Jul 1st, 12:00 AM

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Abstract: Deep Creek is an important tributary of the Okanagan River system in Southern British Columbia. The creek drains a watershed with sediments deposited by multiple glacial events, resulting in a complex pattern of surface and groundwater connections throughout the basin. Further, the basin is experiencing changes in agricultural enterprises as well as population growth, and may be heavily impacted by climate change. The MIKE SHE integrated hydrological modeling system is being used to develop a model of the basin hydrology. The watershed is relatively small – with only a couple of hundred agricultural water users – lending itself to a high resolution modeling project. We are at the initial stages of developing an Agent Based model to forecast land use change in the basin. The MIKE SHE model will be used to calibrate the hydrologic features of our model, and the water use predictions of our model will serve as inputs into the MIKE SHE model, as an iterative process to forecast the impacts of climate change in the basin. Conventional climate change impacts on precipitation and temperature will be considered, as well as various changes in input and output prices which may occur. The latter have been little studied, although there is general agreement that agricultural production will shift to more northerly regions, and that this will be driven by price changes as well as new opportunities. After considering various approaches and software options, we decided that REPAST provides the power and flexibility to meet our objectives. We are presently at the preliminary stages. This paper outlines the study location and preliminary conceptual design of the model.

Keyword: Agent based modeling; Climate change impact; REPAST; Simulation; Water demand.

Introduction

Land use patterns are the result of a myriad of individual choices made in response to a diverse range of variables. As these variables change, land use patterns evolve. On top of the usual suspects, climate change is likely to impact on many of the variables that are important to land use choice. This paper documents initial efforts to develop a model that will connect hydrologic process and land used decisions into a tool to understand the impacts of climate change on a watershed in British Columbia. This project is part of the continuation of a long running effort to understand the hydrology of the Deep Creek watershed.

It is doubtful that a relatively simple explanation of why we transform the environment the way we do will be forthcoming (Turner et al, 1990). A theory of land-use change needs to conceptualize the relations among the driving forces of land-use change, their mitigating processes and activities, and human behavior and organization. Further, agricultural land use changes in particular are influenced by individual choices of farmers. A farmer's land use choices are responses to personal, social, institutional and market factors, made in the face of the opportunities and constraints resulting from the farmer's location. Simple models that ignore the idiosyncratic aspects of each farmer's situation may reproduce the general features of land use change, but are unlikely to capture local details. When local details matter, such as where sensitive habitats exist, such results may be of limited value.

Initial activities within the current project focused on understanding the hydrology of the watershed, with particular focus on developing a detailed model of the groundwater resources and their relationship to surface waters. To forecast climate change impacts, a forecast of water demand is required, and this in turn requires understanding how land use will evolve. Land use will respond to several factors. One is certainly the change in opportunities that results from climate change. However, population growth pressures and changing economic conditions – some of which are also a consequence of climate change – will also play an important role. Our objective in the current research is to develop an appropriate model to forecast how land use will change in response to these forces, and an agent based model is the most suitable model for this task.

Study Area

The semi arid Okanagan region lies in the southern interior of British Columbia, in the rain shadow of the Coast Mountains. Deep creek and Fortune creek watersheds are two of many watersheds in the Okanagan valley, respectively covering 230 km^2 and 160 km^2 (Figure 1 and 2). Two small urban areas Armstrong and Spallumcheen are located in the watershed. The elevation of the bottom part of the basin ranges between 340 – 520 meters while upper part of the basin ranges from 370 – 1575 meters above sea level (Wei, 2009).

Figure1. Location of the Okanagan Basin in British Colombia, Canada.

