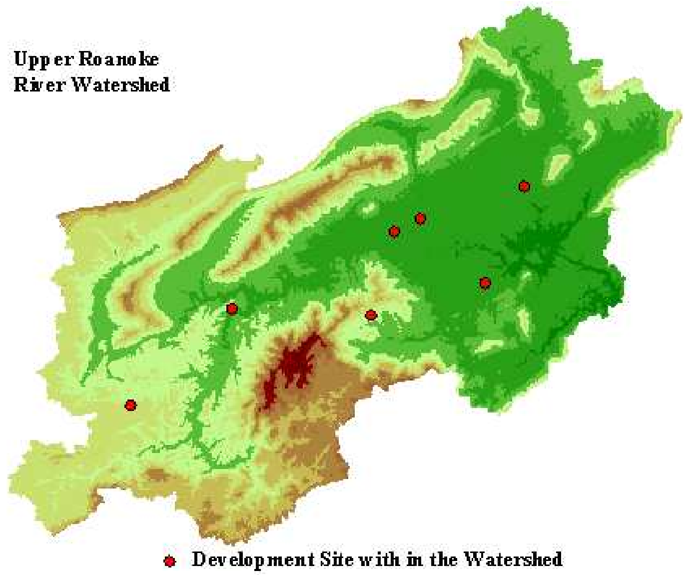

Figure 1: Placement of Development Types in the Upper Roanoke River Watershed.

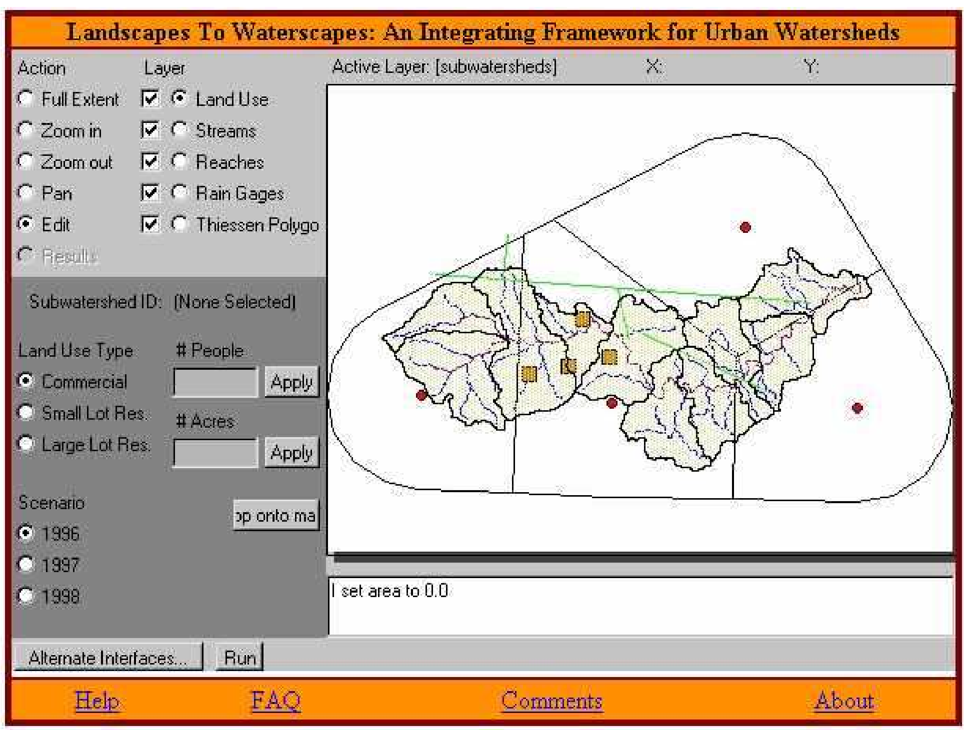

Figure 2: Front-End Decision Maker Interface to the L2W PSE.

