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A Spatial Decision Support Framework for Web-Based, Multi-Stakeholder Engagement: Case Study of Geothermal Power Project Siting in Idaho

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A Spatial Decision Support Framework for Web-Based, Multi-Stakeholder Engagement: Case Study of Geothermal Power Project Siting in Idaho

by

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Dedication

This work is dedicated to my parents, John and Katherine Noll, who have provided support and guidance throughout my life.

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There are many faculty members who I wish to thank for their contributions to this work and to my graduate studies. I would first like to acknowledge my advisor and friend Suzanne Pierce who patiently and consistently offered her time and assistance over the course of my time at the university. I thank Charles Cooke for his mentorship during my professional career and research assistantship at The University of Texas Energy Institute. I would also like to thank John Butler, Varun Rai and Catherine Weaver for always leaving their door open and for the help they provided along the way.

Abstract

A Spatial Decision Support Framework for Web-Based, Multi-Stakeholder Engagement: Case Study of Geothermal Power Project Siting in Idaho

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Multi-criteria decision analysis (MCDA) represents an emerging decision aid tool in the field of natural resource decision-making. This thesis involves research into the application of a multi-criteria spatial decisions support system (MC-SDSS) to support favorability mapping of geothermal resource potential. The main goal is to provide proof of concept of a tool that can facilitate multi-stakeholder engagement during site selection of a potential power generation facility. It presents information on the history and development of spatial decision support systems in the field of environmental and natural resource decision-making, as well as a case study of a MC-SDSS tool—entitled the "Heatseeker" application— developed and applied to geothermal resource potential in the Eastern Snake River Plain, Idaho. This research was first conducted under a grant from the U.S. Department of Energy National Geothermal Student Competition.

The Heatseeker application and supporting infrastructure utilizes a client/server system architecture that provides users with access to spatial and tabular data with low bandwidth requirements. Client-side scripting is used to execute a weighted linear combination (WLC) model and provide users with display and report functionality. Additionally, the tool is optimized for use with a gesture-enabled touch device that serves as a boundary object to facilitate participatory stakeholder engagement. The result of this research is a proof of concept in supporting future MC-SDSS design that can be applied both to geothermal favorability mapping and other natural resource management processes.

This work draws upon the research traditions of multiple academic disciplines, including operations research, computer science, cognitive and behavioral psychology, economics, and public policy. The initial development and application of the MC-SDSS tool involved a team of graduate and undergraduate students from geoscience and social science disciplines. Transdisciplinary approaches to problem structuring and decision-making such as this are an increasingly common approach to natural resource issues.

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Introduction

When decisions are made about *how*, *when* or even *if* a natural resource should be exploited, it is often assumed that decision-makers will attempt a rational process and choose a course of actions that provides the greatest benefit at the least cost. But what determines how benefits and costs are defined, or how they are distributed between various groups and over time? Furthermore, whose views and expert opinions should be part of the decision-making process? How can tradeoffs be made between conflicting values, or heterogeneous data that contains variable levels of uncertainty and risk? In this context, it should not be a surprise that debates over the management of our natural resources often spark confusion, controversy, and conflict.

Making decisions about the development of natural resources often involves multiple stakeholders with different domains of expert knowledge and competing objectives. For decisions to be accepted and implemented, decision-makers (DMs) should exercise an approach that is analytically rigorous, methodologically consistent, and readily transparent. In natural resource management this often implies a strong connection to scientific and technical information as well as tools that link that information to the preferences and priorities of various stakeholders. It also often requires a process that is inclusive and sufficiently flexible to adapt to the needs and requirements of the stakeholders themselves.

The use of multi-criteria spatial decision support systems (MC-SDSS)—an integration of geographical information systems (GIS), decision support systems (DSS), and multiple criteria decision analysis (MCDA) — has emerged as a decision aid tool for evaluating conflicting objectives and stakeholder preferences in the implementation of spatial decision models (Malczewski, 2010; Greene et al, 2011; Demesouka et al., 2013).

These tools aim to support a spatial decision-making process by providing better access to information, increased ease of public participation, and support for distributed collaboration amongst various groups of stakeholders in remote environments.

Goal and Objectives of the Study

This thesis involves research into multi-criteria spatial decision support systems (MC-SDSS) as a tool for favorability mapping of geothermal resource potential. The main goal is to provide a proof of concept decision aid that can facilitate multi-stakeholder engagement during site selection of potential power generation facility. It is widely accepted that including stakeholders in the decision-making process improves the decision outcome (Voinov and Bousquet, 2010). However, structuring a decision process and choosing appropriate methods is a difficult task that requires careful analysis. This research draws upon existing work in multi-criteria decision analysis (MCDA), geographic information systems (GIS), and transdisciplinary research to propose a decision-making framework and tool for application to a geothermal favorability mapping case with potential to transfer its application to other natural resource management processes.

Information is presented on the history and development of spatial decision support systems in the field of environmental and natural resource decision-making, in addition to application of the tool to evaluate a case study to a geothermal resource potential in the Eastern Snake River Plain, Idaho (ESRP). The initial development and application of the MC-SDSS tool—entitled, “Heatseeker” throughout the report—involved a team of graduate and undergraduate students from geoscience and social science disciplines under a grant from the U.S. Department of Energy National Geothermal Student Competition.

METHODS

The Heatseeker tool and supporting infrastructure utilizes a client/server system architecture that provides users with access to spatial and tabular data with low bandwidth requirements. A web-based GIS platform called MapBox and a variety of related, open-source software tools are utilized to create a web-based MC-SDSS environment with spatial overlays. Javascript is used to implement the calculations of the MCDA model and provide users with display and report functionality. Additionally, the tool is optimized for use with a gesture-enabled touchscreen device that serves as a boundary object[1] to facilitate participatory negotiation and stakeholder engagement.

The Geothermal Favorability Case Study (GFCS) involved field research of geochemical data and access of publicly available spatial datasets. Seven input variables were selected for use in the MC-SDSS model: water temperature at depth, basalt thickness, fault zones, land use, road access, and proximity to transmission. In some instances, these attributes were measured on a natural scale, such as depth from land surface or travel miles. In other instances, it was necessary to construct scales that required estimates for alternatives based on expert judgment, such as with land use restrictions. Spatial analysis of model inputs was performed using ArcGIS prior to their inclusion in the MC-SDSS model.

To measure the relative attractiveness of each alterative the values for each attribute were normalized onto comparable scales using single-attribute utility functions.[2] These functions were both linear and non-linear as dictated by decision-maker preferences. Constructing and assessing these utility functions was accomplished using the software program Logical Decisions™. The ranking of modeled outcomes was

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[1] Boundary objects are tangible objects that facilitate communication and coordination between the

[2] A single-attribute utility function quantifies decision-maker preferences by describing the utility, or usefulness, of different levels of performance for each decision alternative for a model attribute.

performed within the Heatseeker application using a weighted linear combination (WLC) technique that is consistent with a simple, yet robust, linear additive model.

LIMITATIONS

The scope of this thesis is not intended to provide a comprehensive review of methods and tools in decision support research or multi-criteria decision analysis. Instead, it seeks to review the methods and foundational work most directly relevant to GIS-based MCDA in natural resource applications. Moreover, significant variance in terminology and methods exists between different academic disciplines in the study of decision-making. This work builds most heavily upon terminology and methods prominent in operations research and geographic information systems (GIS) literature.

The Heatseeker application and methods included in the GFCS are intended to provide a proof of concept for use of the tool in multi-stakeholder environments. The actual work of developing and executing the analysis was performed independently and not in consultation with real stakeholder groups or with the use of real stakeholder preferences, which were instead implemented by the research team (decision analysts) using stakeholder interviews and available literature. As a result, single-attribute utility curves for decision criteria were developed based on preferences of the research team, rather than through pair-wise analysis or other commonly used methods. This may have resulted in biased or unrealistic model outcomes and also limits the conclusions from commenting on the efficacy of the tool in a real negotiation scenario. Additionally, the data inputs to the Heatseeker application include only publicly accessible spatial data within the geographic area studied defined by the scope of the GFCS study region.

Outline of Chapters

Chapter 1 provides a background on multidisciplinary approaches to decision making and research in disciplines such as social psychology that justify the use of decision support systems. It provides information on key underlying concepts, such as the nature of natural resource management issues, the importance of boundary objects in facilitating transdisciplinary applied research, and common MCDA techniques applied to GIS-based natural resource problems. The chapter also provides an overview of spatial decision support systems, including its use in natural resource applications and technical information common to spatial decision support system components and structures. Three common MCDA techniques—Analytical Hierarchy Process, Multi-Attribute Utility Theory, and Outranking—are described.

Chapter 2 presents the Heatseeker application and a description of its underlying technologies and development process. A unique SDSS architecture is proposed that reflects the goal of creating a lightweight, flexible application for site selection decision problems. A description of the open-source web-based GIS tools and the modeling algebra executed in Javascript is provided.

Chapter 3 presents a case study for use of the Heatseeker application in favorability mapping of the Eastern Snake River Plain, Idaho. A background on the geological and hydrological setting is provided, including a summary of fieldwork performed in July 2012. Finally, a site selection decision-making process is described along with the MC-SDSS tool. The case study also presents model results, including geotechnical findings, outputs from the MC-SDSS, and a description of the use of the multi-touch user interface.

Chapter 4 presents final conclusions and recommendations for future work.

Chapter I: Background for Natural Resource Decision Making

DECISION ANALYSIS

Approaches to Decision Making

A decision—defined simply as a choice between two or more alternatives—can be evaluated in terms of the process by which the decision is reached, the individual(s) making the decision, or by decomposing the decision into its components, such as the evaluation criterion, range of alternatives, and methods used to arrive at a final choice. The study of decision-making spans a broad range of disciplines—psychology, political science, economics, mathematics, operations research, sociology, etc.—and can vary in level of focus from the study of individual cognition to the political and cultural characteristics of organizations or countries. Kahneman and Tversky (2000) summarize the active research in decision-making into three academic perspectives:

1. Normative – individual decisions viewed through the logic of decision-making, principles of rationality, and the invariant choice it leads to.
2. Psychological – individual decisions viewed in the context of a set of needs, preferences and values they seek.
3. Cognitive – the decision making process must be regarded as a continuous process of integration that is linked to the environment in which decisions are made.

Much scholarly analysis of natural resource problems proceeds from the normative perspective. From this view, the goal of any decision-making process is to select an optimal outcome given a set of decision criteria. Pinchot (1947) defined effective natural resource management as “providing the greatest good for the greatest number, in the long run.” Similarly, Linkov and Moberg (2011) describe numerous case studies from the U.S. Department of the Interior that reflect an adherence to methods such as cost-benefit analysis (CBA) and optimization. In these circumstances, decision-makers (DMs) are often assumed to behave in manners consistent with a “rational” view of behavior, which generally speaking, is described as an attempt to maximize benefits and minimize costs (usually in monetary terms). Applying such methods is useful for organizations seeking to establish internal consistency and logical soundness through various decision-making processes, increase efficiency, and provide transparency to outside groups about the rationale for decisions. This framework can be useful in developing simulations and performing strategic analysis, such as game theory settings, to show how certain decisions might be made. For example, the rational actor assumption employed in the Prisoner’s Dilemma game—a quintessential psychological case example— demonstrates why actors who cannot communicate will choose a suboptimal alternative (Tucker, 1950).