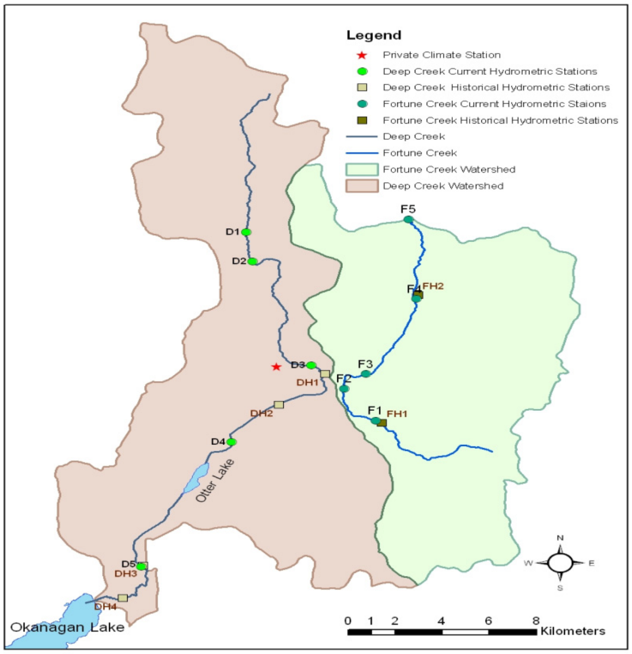

Figure 2. Watershed areas of Deep and Fortune Creek

Winters are short and cold, while summers are hot. Annual average precipitation and the potential evaporation are within the range of 475-575 mm and 850-950 mm respectively while the mean annual temperature is within the range of 6-10 °C. Much of the winter precipitation falls as snow, particularly at higher elevations. There has been a measurable increase in precipitation, particularly winter snowfall. (Wei, 2009). Temperatures have also increased, most noticeably daily minimums (Cohen and Kulkarni, 2001). The frost free period increased by nearly 3.1 days per decade during the 20th century, and now ranges from 120 – 150 days (Zbeetnoff, 2006). For more southerly parts of the Okanagan, Nielsen et al (2001) expect climate change to significantly alter the ranges for horticultural crops, moving north and to higher elevations. While perennial horticultural crops are not presently important in the north Okanagan, climate impacts are likely similar. Farmers will modify their practices in response to the opportunities and threats created by the changing climate. Further, many crops in the Okanagan rely on microclimates created by the complex topography (Cohen et.al, 2006). These facts further emphasize that predicting the impacts of climate change on land use in the north Okanagan must consider the unique aspects of the landscape and the importance of indivual responses to these changes.

The availability and access to water is the vital factor for agricultural activities in the semi arid climate regions. Deep and Fortune creeks have a limited ability to supply water over much of their range, making groundwater particularly important. The study area has seen multiple glaciations, leading to a complex geology and consequently a complex hydrology. Groundwater head levels vary between 350 – 500 meters above average mean sea level through the valley bottom. Over the last 30 years, groundwater levels have dropped in many of the aquifers from which water is withdrawn. Head levels drop in the summer due to irrigation pumping in all shallow and moderate aquifers. The sensitive range of water depth varies from 50 to 70 meters. Mountain system recharge is a major contributor to the deep regional aquifers, from which there is recharge of some overlaying aquifers and in places artesian flows (Wei, 2009). Given the critical role of water, coupling a land use and hydrologic model is necessary to forecast the land use impacts of climate change.

Important activities in the study area include forestry, agriculture, manufacturing and tourism, with agriculture the most important. Cattle farming is the most prominent, representing about 21% of all operations. Other common farm types include hay and forage (17.2%), horse and pony (15.2), poultry (6.8), and dairy (6.1%) (Zbeetnoff, 2006). In response to high land prices near Vancouver and a growing population of retired residents, agriculture has been shifting towards more commercial animal agriculture, and smaller hobby farms. Such changes, driven by economic and demographic trends, are factors that will affect how we respond to climate change, and should be incorporated into land use change modeling.