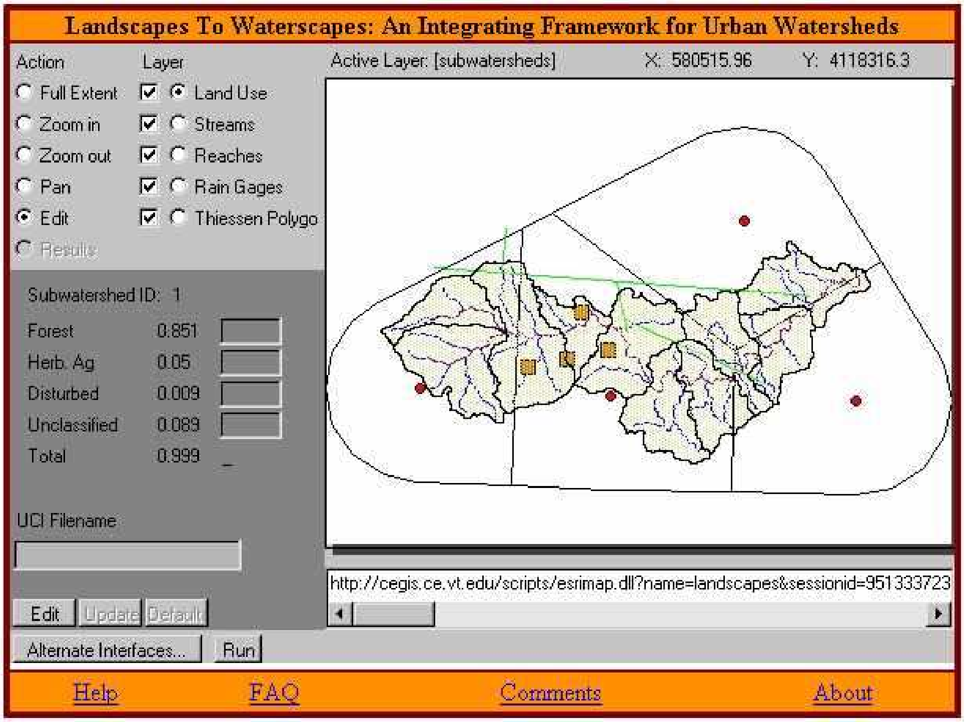

Figure 3: Front-End Hydrology Expert Interface to the L2W PSE.

erty values, property tax base, and property tax revenues. Length of pipe, number of valves, hydrants and manholes, number of booster pumps and pump energy and maintenance requirements are determined according to the layout of each development and its location relative to existing water and sewer lines. These infrastructure requirements are used in conjunction with unit cost data from generally accepted industry sources to calculate total costs.

Since the potential users of a watershed management system may have a wide range of expertise in the various disciplines represented by the system, the interface is designed to permit users to have more or less control of any specific modeling component. In particular, the user can decide to specify parameters to HSPF in terms of land use percentages within each subwatershed, or in terms of settlements placed at specific locations. By selecting the "hydrology expert" interface over the "decision-maker" interface, hydrologists can use an HSPF input file that they have created, allowing more control when greater expertise is available. Conversely, the "decision-maker" interface restricts the user to a subset of simpler input choices, protecting them from the complexity of the many required physical and meteorological parameters necessary to run HSPF.

4 Case Study: Upper Roanoke Basin

An initial prototype of our system is available at the URL `http://landscapes.ce.vt.edu` and covers the 57-sq. mile Back Creek sub-watershed of the Upper Roanoke River watershed (see Fig. 1) in Southwest Virginia, USA. Typically, the user invokes the thin-client Java applet (see Fig. 2) depicting the Back Creek sub-watershed and uses the cursor to specify landuse distributions for individual land segments. The cursor locations are converted and communicated via messages to a server, where each individual message contains details of the coordinates on the map (where clicked), parameters for running a simulation, or a command to indicate a particular simulation. Using MapObjects on the 600-sq. meters per pixel grid helps us provide map layer functions, automatic drawing of the map on the server, and transmission of maps across the internet. In particular, MapObjects provides primitives for intercepting coordinates of clicks on the map in