An underlying assumption of this paper is indeed that the desired end goal for any natural resource management issue should be to facilitate decisions that adhere to a rational choice model. Namely, that DMs seeks to maximize benefits while minimizing costs through the selection of an optimal solution that addresses most if not all of the concerns of stakeholders impacted by the decision at hand. However, this definition implies both a) a holistic view of the natural resource issue by the DMs and b) the existence of varying opinions and priorities of multiple stakeholder groups. In real world decision-making environments, numerous barriers often prevent DMs from properly conceptualizing and accounting for the scope of alternatives, evaluation criteria, and the variety of stakeholder views that should be taken into account. Cognitive and psychological approaches to decision-making, by contrast, attempt to account for these limitations and thus provide an important justification for the use of decision support systems.

The Cognitive Basis for Behavior

From psychological and cognitive perspectives, both the methods for organizing and structuring decision activity as well as the cognitive processes of individual decision makers are taken into account (Nutt and Wilson, 2010). As such, decision-making is viewed as a process whereby both reason and emotion are encountered and differences in cognition and bias are important factors to be considered (Howard 1966). Various dynamics are indicative of cognitive processing. For example, decision 'heuristics' are simplifying rules that result from the human mind's inability to carry out the complicated calculus of a rational model due to the high cost of information gathering, time constraints, misperceptions, and other factors. Given these constraints, DMs may intentionally or unintentionally employ heuristics that seek a satisficing outcome rather than an optimal outcome.

Political psychologist Rose McDermott (2004) observes that "recent advances in neuroscience offer a wealth of new information about how the brain works and how the body and mind interact." This includes the influence of emotion on decision-making, judgment, and learning. Any decision-making process begins with a single human brain responding to information. Therefore, how the human brain absorbs this information, analyzes and responds to problematic situations, and chooses a course of action is important to understanding the human cognitive process and has implications for designing a robust decision-making environment.

Chaiken and Trope (1999) describe a “dual-process model” in thought and cognition adopted by social psychology researchers, whereby human thought processing is divided between a deliberate, conscious processing mode and rapid, non-conscious mode. Conscious processing is thought activity that individuals are aware of and undertake with effort and control (Bargh and Chartrand, 1999). While we often think of this type of activity as the basis for decision-making, conscious processing makes up less than 2 percent of brain activity and involves numerous nonconscious mechanisms (Gazzaniga, 2002). Nonconscious processing, on the other hand, involves implicit memory and contextualizes new information by aligning it with background beliefs and knowledge that reflected the learned history of the individual (Evans et al. 2003). DMs are often unaware of the nonconscious processing mechanisms through which they evaluate new information.

Implications for Natural Resource Management

Decision researchers have found that the way in which a question is asked and how options are described strongly affects an individual’s choice, even between alternatives that are equivalent in value (Tversky and Kahneman, 1986). This is because the decision rules, or “heuristics”, an individual employs to make a choice are often not based on logical decision rules (as rational actor models would assume or the DM might intend). Rather, they can be based on nonconscious neural connections that seek to find patterns of recognition between new information and past experiences. This can lead DMs to inappropriately discount new information or apply subjective reasoning to the valuation of specific alternatives. For example, natural resource issues that deal with geological or ecological systems generally involve changes in condition that must be measured in decades, centuries, or millennia. Human perception, on the other hand, can only witness these systems on a shorter time scale. As a result, individuals tend to focus on results and implications that occur within a range of temporal or spatial scales in line with our perceptive capacity while discounting the future or other information that is outside of our ability to detect. Analytical tools, such as decision support systems and multi-attribute methods, address these limitations by providing a formal structure to decision problems that are too complex to solve independently. Furthermore, the cognitive basis for behavior in decision-making underscores the importance of effective communication modalities in addition to the development of formal models that are methodologically consistent and transparent.

CHARACTERISTICS OF NATURAL RESOURCE DECISION MAKING

Decision Typologies

There are a vast number of contexts in which natural resource management decisions are made (Sugumaran, 2010). For example, the National Research Council Committee on the Geographic Foundation for Agenda 21 describes three categories for sustainability development decision-making: (1) resource allocation decisions, (2) resource status decisions, and (3) policy decisions (Jensen et al, 2002). Resource allocation refers to decisions about where to place a limited amount human resources, such as air quality monitors, in order to effectively collect data. Resource status decisions involve the use of dynamic data, usually collected over time, to monitor changes in status within a particular area, while policy decisions refers to the implication of policy measures (such as a tax incentive) on the distribution of benefits. Each decision type may also vary in terms of the number of decision makers, the quality of data available, and a variety of other factors that influence the choice of appropriate DSS methods.

Decisions about natural resources often involve the use of spatial data as a key dimension in evaluating information. Kemp (2008) divides spatial decisions about resource use into four categories: (1) site selection, (2) location allocation, (3) land use selection, and (4) land use allocation. According to Kemp, site selection refers to decisions about where a DM may choose to locate a new project, such as a power plant, according to a variety of characteristics about the necessary conditions for selection. Location allocation, on the other hand, describes the choice of a location for a project based on an optimization of one characteristic, such as minimizing driving time for employees of the power plant. The last two categories—land use selection and allocation are the opposite and refer to choices regarding the selection and allocation of a particular parcel of land by evaluating one or more factors. This taxonomy is particularly applicable to energy project development that most always involve the use of spatial data to make decisions about where to locate a project or how to evaluate the use of a specific location.

Keeney (1980) discusses in detail the methods and processes of site selection for energy project development. The process often involves two basic components—the identification of candidate sites and the selection of the best site from the candidates. Different procedures are typically used for each component and may vary depending on a number of factors, such as the presence of multiple interest groups. Keeney (1980) identifies three screening procedures commonly used for the initial phase of selecting candidate sites:

1) *Exclusion Screening*. A site is excluded by the list of potential candidates because it does not meet an exclusion criterion. For example, land use restrictions around sensitive wetland areas or a restriction on locating a

nuclear power plant within a buffer zone surrounding a population area are examples of exclusionary criteria.

2) *Inclusion Screening*. A site is included as a candidate site because it does meet a particular criterion. For example, the inclusion of any site proximate to a coal mine for a coal power plant.
3) *Comparison Screening*. Sites are rated on a weighting scale and compared to determine their degree of suitability. A minimum cutoff level is used to categorize sites as potential candidates.

It is common for multiple techniques to be used in the selection of alternatives based on considerations such as available data, number of candidate sites included in the consideration of a set of alternatives, number of exclusionary of inclusionary factors, etc. The goal of this initial phase is simply to reduce the number of potential candidates to a small number that is practical to evaluate in greater detail. As such, non-compensatory methods[3] such as GIS-based Boolean overlays are a common method for performing screening procedures. Once such a screening process has been conducted, the remaining site alternatives can be evaluated against site-specific data that can serve as a basis for comparison. Keeney (1980) describes six categories for approaching a screening phase of the site selection process:

1. *Favorability Selection*. Sites are considered good enough based on their merits alone, rather than in comparison to other sites. Favorability scores are given to

[3] Decision rules are non-compensatory when low performance on one attribute cannot be offset by high performance on another attribute.

each candidate site by rating against a set of criteria typically yielding a set of potential candidate sites that meet a minimum score.

2. *Qualitative Comparison*. The comparison between potential sites is done in a performance matrix consisting mainly of qualitative descriptions of possible impacts.
3. *Cost-Effectiveness Analysis.* A focus on economic factors and impacts that can be easily monetized, whereas other dimensions such as aesthetics and judgments are typically omitted.
4. *Site Rating*. For the data collected in a performance matrix, a rating is assigned to each site via an informal method. Ratings are supported by value judgments that are never made explicit.
5. *Dominance*. A candidate site is ranked above other candidate sites if it ranks higher in each area of general concern.
6. *Cost-Benefit Analysis*[4]. Weights are assigned to each area of general concern. Each site is rated with respect to each concern, resulting in a rating of each cell in a performance matrix. Ratings are subsequently multiplied by a weight indicating the importance of each aspect of performance to derive a final site ranking.

Understanding Complexity

Not only are there a myriad of different decision types concerning the use of natural resources, but natural resource decisions are inherently complex. The development (or conservation) of resource endowments—mineral reserves,

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[4] Keeney's description of CBA would more appropriately be referred to as multi-criteria analysis as the methods and process he describes are common to a variety of multi-criteria procedures. Additionally, CBA is today commonly restricted to applications that compare decision variables in monetary terms alone, which is not his usage of the term in this context.

hydrocarbons, geothermal reservoirs, aquifers, coral reefs, etc.—leads to unequal benefits and costs for different groups of people at different points in time. Part of this complexity stems from the fact that the natural world is full of complex interactions between dynamic human, ecological and geological systems that interrelate through a variety of relationships expressed over different scale levels (ontological complexity). Second, natural resource DMs—whether they are politicians, regulators, private developers, or activists— must consider and weigh the importance of objective scientific data associated with risk assessments, economic valuations associated with immediate and future benefits, and normative claims stemming from local community values. This involves the need to balance overlapping and competing claims from various groups of people for whom a natural resource may hold different purposes, benefits, and meanings (societal complexity). And finally, human understanding of natural resources systems is often incomplete and clouded by uncertainty. This fact is further complicated by a human understanding of natural systems that is subdivided between various academic disciplines, which must be integrated to achieve comprehensive understanding of the problem at hand (analytical complexity).

Mollinga (2010) states that such sources of complexity necessitate a transdisciplinary approach to decision-making. This fact is in part due to the increased specialization and division of labor that exists between both expert communities and stakeholder groups. It is rare that DMs will hold complete knowledge over complex natural resource problems. More likely, information is distributed between technical experts, formal decision-makers, and stakeholders who each have specialized knowledge over some part or aspect of the complex social-ecological system in question (Beratan 2007). Transdisciplinary research is an approach to problem solving that seeks to address these challenges. It is defined as a research approach that includes multiple academic disciplines and includes interest groups (stakeholders) in all phases of the research. A transdisciplinary approach becomes necessary when 1) there is a socially relevant problem field, 2) those involved have a major stake in the issue, 3) there is societal interest in improving the situation, and 4) the issue is under dispute (Pohl and Hirsh Hadorn, 2007). Making good decisions about whether and how to develop a resource, therefore, requires not only collecting and analyzing a vast array of data, but a process that synthesizes information that is segmented between different groups.

Stakeholder Engagement

Over the last 50 years there has been a growing recognition that stakeholder participation is an important part of the decision-making process and crucial to help reduce conflict during a decision's implementation (Voinov and Bousquet, 2010). The siting of energy projects, in particular, has often led to controversy and conflict due to competing visions for land allocation or well-publicized studies of potential negative environmental or human health impacts of co-locating projects near urban populations. Mostashari (2011) discusses an example in the public debate that began in 1999 over the construction of the Cape Wind Offshore Wind Energy Project in Nantucket Sound, Massachusetts. More than a decade after the project was first proposed, fierce debate between those wishing for a new source of CO2 emission-free electricity and those seeking to protect the natural views of the bay resulted in numerous lawsuits that continue to slow the project's implementation. Mostashari observes that the failure to implement a coherent mechanism for involving different groups in the decision-making process has resulted in "conflict, politicization of the decision-making process, and distrust in the ability of the decision-maker to account for public interest and the understanding of the technical and engineering analysis process".