Alternative Land Use Models

Two dominant approaches in land use/cover change modeling are pattern based models and process based models. Pattern based models are mainly GIS oriented models which forecast spatial patterns, and generally have minimal behavioral content. Numerous spatially disaggregated and heterogeneous land use change models exist, taking advantage of the vast amounts of spatially disaggregated land use/cover data that are now available (Pontius and Malanson,2005; Schotten et al. 2001; Verburg et al. 2004; Pijanowski et al.2005; Verburg and Veldkamp 2004). Spatially-explicit LUCC models typically begin with a digital map of an initial time and then simulate transitions in order to produce a prediction map for a subsequent time. Such approaches do not model the decisions of individual land owners. They therefore cannot incorporate responses of land owners to economic and social changes that are not already driving pattern changes, nor can they effectively include polices that use economic incentives to change land use decisions.

The alternative process based models explicitly model the behavior of individuals. These models allow the incorporation of the human decision making process in a formal and spatially explicit way, incorporating the influence of social interaction, responses to local conditions, etc. on decisions. This approach can explicitly incorporate a range of social processes – interactions among human 'agents' – and environmental processes in a spatially explicitly way. There have been a number of recent implementations (Kirtland et.al. 2000; Lei et.al. 2005; Polhill et.al. 2001), The Mathematical Programming based Multi Agent System – MPMAS (Berger, 2001) is one of a small number that consider changes in agricultural landscapes. Given the spatial heterogeneity of the physical landscape, the sensitive nature of some local environments, the relatively small size of the watersheds, the presence of detailed data on the physical features and in particular the groundwater processes, agent based modeling is an appropriate tool for our study area. However, our intention to incorporate spatially explicit features at a smaller scale than MPMAS, together with the need to integrate and utilize GIS data makes MPMAS an inappropriate tool. We have therefore chosen REPAST, the REcursive Porous Agent Simulation Toolkit (North et.al., 2005a), for our model.

Implementation in REPAST

Even though REPAST has not been used much in agricultural land use simulation, it has the flexibility to handle any kind of simulation requirement. REPAST borrows many concepts from the SWARM agent-based modeling toolkit. However, unlike SWARM, REPAST is implemented in JAVA, proving both a well known language, and access to a vast collection of software that can be incorporated into REPAST models. In particular, REPAST is one of the few simulation / modeling software systems that supports the integration of geospatial data, especially that of vector-based geometries and ability to represent dynamics (Crooks, 2006). One can obtain further information about REPAST from its web link.

A REPAST simulation is composed of agents and a space, bound together in a model. All three (Agent, Space and Model) are JAVA classes. The space class is flexible enough to implement a cellular automaton hydrologic model, enabling one key aspect of the study area to be explicitly incorporated into the simulation. The agent class itself also enables a rich decision set to be considered, as well as sophisticated learning processes and a range of interactions between agents. Finally, the model class can manage both sequential and simultaneous action time steps, and as a programmed class, can embody interactions that are customized to the specific case under study. Figure 3 illustrates the basic design elements of the model we are developing.

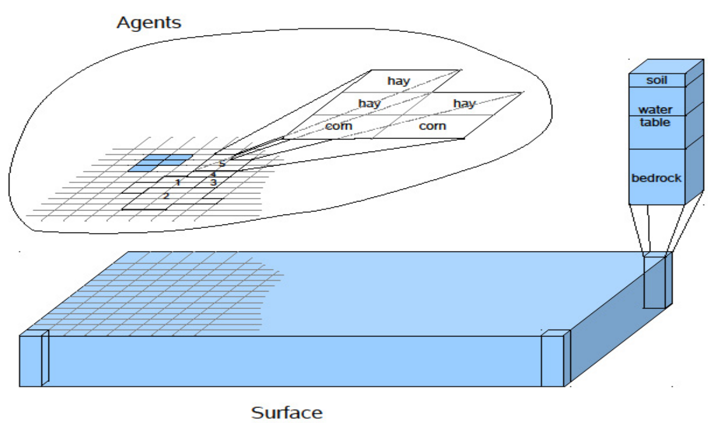

Figure 3: Basic design elements of the Agent Based Model (ABM) simulation.