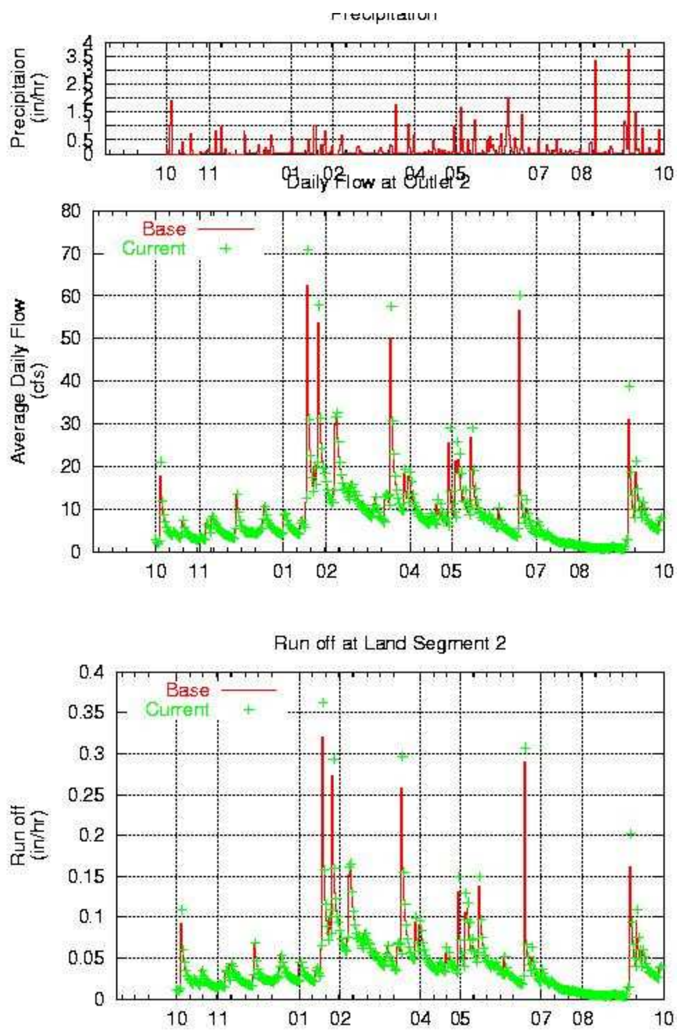

Figure 4: Graph output indicating runoff impact resulting from altering landuse values.

the applet. Based on the user input, L2W calculates the new distribution of landuses, suitable for input to HSPF, which is then run on one "base" rainfall pattern for a pre-selected duration. The prototype allows the user to specify: (1) changes to the land-segments in terms of settlement patterns (for example, "add 1000 people in a settlement pattern equivalent to Preston Forest") and (2) a choice of simulating several pre-determined rainfall scenarios ("dry summer", "wet summer", "fall with a hurricane"). The hydrologic simulation results include comparison of annual runoff (in inches), selected storm peaks with a baseline scenario and can be viewed at sub-watershed scale as also at the outlet of the watershed. Once this is complete, users will be able to analyze effects of various possible land settlement scenarios in a way that is meaningful to a city planner, economist or a hydrologist. The L2W prototype provides hydrographs (continuous record of streamflow at selected points) and relevant tabular statistics of annual runoff in inches, changes in storm peaks, and statistics of low flow. Figs. 2 and 3 present the input interfaces to our system and Fig. 4 identifies sample outputs obtained from an evaluation. Note that Fig. 4 provides comparisons between the effects of the alternative landscape scenario with a baseline case. In turn, these are useful in making biological impact assessments (on aquatic conditions), changes in flood risk, and land price changes.

5 Concluding Remarks

The long-term goal of our project is to provide a holistic approach to watershed management by an integrated assessment of the alternative landscape scenarios that occur during the urbanization/suburbanization process. On the PSE front, we plan to explore the implementation of scenario management modules, collaboration support, optimization (selecting the 'best' configuration to balance competing goals within a watershed), preservation of expert knowledge and recommender systems (for selecting among various choices of simulation models) within the L2W framework. While each feature described in this list is a research issue in its own right, the synergy resulting from integrating them into a single system will be an important aspect for the usability and eventual acceptance of PSEs for watershed assessment.

References

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