Strategies to avoid such an outcome can occur within many different domains. Departments, committees, companies, local and national governments, and any other group with a responsibility to make decisions has a vested interest in ensuring that the needs of those affected by a decision are met. To describe the individuals and groups who should be included in the decision-making process, we use the term "stakeholder", which in this context is defined as any subdivision of the public at large—policymakers, regulators, private businesses, non-profit organizations, citizen groups, financial institutions, scientific advisory boards, independent experts, etc.—that have a vested or professional interest in the decision outcome and are crucial to the success of any negotiated policies. Stakeholder groups can be small, such as in a private negotiation between a project developer and a potential investor, or large, such as in a public forum where siting approval is decided after numerous stakeholder groups are consulted. In either circumstance, a structured method of evaluating the competing objectives and preferences of each stakeholder group can facilitate better decision-making and increase the likelihood of a successful decision-making process. It is almost taken for granted today in western, democratic societies that some effort will be made to consult with citizens in matters that pertain to the "public good". Yet particularly in science and technology-intensive areas, public participation has historically been ad hoc and ineffective (Gough, 1998). Instead, decision-makers often rely solely on scientific and technical experts to provide opinions that, while technically feasible, ignore the social and institutional constraints that are just as important to a project's success.

In developing a structured site selection decision-making process to facilitate stakeholder engagement, a framework composed of two phases is proposed (Figure 1).

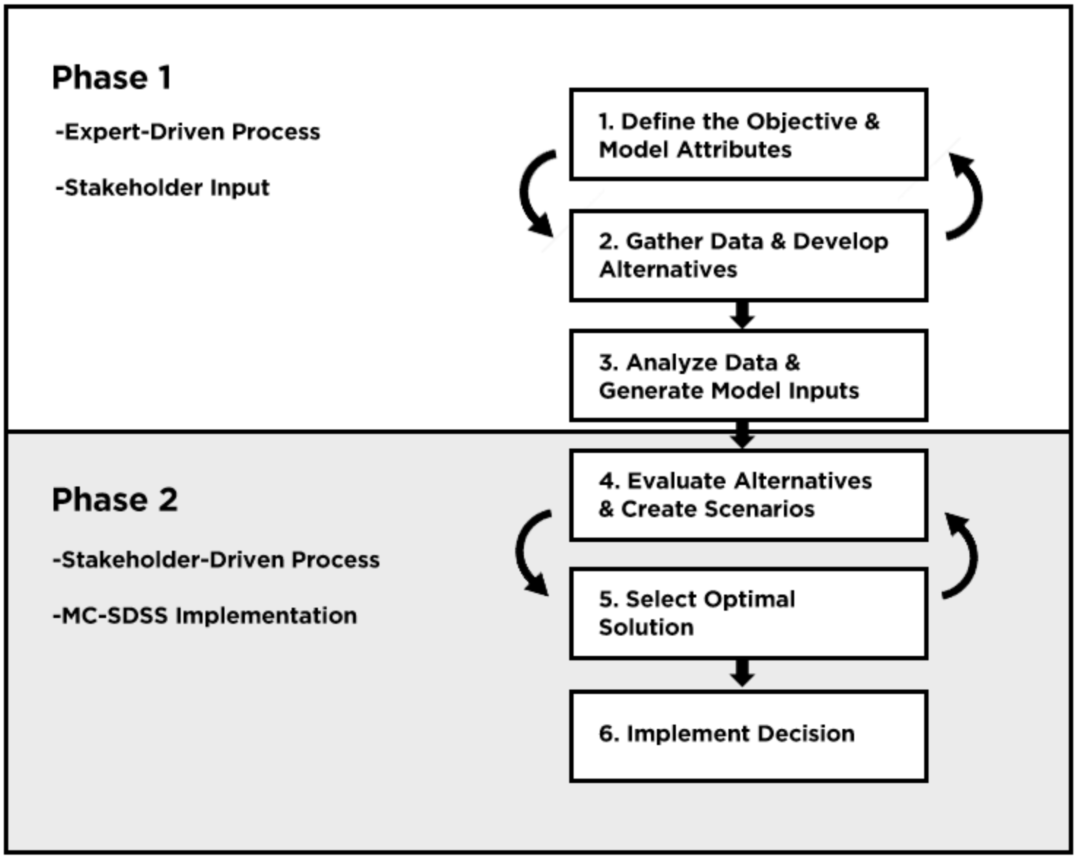

Figure 1: A two-phase process for structuring decision-making processes for site selection. Phase 1 describes problem framing, definition and analysis. Phase 2 involves the ranking, selection, and implementation of a decision.

Phase 1 represents the initial steps for defining the objectives and model attributes, gathering data and identifying siting alternatives, and evaluating spatial data to develop model inputs. These stages are guided by the judgment of the decision-makers and imposed by limits of available data. In a multi-stakeholder environment, the process of structuring a model hierarchy and gathering data should be a recursive process that allows for revision and improvement as stakeholder input is received, however, this phase is primarily expert-driven. This is because the process of developing formal analytical models, gathering and evaluation data, and mediating between different stakeholder objectives is a process that requires an external decision analyst or facilitator who holds an understanding of the analytical methods needed to perform the analysis as well as an objective view that accounts for competing interests. Furthermore, once the attributes of decision alternatives have been established, data collection and the generation of model inputs relies upon subject matter experts who are capable of analyzing, standardizing, and processing data inputs for use in the MC-SDSS. In the case study, this involved a literature review, fieldwork to collect geochemical data, and spatial analysis to synthesize and process multiple datasets.

Implementation of a MC-SDSS tool (explained in chapter 3) begins in Phase 2 once model inputs have been established. Stakeholder groups can use the MC-SDSS to view thematic map layers that contribute to attribute value calculations, access tabular and spatial representations of attribute data, and create scenarios by dynamically adjusting attribute weights within the model and exporting the results for comparison. As in Phase 1, the process for evaluating alternative scenarios and selecting a satisfying solution may be non-linear and involve multiple rounds of iterative revisions before a solution is selected. Importantly, the inclusion of stakeholders in each stage of the decision making process increases the likelihood that a group will accept the decision outcome. This fact is reinforced by the concepts of boundary work that seeks to engage stakeholders in transdisciplinary research and use boundary objects to anchor stakeholder dialogue.

Boundary Work

There are many boundaries, or obstacles, that can potentially interfere with the execution of transdisciplinary research and/or stakeholder engagement. Boundaries can include intellectual boundaries between academic disciplines, cultural boundaries between different interest groups, expert-novice information gaps, etc. (Becher and Trowler, 2001). Oftentimes these boundaries can lead to "a profound mutual suspicion and incomprehension, which in turn has damaging consequences for the prospects of applying technology to the alleviation of the world's problems" (Arias and Fischer 2000). Moreover, effective environmental and natural resource policy decisions often require these boundaries to be crossed. White et al. (2010) states, that "effective environmental policy and decision-making requires action through coordination and communication between individuals and institutional actors spanning scientific and political spheres."

Numerous studies have examined the intersection between scientific and political knowledge spheres in an attempt to understand and enhance communication with respect to natural resource management (Jones et al., 1999; Cash et al., 2003; Lemos and Morehouse, 2005). These works provide the following observations:

1. The way issues are framed influences how knowledge and action are linked, which actors are empowered or disenfranchised, and what decision outcomes are reached.
2. The quality and depth of the linkage between information and action is related to stakeholder perceptions of the knowledge system and their perception of its credibility, salience, and legitimacy.
3. Boundary-spanning processes, organizations, and outcomes are a significant part of effective communication between multiple social spheres by facilitating interaction, communication, and stabilization.

To negotiate decisions between actors across different social spheres (scientific, political, indigenous populations, industry, etc.), boundary theory provides two key concepts: boundary organizations and boundary objects. According to Miller 2001, boundary organizations “refer to those social arrangements, networks and institutions that increasingly mediate between the institutions of ‘science’ and the institutions of ‘politics’ ñ understood as labels of different forms of life in modern society”. This same logic can be applied to boundaries between other social or economic spheres, such as the divide between a foreign multinational corporation seeking to develop an energy resource and a nation’s local or indigenous populations. In such circumstances, numerous boundaries (language, cultural, scientific, information, etc.) become intermixed. Boundary organizations play an important role in such scenarios by “internalizing the differences between actors and institutions on both sides of the boundary, negotiation across them to develop decision-making options, and producing boundary objects applicable to either side” (White et al., 2010). Moreover, when multiple stakeholder groups are present in a decision-making process, a decision analyst or team of decision-analysts may assume the function of a boundary organization by facilitating interaction between stakeholder groups, developing and articulating a formal process for accounting for stakeholder positions, and bridging the gap between analytical decision models and the their outputs. Figure 2 describes the relationship between stakeholder groups, an intermediary decision analyst or facilitator, the components of a decision support system, and the outputs of a decision-making process in the form of vision scenarios and choices.

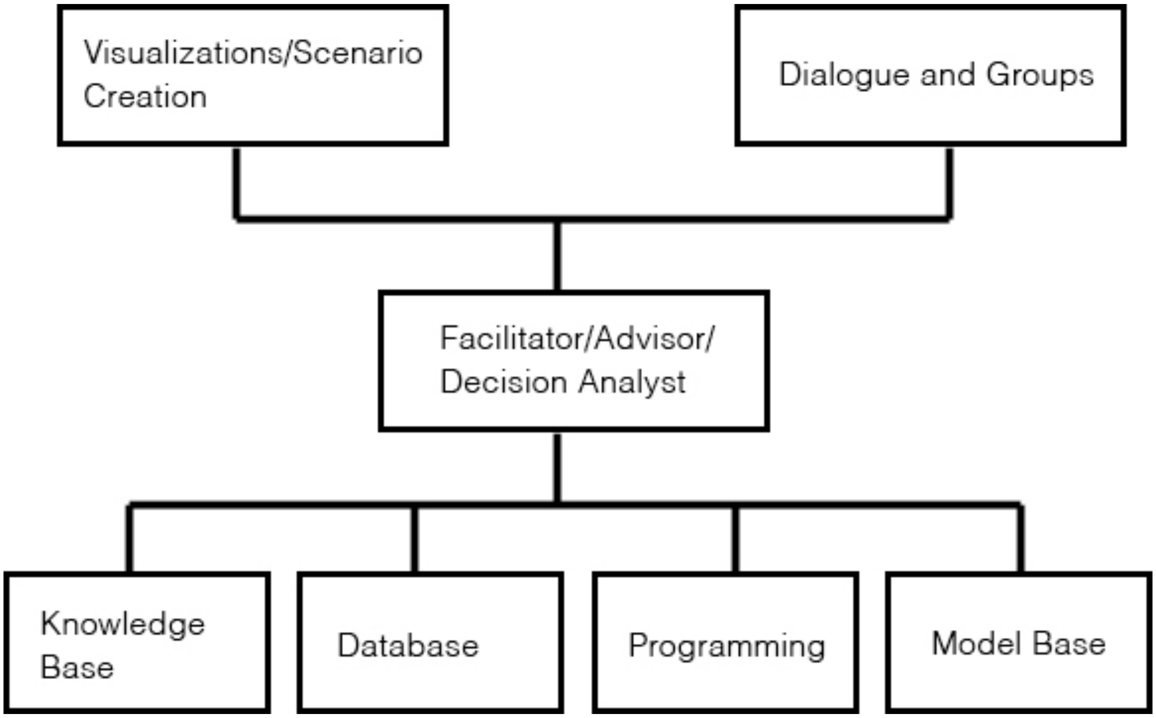

Figure 2: A decision-making schema describing the relationship between stakeholder groups, an expert facilitator, and decision model data and outputs (Hall 1997).