Space Class

The space object will be a cellular automaton implementation of a hydrological model of the study area. Each cell will contain information relevant to determining the productive potential of the surface land represented by that cell, and the water table level in the cell. As the focus is on the impact of climate change, the detailed modeling of each cell will be restricted to those variables that will be impacted, or that relate to other variables that will be impacted by climate change, and/or that otherwise restrict the potential uses of the land, relative to other locations in the study area. Soil type – clay, sand, gravel, etc. – impacts crop growth, soil temperature, and water retention. Slope and aspect of the surface affects radiation received. Elevation determines the temperature regime. Location of the cell within the watershed will also determine the precipitation received. Table 1 lists a number of characteristics of each cell in the surface class of the model that we are planning to incorporate.

Table 1: Characteristics and processes for cellular automaton surface class.

Static Characteristics	Dynamic Characteristics	Interactive Processes
- slope	- organic matter	- depth to water table
- aspect	- soil nutrients	
- elevation		
- top of aquifer		
- bottom of aquifer		
- soil type		
- coordinates		

The ground and surface water model will implement a Darcy's Law style of relationship between the cells, focusing on the relationship between the upper aquifers from which water is withdrawn for irrigation, and which interact with the surface water in the watershed. Important connections between the modeled water flows and deeper aquifers, mountain recharge areas, etc. will be incorporated as constant flux and/or head boundaries. Parameter values will be chosen to approximate the results generated by Wei et al (2009), in their MIKE SHE based simulation of the hydrology of the Deep Creek watershed. Wei et al's simulation will be used to calibrate the hydrologic layer of our model. Water use projections from our ABM model will serve as inputs into the MIKE SHE model for trial scenarios. Iteration of this process will continue until water use decisions by the agent and its impacts are consistent with the MIKE SHE hydrologic model.

Agents Class

Agents make management decisions for a collection of cells. In the figure 3, all cells owned by an agent are contiguous, but this need not be the case. Agents choose the enterprise to engage in (livestock production, crop production, etc.), which crops to grow, and the levels of inputs to use. Of particular interest is water use. Agents decide how much water to apply to the land, in response to the land use decision previously made and the climate conditions. Table 2 lists some of the characteristics, choices, and interactive processes at the agent level that we intend to incorporate.

Table 2: Characteristics, choices and interactive processes for the agent class.

Characteristics	Choices	Interactive Processes
- demographics	- enterprise	- expectations formation
- assets	- crop	- input markets
	- water use	- output markets

The model will initially be developed with farmer agents only, and even there with the focus first on the choice of crop and pumping level alone. The sophistication of the agent will then be expanded to include multiple enterprises and then permit the trading of land between agents. With a land market, a second type of agent will be introduced, the urban resident or city agent. This will enable population growth to be incorporated into the simulation. If implemented as individual urban resident agents, then these agents derive a relatively small share of their income from the land use choice. In the spirit of the monocentric city model, these agents will also put a large cost on distance from the center of the relevant urban location. Alternatively, a city agent can be added for each urban center, with must enter the land market to expand and accommodate population growth.

Farm equation

Agent decision making falls into two broad categories: optimization or heuristics. While often strongly contrasted, both of these approaches assume goal-oriented behavior, and become more realistic when using detailed production and consumption functions (Schreinemachers and Berger, 2006). Optimization models have certain advantages for land use modeling, such as the inclusion of multiple input and output decisions, solving the decision problem simultaneously, and clearer policy relevance of outcomes. Among the possible functional forms, linear functions and fixed input/output relations are generally seen as unrealistic, while quadratic and Cobb-Douglas functions are more widely accepted (Mundlak 2001). With an input like water, where surplus will harm the crop, the quadratic form is particularly attractive.

Alternative functional specifications are also possible, and we will investigate those used in the MPMAS (Berger, 2001) system, as well as linear programming and other constrained optimization approaches. These various approaches will be assessed for their ability to incorporate crop response to water availability, the choice of water use, etc, and the ease of making them sensitive to physical characteristics of the agent's location on the surface. The speed of calculation will also be considered, an important component in ensuring that the model remains tractable.

Model Class

REPAST's model class implements the schedule that governs the evolution of the model. It is also the logical level at which to base processes that are not a consequence of the evolution the surface or the interactions between the agents located on this surface. This is where climate change scenarios and scenarios for economic variables impact on the model.

