Environmental Modelling & Software 69 (2015) 111–127

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

A web-based software tool for participatory optimization of conservation practices in watersheds

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A R T I C L E I N F O

Article history:
Received 18 January 2015
Received in revised form
18 March 2015
Accepted 18 March 2015
Available online

Keywords:
Interactive optimization
Participatory design
Conservation practices
Web-based
Subjective criteria
Watershed planning and management

A B S T R A C T

WRESTORE (Watershed Restoration Using Spatio-Temporal Optimization of Resources) is a web-based, participatory planning tool that can be used to engage with watershed stakeholder communities, and involve them in using science-based, human-guided, interactive simulation–optimization methods for designing potential conservation practices on their landscape. The underlying optimization algorithms, process simulation models, and interfaces allow users to not only spatially optimize the locations and types of new conservation practices based on quantifiable goals estimated by the dynamic simulation models, but also to include their personal subjective and/or unquantifiable criteria in the location and design of these practices. In this paper, we describe the software, interfaces, and architecture of WRESTORE, provide scenarios for implementing the WRESTORE tool in a watershed community's planning process, and discuss considerations for future developments.

Software availability

Name of software: WRESTORE (Watershed REstoration using Spatio-Temporal Optimization of Resources)
Developers: Vidya Bhushan Singh, Meghna Babbar-Sebens, Adriana Debora Piemonti, and Snehasis Mukhopadhyay
First available year: 2014
Software requirements: Web-browser
Programming language: Java
Language: English
Minimum hardware requirements: Intel Pentium II, 200 MHz, 128 MB RAM
Contact person: Meghna Babbar-Sebens (Corresponding author)
URL: http://wrestore.iupui.edu/

1. Introduction

Recently, there has been an increased effort to help mitigate the effects of increased climate change induced flooding by restoring degraded upland and downstream storage capacities of watersheds via conservation practices. For example, Hey et al. (2004) reported that the 80-day Mississippi River flood in 1993 – which generated 48 billion cubic meters (or, 39 million acre-feet) of floodwaters at St Louis, MO – could have been contained within the 49 billion cubic meters (or, 40 million acre-feet) storage that could have been provided by adding storage capacities of the drained wetlands to the existing levees and existing wetlands. Lemke and Richmond (2009) and Babbar-Sebens et al. (2013) have also suggested that re-naturalization of the hydrologic cycle with best management practices (or, conservation practices) on the landscape can solve both water quantity and water quality problems in mixed land use watersheds. However, design of a system of conservation practices for upland storage is a complex process because there can be a large number of alternative sites, scales, and mitigation methods, and because – with multiple stakeholders – there can be multiple criteria and constraints for selection among alternatives. Additionally, achieving the desired level of restoration in a watershed will depend not only on the diverse costs and benefits of modifying the landscape but also on whether the landowners and other stakeholders will find prescribed practices acceptable when they are constrained by their subjective perceptions, uncertainty in human behavior, and local field-scale conditions (Wilcove, 2004).

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http://dx.doi.org/10.1016/j.envsoft.2015.03.011
1364-8152/

Therefore, successful restoration of hydrology requires obtaining a thorough understanding of the people and ecological processes that are unique to the watershed system, and then using this understanding in the design of appropriate management alternatives for restoring/creating upland storage systems.

Designing or generating alternatives is an integral part of problem-solving and decision making processes. In commonly used models (and their adaptations) of decision-making processes, such as those proposed by Mintzberg et al. (1976) and Simon (1977), the design of alternatives usually occurs in the second phase of a three phase process that includes – (1) problem identification and definition phase, (2) problem development and alternatives generation phase, and (3) negotiation and selection phase. The first phase involves interaction with stakeholders and experts to identify, structure, and define the problem. For example, for the restoration problem, this would involve developing a conceptual model of the combined human-physical system, and quantitatively defining the various objectives and constraints of the restoration project based on projects costs, economic benefits, environmental benefits, and stakeholder values and preferences. Conducting interviews with stakeholders and constructing quantitative economic valuation of the various ecosystem services provided by the upland storage systems would be an integral part of this phase. The second phase involves use of various computational tools, such as, simulation models and search/optimization algorithms. These models and algorithms along with the parameters of the search/optimization algorithm, and quantitative representations of the problem objectives and constraints defined in Phase 1, are then used to generate optimized sets of alternatives (or, scenarios of solutions) that would satisfy or outperform the problem objectives. When multiple conflicting objectives exist in a natural resource planning and management problem, a non-dominated set of alternatives are generated by the optimization algorithms, which is also called the Pareto-optimal set or a tradeoff curve. This phase is computationally intensive, and generally assumes that multiple stakeholder values and preferences obtained in Phase 1 can be quantified and reliably used to search for alternatives and to generate a search outcome for Phase 3. Once, the search has ended in Phase 2, the alternatives are then presented to the stakeholders in Phase 3 for decision making and selecting a final alternative for implementation. Many multi-criteria decision aid techniques exist in the literature (Haimes and Hall, 1974; Soncini-Sessa et al., 2007; Assaf et al., 2008; Castelletti and Soncini-Sessa (2006, 2007)), which can be used to include stakeholder feedback to select the "final" alternative in Phase 3 from a set of optimized non-dominated optimal alternatives, based on multiple quantitative and qualitative criteria. However, by the time the stakeholders reach Phase 3 for decision making it is typically assumed that the search/optimization process in Phase 2 has used an accurate or close to accurate representation of the stakeholder criteria, and, therefore, alternatives optimized for these quantitative representations will be "optimal" solutions to the problem. This is, however, not true since in real-world watershed problems there can also be local knowledge, non-quantifiable beliefs and values, and incomplete/unstated preferences of the stakeholders that may not be captured in simulation–optimization models (Andradóttir, 1998; Fu, 1994, 2002; Gosavi, 2003; Law and Kelton, 2000). This can lead to stakeholders' dissatisfaction with the optimized alternatives and poor adoption of prescribed alternatives (Soncini-Sessa et al., 2007). In summary, though many methods in the literature have been developed for incorporating active stakeholder involvement in Phases 1 and 3, active involvement of stakeholders has been limited in the search and design process (i.e., Phase 2).