To support individuals or organizations facilitating a dialogue, boundary objects are tangible objects that serve to communicate and coordinate the perspectives of various constituencies in situations where each constituency has only partial knowledge and partial control over the decision making process. In this manner, boundary objects perform a brokering role involving translation, coordination and alignment between the perspectives of different stakeholders (Fischer and Reeves, 1995). This is accomplished by both supporting interaction between different stakeholder groups and bridging the gap between the real world problem and the computational models that represent them.

Arias and Fischer (2000) demonstrate the use of a horizontal electronic whiteboard as a boundary object to allow participants to develop a shared understanding and contextualize information. Using a reflection space or surface, they explain how in a decision-making process:

> "participants [can] work 'around the table' creating incrementally a shared model of the problem. They interact with computer simulations in the action space by manipulating three-dimensional, physical objects, which constitute a language for the domain. The position and movement of these physical objects are recognized by means of the touch-sensitive projection surface. In the figure, users are constructing a neighborhood through the use of a physical language appropriate for the problem by placing objects representing houses, cars, traffic lights, and so on. This construction then becomes the object through which the stakeholders can collaboratively evaluate and prescribe changes in their efforts to frame and resolve a problem."

The concept of a 'shared space' was introduced by Schrage in 1995 and it describes the concept of adding symbolic aspects to a dialogue or deliberation in ways that augment shared understanding, interactivity, and memory (Schrage 1995). Recently, multi-touch technology has emerged as a powerful and disruptive tool for enabling interactive 'shared space' by creating a mechanism for collaborative display of information and knowledge for groups (Conklin, 2006).

Collaborative displays act as boundary objects, invoking the concept that technology can act as a translator between different understandings of a problem, or sets of information, and contexts (Bowker and Star, 1999). For example, using the MC-SDSS decision analysis application on a multi-touch surface can support conversations among groups with vastly different understanding of information, such as a geothermal exploration team composed of geophysicists, drillers, managers, engineers, and business consultants. The concept of a multi-touch surface as a boundary object is explained in further detail in the description of the GUI component of the MC-SDSS tool (Chapter 2).

Multiple Criteria Decision Analysis

Figueira et al. (2005) begins a comprehensive review of MCDA methods with a letter from Benjamin Franklin to Joseph Prestly that underscores many implicit assumptions often made about decision-making:

> London, Sept 19, 1772
>
> Dear Sir,
>
> In the affair of so much importance to you, wherein you ask my advice, I cannot, for want of sufficient premises, advise you what to determine, but if you please I will tell you how. [...], my way is to divide half a sheet of paper by a line into two columns; writing over the one Pro, and over the other Con. [...] When I have thus got them all together in one view, I endeavor to estimate their respective weights; and where I find two, one on each side, that seem equal, I strike them both out. If I find a reason pro equal to some two reasons con, I strike out the three. If I judge some two reasons con, equal to three reasons pro, I strike out the five; and thus proceeding I find at length where the balance lies; and if, after a day or two of further consideration, nothing new that is of importance occurs on either side, I come to a determination accordingly. [...] I have found great advantage from this kind of equation, and what might be called moral or prudential algebra. Wishing sincerely that you may determine for the best, I am ever, my dear friend, yours most affectionately.
>
> B. Franklin

Embedded in Franklin's reasoning is the insight that decision is inseparably linked to choices between competing alternatives that often represent different opinions and courses of action. Figueira explains:

> This is the approach considered by…Franklin, i.e., the approach of explicitly taking into account the pros and the cons of a plurality of points of view, in other words the domain of Multiple Criteria Decision Analysis (MCDA). Therefore, MCDA intuition is closely related to the way humans have always been making decisions. Consequently, despite the diversity of MCDA approaches, methods and

> techniques, the basic ingredients of MCDA are very simple: a finite or infinite set of actions (alternatives, solutions, courses of action...), at least two criteria, and, obviously, at least one decision-maker (DM). Given these basic elements, MCDA is an activity which helps making decisions mainly in terms of choosing, ranking or sorting the actions.

Belton and Stewart (2002) define MCDA as "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". Included in this broad description of MCDA are three key dimensions: 1) a formal, structured approach to characterize the decision components, 2) the presence of multiple criteria, and 3) that decisions are made either by individuals or groups of individuals. In contrast to other decision-making techniques (such as cost-benefit analysis), MCDA is a way of looking at complex problems that involve both monetary and non-monetary objectives. By breaking down a complex problem into a structured view of its component pieces – data, value judgments, uncertainties, risks, etc.—it allows the DM to form a coherent overall picture of the problem at hand.

A component of such analysis is the development of a decision hierarchy that indicates the relationship between and among decision objectives, attributes, and alternatives (Figure 3). An objective is defined as the desired end-state of the decision making process, which in the case study for this paper is the selection of an optimal site for siting a geothermal power production facility. Attributes are the variables that act as evaluating criteria for achieving the objective (for example, proximity to transmission lines), and alternatives represent the set of possibilities available to decision-makers in evaluating the objective. According to Keeney (1980), model criteria (or attributes) should be selected to minimize the number of attributes, while ensuring that the set of attributes is (1) complete (the attributes adequately represent all relevant factors underlying an objective), (2) operational (they can be meaningfully used in analysis), (3) decomposable (alternatives can be evaluated based on each attribute independent of the others), and (4) non-redundant (attributes do not reflect the same underlying factors). Often satisfying all of these criteria may not be feasible given available data, however, limitations and assumptions used in selecting model inputs should be presented to stakeholders early on in the decision-making process. Malczewski (2000) provides a summary of best practices for defining and selecting a hierarchical set of process objectives and attributes to be used in a multi-criteria decision model.

Importantly, the purpose of MCDA is not to make a decision, but to serve as an aid to thinking about the decision. As Belton and Stewart 2002 state, the "focus is on eliciting and making transparent the values and subjectivity that are applied to the more objective measurements, and understanding their implications." The objective of a MCDA procedure is not always to identify an optimal solution, but rather to make the linkage between different evaluation criteria, DM preferences, and other decision variables more transparent.

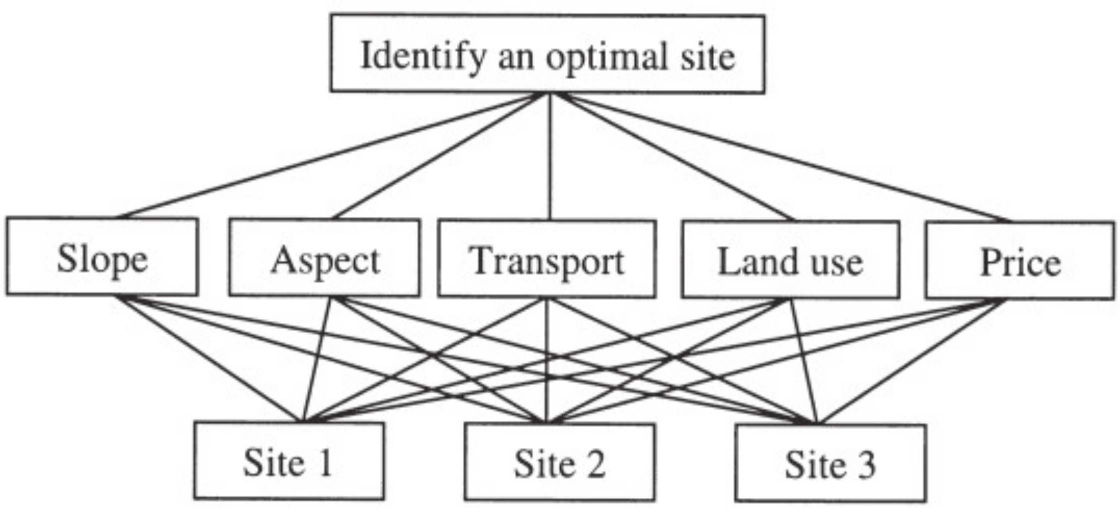

Figure 3: Example Hierarchical Model for Site Selection (Zhu and Dale 2001)

The importance of transparency is highlighted by a notable example of analysis for potential disposal sites of nuclear waste (Merkhofer and Keeney 1987). After five potential sites were evaluated and ranked according to a MCDA procedure, the federal government announced that the three sites to be investigated further were those ranked first, third and fifth in the MCDA. The resulting public acrimony led to a Congressionally-directed investigation and numerous lawsuits filed against the federal government alleging violations of federal laws in the selection process. The investigation concluded that the MCDA analysis was methodologically sound, but that the U.S. Department of Energy's decision to select potential sites from the list of five was flawed. The well-executed MCDA analysis provided an audit trail that allowed an investigation to evaluate the decision-making process. Such transparency and accountability is vital for issues of major public concern, which is relevant to many natural resource issues, and in particular, the siting of energy facilities.

These key dimensions are the primary reason why MCDA methods add value in natural resource management where there is a need to structure and apply a rational approach to integrating key decision variables. Natural resource management almost always involves decisions concerning the multiple possible uses of a resource and the presence of multiple stakeholders groups who each hold their own, independent opinions, goals, and demands on how the resource should be managed (Mendoza and Martins, 2006). MCDA is also well suited to situations where both quantitative and qualitative data is encountered and a decision-making process is often non-linear, iterative, and highly customized to the issue at hand.

Belton and Stewart (2002) summarize the characteristics of MCDA that make it an appealing and practical method as 1) seeking to take account of multiple, conflicting criteria, 2) helping structure the problem from a management perspective, 3) providing a model that can serve as the focus of discussion, and 4) offering a process that leads to rational, justifiable, explainable, and transparent decisions.

Numerous literature reviews have been performed on the use of MCDA in environmental and natural resource fields over the past several decades. Each has found the number of instances where MCDA methods are applied has increased over the years (Figure 4) (Herath and Prato, 2006; Neste and Karjalainen, 2013, Mendoza and Martin, 2013). Linkov and Moberg (2011) conducted a literature review of MCDA applications within environmental decision making for articles published between 1990 and 2009 in a selection of relevant journals and found the number of papers published between 1990-1999 and 2000-2009 increased from 242 to 765. Of particular note, they found that three MCDA methods were most common – Analytical Hierarchy Process (AHP) papers have accounted for an average of 40 percent of those published after 2002, while Multi-Attribute Utility Theory (MAUT) and Outranking accounted for 16 percent and 13 percent respectively.