Comment [JJ1]: I still think there is some confusion here. Agents exist on a surface. The model governs interactions between agents and the evolution over time. Aggregate land use change is an output, resulting from the decisions of the individual agents.

Climate scenarios have been down-scaled for the Okanagan by Nielsen et al (2001). The local predictions embodied in these scenarios will determine the agricultural potential for each land parcel that an agent in the watershed owns, as a consequence of the soil characteristics, aspect, elevation, etc. of that parcel. The commodity price scenarios that correspond to the climate scenarios are a novel contribution of this project. The fact that climate change means a shift in agricultural production from tropical to temperate regions has been recognized for some time (Rosenweig and Parry, 1994; Parry et al, 1999). These shifts in production will only occur if agricultural producers in temperate regions find it profitable to expand production. However, Schmidhuber and Tubiello (2007) find only three analyses that have forecasted the impact of climate change on food prices, and these were limited to international trade. Using works such as those cited by Schmidhuber and Tubiello as guides, we will develop price scenarios to accompany the climate scenarios for important crop options in the watershed.

Table 3: Key elements of model schedule.

	Winter	Spring	Summer	Fall
# steps	1	2-3	6+	2-3
Agent	- predictions	- crop choice	- irrigation	- harvest crop
	- enterprise choice	- plant crop		- realize revenues
	- land market	- pay costs		

Table 3 illustrates the schedule planned for the model. The resolution of the schedule will be finest in the summer and coarsest in the winter. During the late fall, winter, and early spring there is no irrigation activity, and water movement is mostly unaffected by human actions. In the summer, irrigation is the most intensive, and environmental impacts of irrigation are the most significant. Therefore, to track these impacts, resolution is highest.

For the model agents, winter is the period when expectations are formed and the large enterprise decisions are made. For simplicity, the decision to purchase or sell land will also be made during this season. In the spring, the agent chooses the land use and pays the associated costs. Irrigation and any other relevant input choices are made in the summer. In the fall, crop is harvested and revenues are realized.

Progress

At this point, a basic pumping agent model on top of a simple uniform surface cellular automaton hydrologic model has been implemented in REPAST. The hydrologic system responds to constant head sinks and sources located in the grid, and to pumping activity by the agents. Agents choose pumping level in response to pumping costs, which are a function of the head level in the cell in which they are located. Beyond the proof of concept, two key insights have emerged from this work. First, to smoothly manage the implementation of Darcy's law, calculations must be done in two steps. In the first step, inflows and outflows from each cell must be calculated in relation to all neighbouring cells. Once calculated for all cells, the head level in each cell is adjusted in response to this water movement. The second insight relates to water pumping. With the simple implementation, where there is only one time step per year, agents cannot be programmed to optimize pumping choice. Rather, agents must be programmed as adjusting pumping level. When agents instantaneously optimize, the system enters an oscillating pattern where agents pump a large amount in one period, and then nothing in the next. In a more sophisticated model, where irrigation is decided after the crop is planted and a number of pumping decisions are made during the growing season, this problem may not exist.

The results of this analysis will form a key input into the ongoing modeling of the Deep Creek watershed. The land use change scenarios will inform the water use throughout the watershed, and serve as input into the MIKE-SHE model. Given that the models will run relatively separately, an iterative process will be required to find a land use and resulting water use scenario that is consistent with the hydrologic model.

Conclusions

The Deep Creek watershed in the North Okanagan has been subject to a detailed hydrological modeling effort in recent years. The area is expected to experience significant climate change in the decades to come, as well as continuing pressures from population growth, and other economic pressures originating elsewhere in the world. Given the importance of spatial heterogeneity, an agent based approach is the best way to model land use change and the evolution of water demand in the watershed. After reviewing several different ABM tools, we have concluded that REPAST is the best tool for implementing our model. A proof of concept implementation has demonstrated the feasibility of using this tool, and highlighted some of the issues that will need to be accounted for.

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