With the current trend of water resources planning and management approaches becoming more "bottom-up" or participatory (Assaf et al., 2008; Voinov and Bousquet, 2010; McIntosh et al., 2011; Döll et al., 2013; Hamilton et al., 2015), where stakeholders are involved in all stages of modeling and planning, the need for better understanding of people-related processes in design of alternatives has become ever more crucial. Involving stakeholders in the multiple steps of the decision making process, including the alternatives generation phase (i.e. Phase 2), can yield multiple benefits (Bierle, 1999; Daniels and Walker, 2001; Selin et al., 2007). For example, stakeholder involvement (a) gives individuals a sense of ownership in the decision process by allowing them to directly influence the problem-solving process, (b) provides a platform for open and honest expression of stakeholder views, and (c) improves the legitimacy of the planning and management process, while also conveying the complexities and uncertainties associated with this process to the public. With ongoing developments in Web technologies, the internet has the potential to be a robust medium for supporting participation of and communication between stakeholders in natural resources management (Esty, 2004; Rinner et al., 2008; Kelly et al., 2012). Kelly et al. (2012) reports that most of the current research in using the Web in natural resources management has been focused on (a) information delivery to the public by government agencies, with the ability for public to comment on on-line documents (e.g., Beckley et al., 2006; Conrad and Hilchey, 2011), (b) interactive social-web tools for harnessing (or "crowd-sourcing") feedbacks from large groups of individuals via on-line dialogs and discussions (e.g., Kangas and Store, 2003; O'Reilly, 2007; Hudson-Smith et al., 2009), and (c) development of mapping and other spatial decision support tools for effectively communicating spatial data to support decision making (e.g., Kearns et al., 2003; Sheppard and Meitner, 2005; Brown and Reed, 2009; Brown and Weber, 2011). It is worthwhile to note that none of the existing technologies and software cited in these studies provide a truly human-computer collaborative design environment where stakeholders can participate in design experiments to visualize alternatives and provide feedbacks on both the design features and acceptability of system-generated alternatives, and in return have that feedback used to generate new community-preferred alternatives of natural resources management plans.

In a 1985 seminal paper, Fisher (1985) motivated a discussion on optimization/search algorithms that were interactive and allowed humans to be a part of the search process, especially for problems where human thought processes would provide "superior" advantage to the "algorithmic thinking" employed by a computer – for example, processes related to visual perception, strategic thinking, and the ability to learn. According to his discussions, incorporating human interaction within the optimization algorithms could – (a) facilitate model specification and revisions, (b) help cope with problem aspects that are difficult to quantify, and (c) assist in the solution process. A human–computer collaborative decision support framework that uses such a search process would allow stakeholders real-time access to influence the search process of the optimization algorithm by influencing the definition of objectives and constraints, the characterization of alternatives, the simulation models, and algorithm parameters. This not only allows a more flexible and transparent framework for including stakeholders preferences and subjective knowledge to construct meaningful, better performing, and desirable (from the perspective of both humans and quantitative evaluation objective functions) alternatives; it also creates a venue for improving the cognitive learning process of the interacting human (Babbar-Sebens and Minsker, 2012). Also known as human-guided search (Klau et al., 2009), the interactive search/optimization process has been explored in applications such as space shuttle scheduling (Chien et al., 1999), vehicle routing (Waters, 1984), face image generation (Takagi, 2001), and constraint-based graph drawing (do