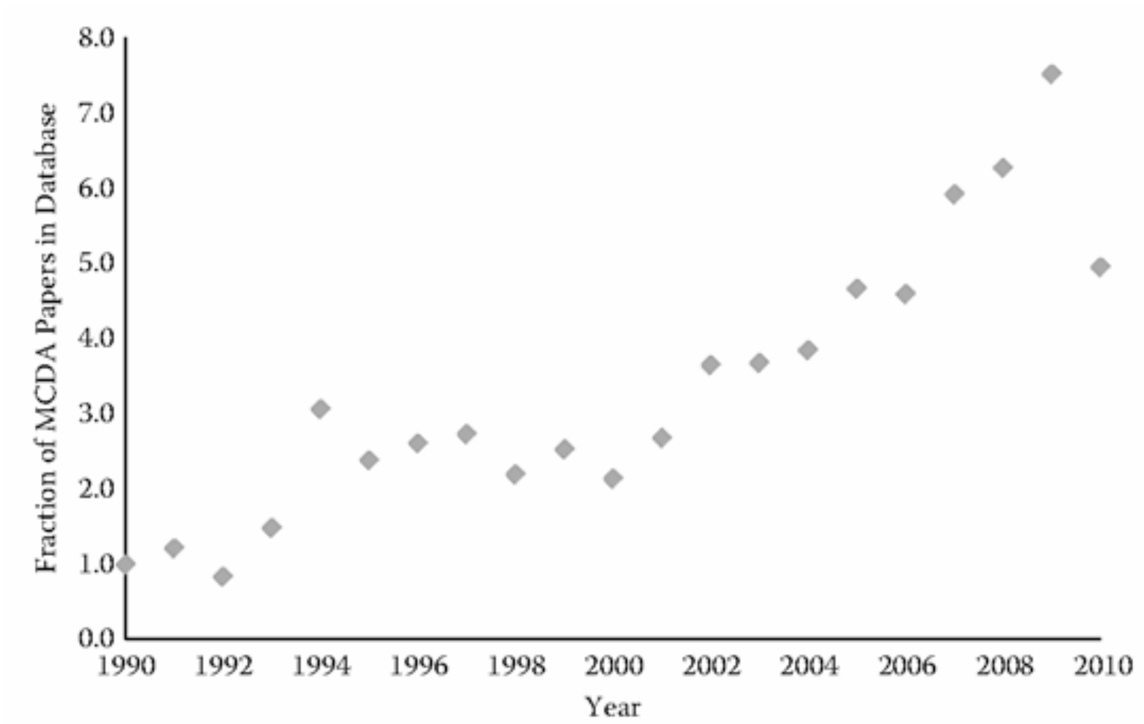

Figure 4: Number of MCDA papers in environmental literature as a fraction of total from Linkov and Moberg (2011).

MCDA Methods in Natural Resource Management

Different MCDA methods can be characterized by the number of, and relationships between, decisions, objectives, and alternatives. In each method, a set of prescribed rules describe a structure for completing a problem solution. At a basic level, most MCDA techniques involve the development of a performance matrix, or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The contents of each cell may vary in measurement between cardinal numbers, binary terms, and qualitative descriptions. It is the formal structure of the matrix that is important to the MCDA technique. Two other common components of MCDA methods are the numerical analysis of a performance matrix by scoring and weighting the contents of each cell. Scoring involves assigning a numerical value to the data contained in each cell according to the strength of preference for each option in the criteria (commonly on a scale from 0 to 100 with higher values indicating a more preferred option). Numerical weights are often assigned for each criterion to indicate the relative importance of high or low scores between each criterion.

Greene et al. (2011) provides a diagram indicating a decision tree that can be used to select appropriate MCDA techniques (Figure 5). The most basic division is between multi-objective (MODM) and multi-attribute methods (MADM). Multi-objective methods are used when competing objectives exist, such as a scenario when future benefits come at the expense of current benefits or when environmental and economic objectives require a tradeoff. Generally, multi-objective decision rules are compensatory, meaning that low values in one attribute can be compensated for by equal or higher values in another attribute. Multi-attribute methods, on the other hand, are most often used when a large number of alternatives must be considered. It can also be used with when multiple objectives are present but are either complementary or hierarchical instead of conflicting. Multi-attribute decision rules can either be compensatory or non-compensatory. Due to the complexity and multiple phases of decision analysis, often a combination of decision rules will be used—for example, a non-compensatory technique could be used for a preliminary screening of alternatives, followed by a compensatory method to support a final decision (as described in Keeney's phases of site selection). The wide variety of MCDA methods that exist reflect the diversity of decision types to which MCDA has been applied, as well as variations in the amount of time, available data, analytical skill, and computing resources available to the DMs. Three main types of MCDA methods commonly used in natural resource management are Multi-attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP), and Outranking.

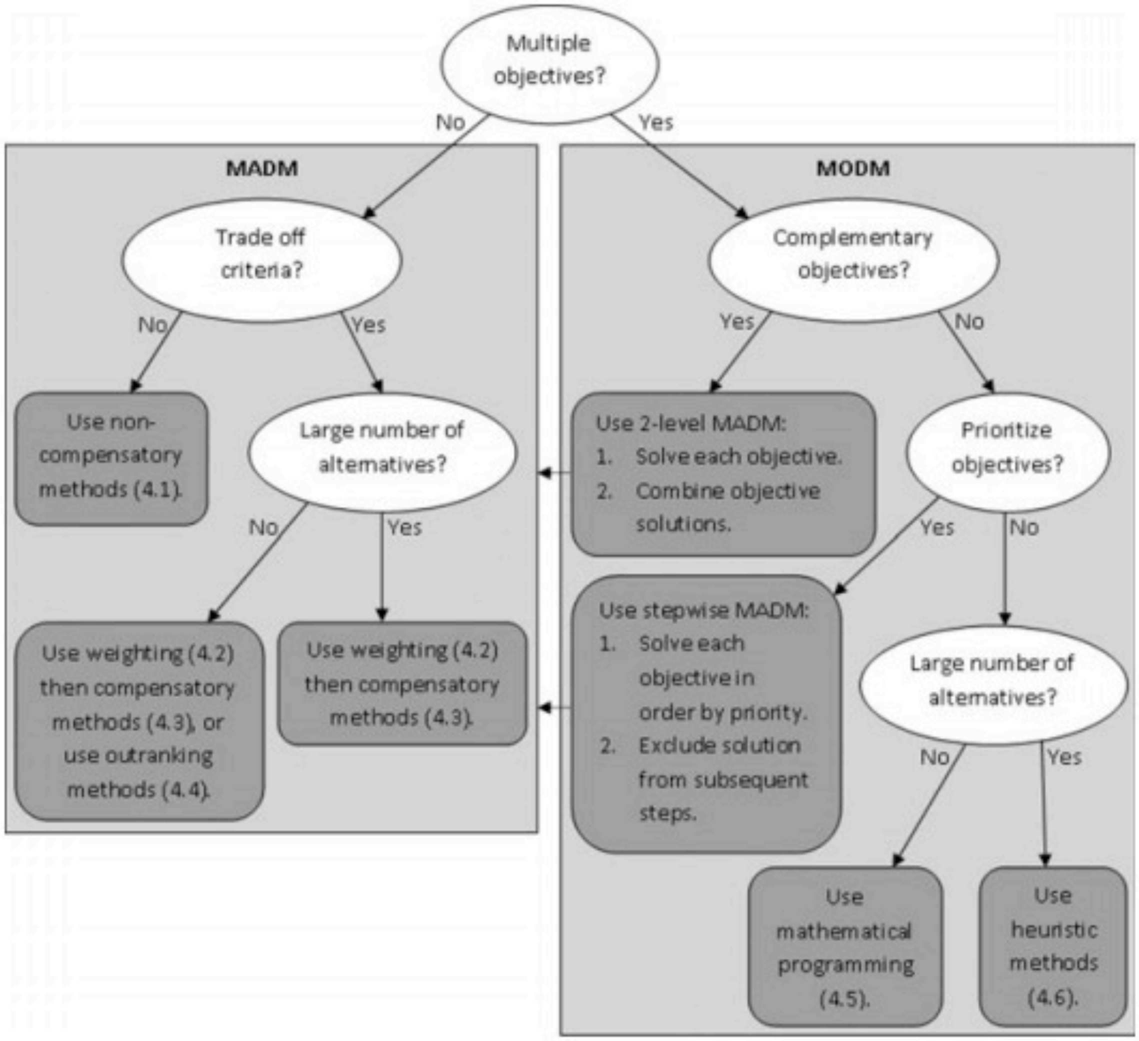

Figure 5: Multiple-criteria decision analysis methods decision tree from Greene et al. (2011).

Multi-Attribute Utility Theory

Multi-attribute utility theory (MAUT), pioneered by Keeney and Raiffa (1976), is an approach that assigns a utility value to each action or alternative considered in a finite set of alternatives. In doing so, MAUT analysis makes use of value judgments that determine the relative desirability of high or low values each alternative received when scored against the decision criteria. In their seminal work, Keeney and Raiffa provide a set of procedures for applying multi-criteria analysis (Keeney and Raiffa, 1976). Their procedure is composed of three principal components. First, a performance matrix is developed that describes the various levels of performance of each alternative across a set of evaluation criteria. Second, procedures are conducted to test the independence of evaluation criteria, and third, a single number index, U, is developed to express the decision-maker's overall valuation of an option in terms of the value its performance has on each of the separate criteria. The primary purpose of this type of analysis is to explore the connection between the ranking of alternatives and the facts, assumptions, and value judgments that influence the ranking. Commonly, the utility of any given alternative is the additive sum of marginal utilities each decision choice (alternative) scores against each attribute (measure).

Methodologically, the critical step is determining a utility function that describes how much satisfaction a decision-maker derives from various levels of performance on each criterion. A simple linear value function could assign a value of 0 for the lowest potential value and 1 at the highest potential value, while other methods may include exponential, step functions, etc. Once each value function is established, an overall score for each alternative is determined by applying an aggregation model to combine different criteria scores into a single value. Numerically, a multi-attribute utility model can be represented as $u(x_1, x_2, \ldots, x_n)$ where x_i represents the performance score on alternative i. The most basic aggregation method is an additive model that can be represented as follows:

$$u(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i \, u_i(x_i) \qquad \text{(Eq. 1)}$$

where $u_i()$ is a single-attribute value function over alternative *i* that is scaled from 0 to 1, w_i is the weight for measure *i,* and $\sum_{i=1}^{n} w_i = 1$. Importantly, the use of an additive model is dependent upon the assumption of mutual independence among preferences.[5] Criteria are preference independent if preference scores for one criterion can be assigned without knowledge of the preference scores for other criteria. In cases where independence of preference cannot be established, the following multiplicative model may be used:

$$1 + kU(x_1, \ldots, x_n) = \prod_{i=1}^{n}[1 + kk_i u_i(x_i)] \qquad \text{(Eq. 2)}$$

where $u_i()$ is the single-attribute value function scaled from 0 to 1, k_i represents scaling constants subject to the constraint $0 \leq k_i \leq 1$, and k is an additional constant indicating the interaction effect of different criteria.

Analytical Hierarchy Process

One of the most commonly applied methods in natural resource management is the Analytical Hierarchy Process (AHP) developed by Saaty (1980). Instead of using weights and value functions, each criterion is compared to another criterion through pair-wise analysis. In this process, the judgment of the decision maker(s) is used to determine the relative importance of each criterion, which results in the AHP equivalent of weights. Typically, AHP is conducted through series of questions where DMs rate the relative value of two criterion and these judgments are converted into numerical scores from 1-9. This analysis continues until all criteria have been evaluated. In AHP, the assumption of

[5] The requirement of preference independence is implicit across all multi-criteria techniques that employ a sum of weighted averages method of aggregation.

rational decision-makers is relaxed and comparisons by different decision-makers are not expected to be consistent (Linkov and Moberg, 2011). This makes the method appropriate for situations when the individuals selecting criterion weights come from a large group of stakeholders or interest groups.

After a set of criteria has been established, the method of pair-wise comparison involves a series of questions about the relative importance of each criteria as follows:

How Important is A relative to B	Preference Index Assigned
Equally Important	1
Moderately More Important	3
Strongly More Important	5
Very Strongly More Important	7
Overwhelmingly More Important	9

Table 1: Example preference index for AHP procedure (Saaty 1980)

A judgment value is assigned both to the comparison between A and B and its reciprocal B and A. For example, if B is felt to be very strongly more important than A, then the value of 1/7 would be assigned to A relative to B. From this information, a set of weights is assigned. Saaty (1980) sets forth a process for deriving weights that involves complex calculations usually performed with a special AHP computer package. However, the result is roughly equivalent to the following procedure. Consider a hypothetical matrix comparing pairwise judgments between three criteria:

$$\begin{bmatrix} 1 & 5 & 9 \\ 1/5 & 1 & 3 \\ 1/9 & 1/3 & 1 \end{bmatrix}$$

Weights for each criterion can be derived by 1) calculating the geometric mean of each row, 2) summing the geometric means, and normalizing each by dividing by the total for all combined averages. For the theoretical matrix above this calculation is indicated in Table 2.

Geometric Mean			Weight
Criterion 1	$(1 \times 5 \times 9)^{1/3}$	3.5568	0.751
Criterion 2	$(1/5 \times 1 \times 3)^{1/3}$	0.8434	0.178
Criterion 3	$(1/9 \times 1/3 \times 1)^{1/3}$	0.3333	0.07
Sum		4.7335	(=1.00)

Table 2: Calculation of AHP weights using geometric mean.

The process of pairwise analysis and weighting is performed for each level of a decision hierarchy. Finally, a check for consistency between weighting measures is performed by calculating a consistency ratio that is composed of a consistency index and random index[6].

Outranking

The use of outranking as a MCDA method originated with the work of Bernard Roy in France in the 1960s (Roy and Vanderpooten, 1996) Outranking involves the ordering of alternatives in an attempt to identify those that outperform or dominate other alternatives. In aggregating scores across multiple criteria, outranking models seek to establish evidence supporting the superiority of an alternative across the greatest number of criteria. In contrast to AHP, pairwise comparisons are performed between alternatives rather than between evaluation criteria. The use of outranking is common when criteria metrics are not easily aggregated, measurement scales vary greatly, and when units are incommensurate or incomparable (Linkov et al., 2004).

[6] Numerical representation of the consistency ratio is not performed here, but involves a calculation on the maximum eigenvalue of the matrix (λmax). A consistency ratio value less than or equal to 0.1 is deemed acceptable. Larger values require the decision maker to reduce the inconsistencies by revising judgments.

One of the most well-known outranking methods is the ELECTRE method (Elimination et Choix Traduisant la Réalité). It develops a subset of alternatives (E) such that any alternative outside E is outranked by at least one member of E. The aim of the analysis is to identify a short list of alternatives that is as small as possible. This is achieved through a process of defining and combining a concordance and discordance index. For each ordered pair of alternatives, the term concordance index, c(*i,j*) refers to a calculated value that is the sum of all the weights for each criteria where alternative *i* performs better than alternative *j*. By contrast, the discordance index, d(*i,j*), is calculated as a ratio between differences in performance between alternative *i* and *j* and the maximum observed difference in performance between any two alternatives on the criterion being evaluated. Finally, a minimum threshold value for a concordance index and maximum threshold value for the discordance index are used to establish dominance between alternatives.

GIS and MCDA

For approximately 40 years, MCDA methods have been used for spatial problems by coupling them with geographic information systems, or GIS (Carver 1991). GIS are computerized decision aids composed of geographical data (attribute data tied to locational information), an input/output process, a data analysis method, and a user interface. Malczewski (2004) provides a comprehensive review of the origins and history of GIS development. In its early stages, GIS was the domain of a small group of trained specialists. Before the advent of advanced computing technology, spatial analysis for tasks such as land use suitability began with the manual creation of shaded overlays that were displayed together to identify areas of conjoining or disjoining criteria[7]. Today, a

[7] Conjoinment and disjoinment are two commonly used spatial techniques to identify areas of intersection and exclusion based on relationship between spatial data layers.

variety of spatial evaluation tools are included in common GIS software packages, such as ArcGIS, which perform similar operations. Malczewski (2004) divides the modern era of computerized-GIS into three time periods: 1) the GIS research frontier between 1950-1970 where significant innovation occurred, 2) the development of general purpose GIS software throughout the 1980s (integration period), and 3) the proliferation stage where a variety of user-oriented GIS technologies have proliferated. It is during this last period from the mid-1990s to present where numerous technological advances have increased the adoption of GIS-based procedures across local, state, and federal governments as well as the private sector. Sugumaran (2011) writes,

> The ability to incorporate location information into decision-making processes has been democratized through the use of inexpensive Gobal Positioning Systems (GPS) and navigation systems as well as Web-based neo-geographical services provided by sites such as Google Maps, Google Earth, Yahoo! Maps, and MapQuest. These and many other Web sites use underlying databases of spatial information and processing algorithms to provide information to individuals and businesses about directions, locations of property for sale, locations of businesses such as hotels or restaurants, or weather forecasts for a particular place.

The evolution and democratization of these technologies has led to an exponential growth in their use by commercial, governmental, and academic decision-makers for a variety of complex problems. Issues such as emergency response and hazard management, land use planning, and public welfare services all now rely on complex spatial data matrices. Worrall (1991) estimated that 80 percent of data used by managers and decision makers is geographically related. The proliferation of spatial data since that time is only likely to have increased the pervasiveness of spatial data.

GIS practitioners have developed over the years a set of analysis procedures for processing spatial data. Greene et al. (2011) identifies numerous MCDA techniques developed by GIS practitioners to evaluate decision alternatives as well as weigh and aggregate multiple criteria. For example, GIS software typically includes spatial analysis tools for weighing and prioritizing spatial layers using ratings, ranking, trade-off analysis, and AHP. Non-compensatory aggregation methods are also a common feature and include the ability to combine spatial data through conjunctive, disjunctive, lexicographic, elimination by aspect, and dominance strategies (Belton and Stewart 2002, Malczewski 1999).

An example of a compensatory aggregation method in GIS is weighted linear combination (WLC). WLC, sometimes referred to as simple additive weighting, is one of the most commonly applied MCDA techniques in GIS research (Sugumaran, 2011). In GIS, WLC is used as a method of combining data layers of heterogeneous types in an attempt to capture the value judgments and expert opinions in a spatial environment. The WLC approach involves assigning weights of relative importance to each map layer in a way that reflects stakeholder or DM preferences. Malczewski 1999 summarizes the steps in the process as follows:

1) Define the evaluation criteria or map layers
2) Standardize each criterion map layer
3) Define the criterion weights or weight of relative importance
4) Construct the weighted standardized map layers
5) Generate an overall score by adding the weighted standardized map layers
6) Rank the alternatives according to the overall performance score

The method adds a layer of sophistication to GIS-based models by producing a range of scores across each alternative site as opposed to a simple binary representation of suitable and unsuitable sites. Criticisms of WLC have been made when there is a lack of independence among suitability criteria and the subjectivity of weights based purely on the experience of decision makers (Malczewski, 2011). Nevertheless, WLC remains one of the most commonly employed techniques in GIS-based suitability mapping.

SPATIAL DECISION SUPPORT SYSTEMS

Origins and Foundations of DSS Research

The literature on decision support systems has developed since the early 1970s through academic research across a broad range of disciplines and widespread commercial application of DSS technologies. Computer systems were first developed to support managerial tasks, such as the processing of payroll and inventory, and operational tasks, such as customizing delivery schedule to changing weather conditions, as early as the 1950s (Power et al., 2008). The development of a formal academic discipline studying the design and application of computerized decision support was not, however, established until Gorry and Scott Morton (1971) first coined the term in an article in the Sloan Management Review. Gorry and Scott Morton used the term to describe a framework for supporting managerial activity in unstructured and semi-structured decision environments—a framework that built upon Anthony's categories of managerial activity (Anthony, 1965) and Simon's taxonomy of decision types (Simon, 1960, 1977). As a result, the DSS discipline, established as a subset of information systems (IS) research, began with a primary focus on managerial, long-term, strategic decision-making.

Alter (1980) expanded the DSS framework by evaluating and grouping early DSS examples into seven distinct categories that described the basic operations they performed: file drawer systems, data analysis systems, analysis information systems, accounting and financial model-based DSS, representation model-based DSS, optimization model-based DSS, and suggestion DSS based on logic models. These categories were later revised—most recently by Power (2001, 2004)—to reflect advances in technology that have expanded DSS capabilities. Power's taxonomy grouped Alter's first three types as data-driven DSS, the second three as model-driven DSS, renamed suggestion DSS to knowledge-driven DSS, and adds communications-driven and document-driven DSS. Additional works that helped define the DSS discipline and provide a foundation for subsequent research include Scott Morton (1971), McCosh and Scott Morton (1978), Keen and Scott Morton (1978), and Sprague and Carlson (1982) (Arnott and Pervan, 2004).

As DSS evolved to become a distinct and unified discipline, several researchers have attempted to catalogue the intellectual structure and major subdivisions that have evolved within the field. Reviews of the history and evolution of DSS are provided by Powell (2001), Bargava et al (2007), Power (2008), and Sumugaram (2010). Other researchers have conducted empirical studies of DSS literature using bibliometric and co-citation analysis (Eom, 1995; 1996; 1999; 2004; Eom and Lee, 1990; 1993; Arnott and Pervan 2004).

Finally, the development of the Internet is one of the most significant advances in DSS and has given rise to the development of numerous web-based decision support applications. Web-based DSS are support systems built so DSS components can be accessed via an Internet connection (Chen et al. 2007). Web-based technologies facilitate collaboration between remote groups and allow systems to leverage computing resources beyond the capacity of Desktop solutions.

SDSS Components

The complicated nature of spatial decisions, wherein a vast amount of data must be gathered, stored, analyzed gives rise to a need for computer-based decision aids. Malczewski (1999) defines a spatial decision support system (SDSS) as “an interactive computer based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structures spatial decision problem”. As the name would suggest, SDSS is a combination of computerized support that integrates features of GIS and DSS. Figure 6 displays the structure of DSS and GIS components. The main difference between SDSS and GIS is the extension of GIS to include more sophisticated analysis procedures— for example, MCDA models suited to evaluating both spatial and non-spatial data—that are not inherent in GIS applications.

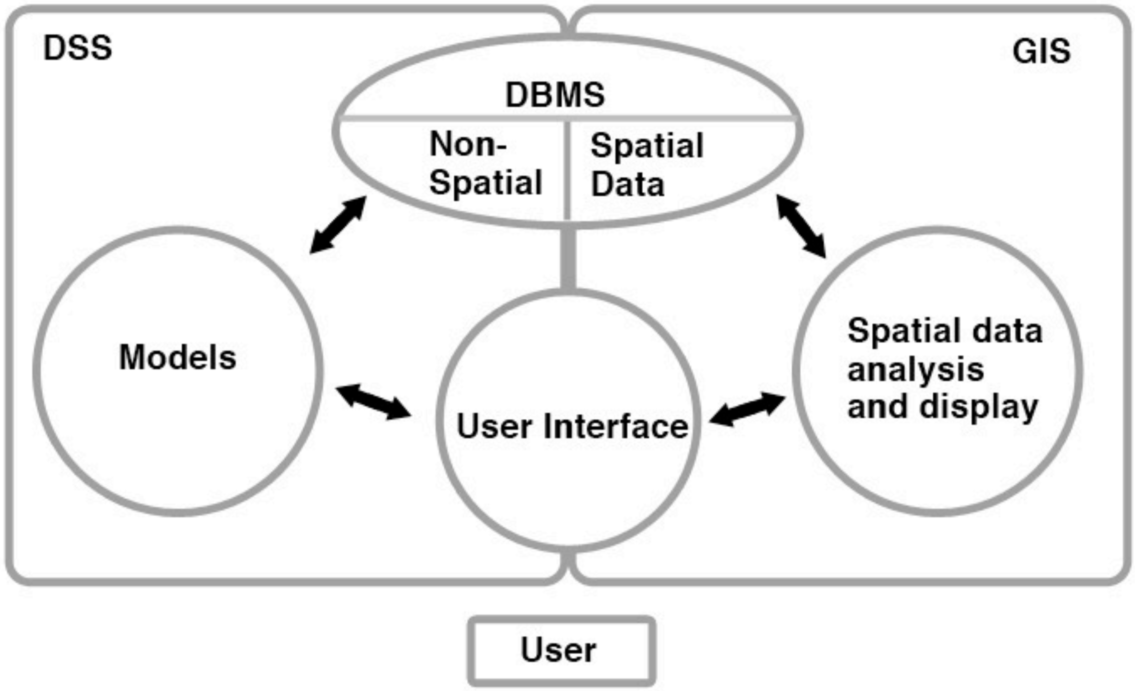

Figure 6: Traditional DSS and GIS components from Sugumaram (2011)

Goel (1999) and Sugumaram (2011) summarize numerous traits of SDSS, including that they are designed to solve ill-structured problems, they have user interfaces, they have the ability to flexibly combine models and data, they contain tools to help users explore solution space to aid in the generation of feasible alternatives, and they can provide an interactive and recursive problem-solving environment.

The main components of a SDSS can be divided into four categories—data management systems, analysis procedures, display and report generators, and a graphical user interface (Densham and Goodchild, 1989). There are numerous different models for how these components can be integrated. Nyerges (1992) developed a conceptual framework for integrating GIS with analytical models based on the degree to which the two tied together. He designates four levels with increasing degrees of integration:

- *Level 1: Isolated Application.* GIS and analytics models are embedded within separate physical systems. Data between systems is transferred manually through off-line file transfers.
- *Level 2: Loose Coupling*. The GIS and analytical models are run on the same machine or on networked computers. Data transfers are performed online, but formatting of input files is done manually by the user.
- *Level 3: Tight Coupling*. Data input/outputs are standardized between the GIS and analytical model databases. No manual processing is required, but the GIS and analytical models exist within separate software.
- *Level 4: Full Integration*. The system performs like a single program in which a single database management system serves both GIS and the analytical models.

These components should be designed and customized to maximize the usefulness of the tool to the stakeholder groups that rely upon the tool to interact with model parameters, evaluate alternatives and compare scenarios. Figure 7 describes the general architecture of a spatial decision support system as it relates to the different stages of a decision-making process. Importantly, different aspects of a SDSS are relevant to different stages of the process. During the initial stage of defining a problem and developing an evaluation criteria (intelligence phase), GIS methods are used. Once a decision criterion is developed, the evaluation of potential alternatives relies primarily on MCDA and the analytical models that will evaluate each alternative against the criteria and generate a performance matrix (design phase). And finally, during the final stage where DMs evaluate information, generate scenarios, and test the robustness of the MCDA model results, elements from both the GIS and DSS may be used.

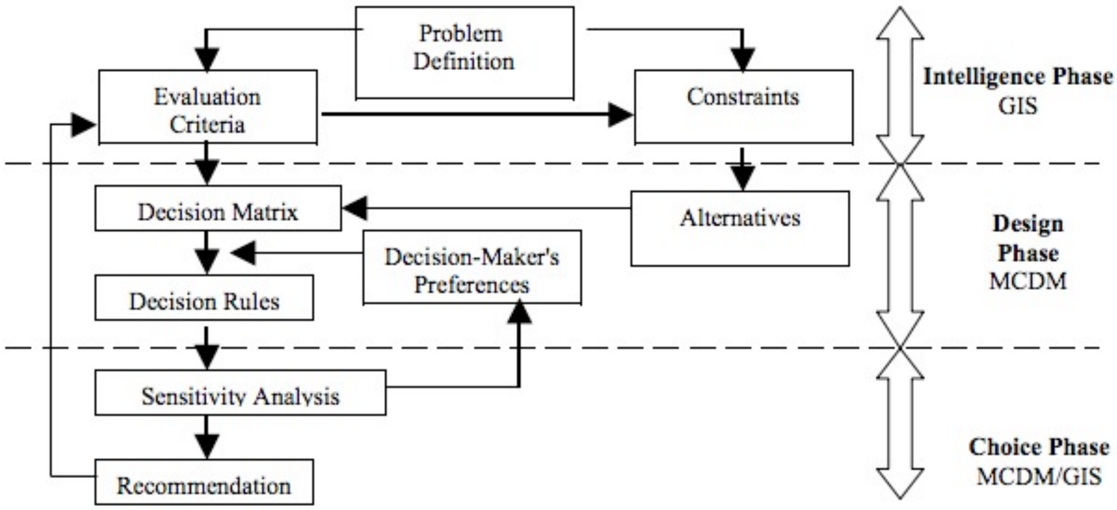

Figure 7: General architecture of spatial multicriteria decision analysis from Ozan et al. (2003)

Natural Resource Applications

In no field has the application of DSS been more prevalent than in the management of natural resources from both an energy and environmental perspective. This is not surprising as both fields were early adopters of geospatial analysis given the preoccupation in both fields with issues such as land use planning, environmental and watershed management, and habitat development. Sumugaram (2010) found in a survey of DSS application domain areas between 1978 and 2008 that natural resource management and environmental studies accounted for 23 and 14 percent of all publications respectively. Case study examples of DSS use in natural resource management include: Zhu et al. (1996), Geneletti (2004), and Pierce (2006). Segrera et al. (2003) describes the evolution of DSS architectures specific to natural resource applications.

Chapter II. Designing and Implementing the Heatseeker MC-SDSS Tool

The use of DSS to solve natural resource issues is increasingly common in both academic and business environments. Many commercial and open source software packages are available to perform DSS tasks for both spatial and non-spatial data. However, the desire to create a new MC-SDSS tool addresses numerous limitations of available DSS packages. First, DSS applications are often created for use on specific problem typologies and within specific spatial contexts (geographic region, scale of resolution, etc.). As such, DSS commonly include functionality that is not flexible enough to accommodate the range of tasks needed to apply the same tool to a new decision environment. Moreover, packages that are flexible are often labor-intensive and require significant cost and time overhead on the part of decision-makers to implement their use into a decision-making process. The ability to extend and modify DSS capabilities to accommodate new problem scenarios is often limited to the original group of creators, thus limiting its usefulness for decision problems that were not part of its development scope. The use of open-source, web-based GIS tools seeks to address this limitation and allow for incremental innovation by future developers. However, web-based DSS often encounter many of the same limitations. DSS applications are also rarely capable of being deployed in remote environments where limited computing resources are available. Web-based DSS applications typically do not have the ability to operate 'offline' in remote environments.

The following development and functionality requirements were identified as key to creating a flexible MC SDSS tool:

- Support spatial overlay consistent with favorability mapping and site selection procedures

- Accessibility using a standard web-browser with zero or minimal client-side dependencies
- Utilize open source software to the greatest extent possible
- Maintain data in a central repository with efficient input/output procedures
- Facilitate real-time collaboration among users through scenario generation
- Optimize the application for use on a multi-touch surface device

From this set of initial requirements, existing technologies were evaluated in relation to achieving these goals. This survey of existing technology yielded a secondary set of system requirements:

- Utilize open source libraries that work in popular and established browsers (such as Javascript libraries and Internet Explorer 7+ browsers)
- Avoid technologies with high client-side requirements (such as Flash, Silverlight, or ArcServer)
- Identify a data schema for storing data inputs that is interoperable with an open source GIS platform

Implementation

Typically, a web-based SDSS hosts the data management system, analysis procedures, and display and report generators on a remote web server that is accessed through HTTP queries submitted by a user through a web browser (Sugumaram 2010). The web browser in turn supports the graphical user interface (GUI) that provides users with access to the information. In the Heatseeker MC-SDSS tool, these capabilities are performed by client-side Javascript programming (Figure 8). The only server-side dependencies of Heatseeker are the spatial and non-spatial data inputs—thematic map layers, spatial and tabular data, etc.— that are retrieved when the MC-SDSS is accessed.

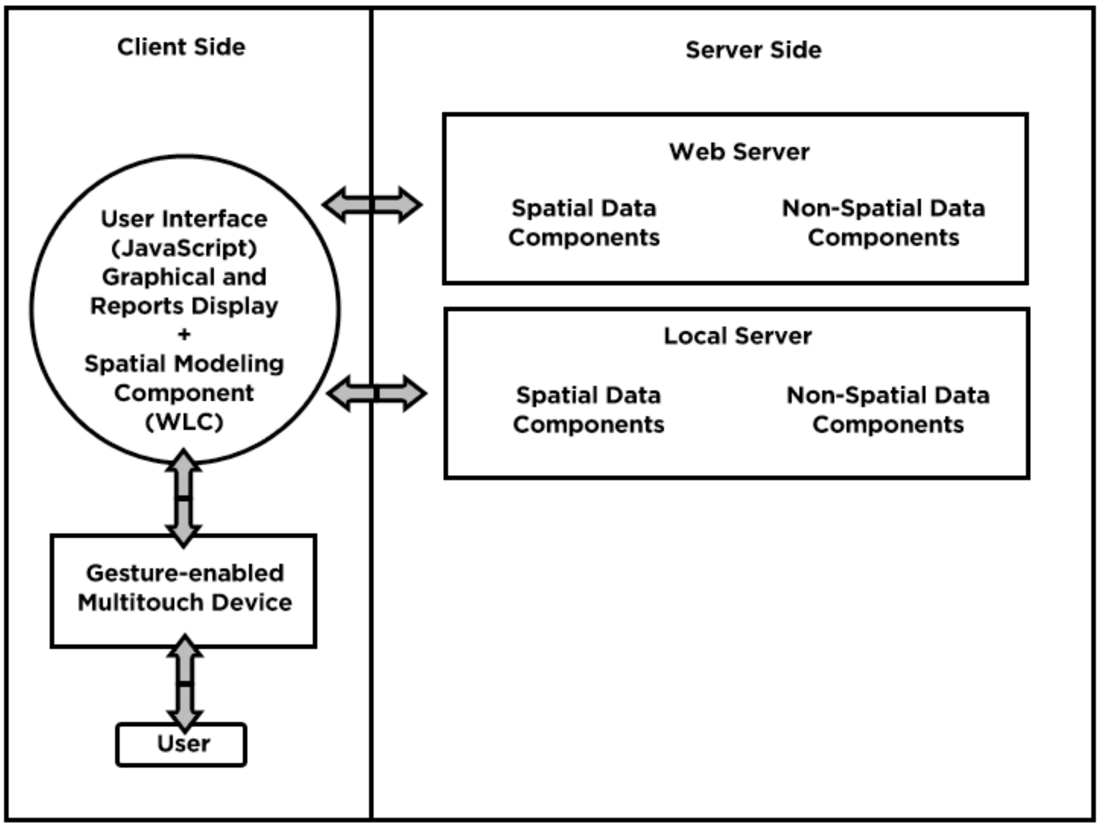

Figure 8: Client-side and server-side arrangement for the Heatseeker application.

An open source software solution called Mapbox was chosen for inclusion in the Heatseeker MC-SDSS to generate and integrate spatial data such as base layers, thematic map elements, and other information.. Mapbox provides numerous Javascript libraries and remote servers to host spatial data that can be integrated into a flexible and customizable map environment.[8] An accompanying software packaged called TileMill is used to create custom map features. One such feature is the ability to draw base layers and spatial overlays and output them as high resolution PDF files. In doing so, such output files can replace map elements hosted on remote servers, giving the tool the ability to operate without Internet connectivity. By implementing a flexible spatial database management system, a workflow is created that allows the tool to be viewed in 'offline mode' while retaining data analysis functionality.

The Heatseeker MC-SDSS tool relies on a number of Javascript libraries and APIs to perform various integration operations. For example, Mapbox.js and Wax.js are open source libraries that support the integration of spatial layers created in existing online mapping applications, such as TileMill, Modest Maps, or OpenStreetMap. Leaflet.js is an open-source library that supports mobile-friendly interactive map elements such as vector layer overlays, geoJSON[9] files for incorporating key features, map markers and controls, as well zoom and panning animation. These libraries are accessed either locally or online through an HTML container to perform basic map display functions.

A summary of the primary tools used in the Heatseeker prototype application and case study example (describe in Chapter 3) is summarized in Table 3. By relying on open-source APIs and Javascript libraries, the Heatseeker prototype develops a MC-SDSS tool that is flexible and easily adapted or modified for future use with technology solutions that are available free of charge, well documented, and easy to modify.

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[8] Detailed documentation on Mapbox, its API libraries, and functionality is available from http://mapbox.com

[9] geoJSON is a file format for encoding a variety of geographic data structures, such as polyline, polygon, and multipoint geometries.

Component	Technology	Source (if external)
Base layers	TileMill OpenStreetMap Mapbox	http://mapbox.com/tilemill/ http://www.openstreetmap.org/ http://mapbox.com
Javascript Library APIs and Spatial Processing	mapbox.js leaflet.js Wax	http://mapbox.com/ http://leafletjs.com/ http://mapbox.com/wax/
Vector Image File Format	SVG	
Tabular Data	Microsoft Excel XLS	
Display, Analysis and Report Procedures	Javascript	
Aggregation Method	Weighted Linear Combination (WLC)	
Web Browser	Internet Explorer 8.0+	
Single-Attribute Utility Functions	Logical Decisions	http://www.logicaldecisionsshop.com/

Table 3: Main component technologies used in developing the Heatseeker MC-SDSS

A key component of the MC-SDSS tool is the mechanism for connecting the tabular and spatial data associated with both the on screen display and the modeling operations. A Scalable Vector Graphic[10] (SVG) file is used to connect locational information about the spatial distribution of siting alternatives (coordinate data) to a relational database storing attribute values. In the case study, tabular data is stored in a Microsoft Excel document to facilitate any modifications or and updates to attribute data. These two features are connected through a unique ID tag for each alternative that can be queried to retrieve values used to perform map algebra and model operations. The SVG is generated prior to being imported into the MC-SDSS tool and includes coordinate data

[10] SVG is an XML-based vector image format that can be searched, indexed, and scripted.

that defines the positioning of the vector image to represent a geographic area. The SVG image then acts as the mechanism for displaying calculations generated by the aggregation and manipulation of elements in the MCDA model.

Beyond the display of spatial data, the core functionality of the MC-SDSS is the ability of users to view tabular and spatial representations of attribute values, adjust the attribute weights within the weighted linear combination (WLC) model, and export scenarios that reflect their preferences and value judgments.

Data Model/Analysis Procedures

The prototype Heatseeker MC-SDSS tool was initially developed to facilitate a site selection process for locating a geothermal energy facility and/or geothermal exploration/development strategy. Heatseeker is an interactive tool to support a decision process that involves spatial analysis of multiple criteria against a set of candidate sites. Figure 9 is a schematic representation of the conceptual aggregation and downselection process using spatial data and other problem specific attributes that forms a preliminary basis for implementation of the Heatseeker MC-SDSS tool to the initial case study. In the diagram, the use of single-attribute utility functions is described as the method for deriving numerical scores for each candidate site. However, the use of the Heatseeker MC-SDSS tool can be adapted for use in any MCDA method that develops single-attribute scores that are normalized onto comparable scales. From utility scores, the analysis procedures embedded within the system aggregates the single-attribute scores using an additive model.

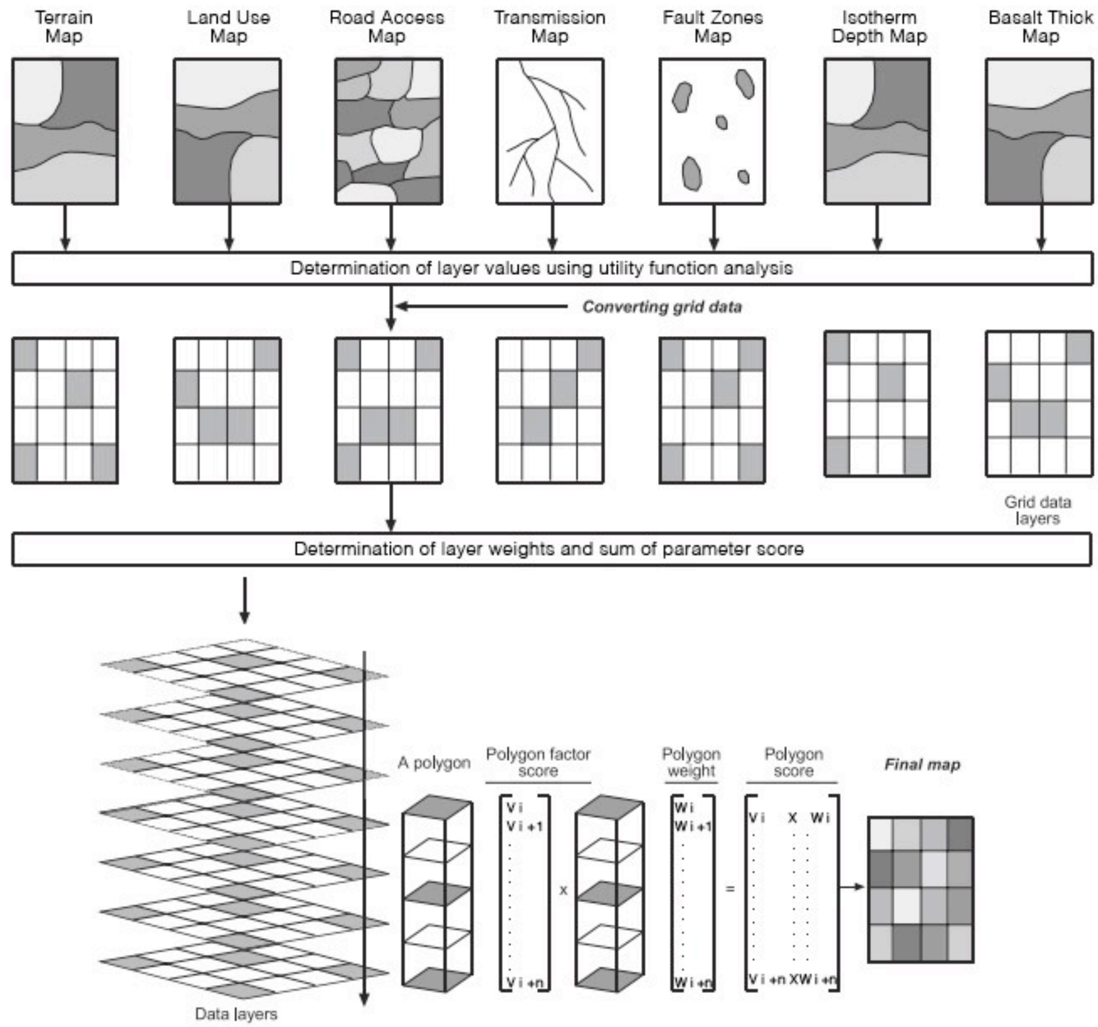

Figure 9: Schematic representation of spatial data processing through a MC-SDSS adapted from Ersoy and Bulut (2009).

The set of siting alternatives can be represented by $X = \{x_! \mid i = 1, 2, \dots, i\}$. Each alternative is represented by a set of coordinates stored within the SVG image file with the index i (acting as a unique ID tag) indicating the location of the i-th alternative.

Furthermore, each alternative can be described in terms of its locational attribute (coordinate data) and attribute data (values associated with the location).

The decision outcome (criterion value) can be designated by x_{ij}, which represents the level of the j-th attribute with respect to alternative i. As such, alternative i can be characterized by the vector in equation (1), and the levels of the attributes across the alternatives can be represented by the vector in equation (2).

$$x_{i*} = (x_{i1}, x_{i2}, \ldots, x_{in}) \qquad for\ i = 1, 2, \ldots, m. \qquad (Eq. 3)$$

$$x_{*j} = (x_{1j}, x_{2j}, \ldots, x_{mj}) \qquad for\ j = 1, 2, \ldots, n. \qquad (Eq. 4)$$

In the Heatseeker MC-SDSS tool, the input data for equations (1) and (2) can be organized and viewed in tabular form, using a Chart function, or stored and displayed in the GIS as a choropleth map that uses the SVG image container to associate attribute values with a color scale. Color values allow users to distinguish high performing alternatives from low performing alternatives in a visually accessible manner. In the case study example, the set of alternatives represents 104 equal area cells. However, because the SVG image container relies upon coordinate data, the set of alternatives can be composed of any number of two-dimensional coordinate systems that do not necessarily need to be equal area. The MC-SDSS scripting allows for a flexible number of attributes to be associated with the SVG image file for use in the WLC model.

A WLC model is applied to weigh attribute values and obtain an objective score (criterion value) for each decision alternative. This method is a widely used decision rule in GIS that is often applied for a variety of natural resource decision problems, such as land allocation, site selection, and resource evaluation (Hobbs 1980, Han and Kim 1988, Eastman et al 1995).

Given the input data, the WLC procedure is derived by the following value function:

$$V(x_i) = \sum_j \omega_j v_j(x_j) + \sum_k w_k v_k(x_k) = \sum_j \omega_j x'_{ij} + \sum_k w_k x'_{ik} \quad \text{(Eq. 5)}$$

subject to

$$0 \le \sum_j \omega_j \le 1 \quad (Eq.6)$$

$$\sum_k w_k = 1 - \sum_j \omega_j \quad (Eq.7)$$

where ω_j and w_k are the normalized weights of an attribute variable in each decision variable category, such as $\sum \omega_j = 1$, $v_j(x_j)$ and $v_k(x_k)$ are the value functions for the *j*-th and *k*-th attributes in each of two decision variable categories, and x'_{ij} and x'_{ik} are the values of each attribute after being transformed into a comparable scale. The choice of two decision variable categories was chosen based on the attributes chosen in the case study example, however, this value function can be modified to evaluate one or more categories depending on how decision-makers decide to structure the attribute-objective hierarchy. The weight of each attribute in the model must assume a value between 0 and 1, and are constrained by equation (5) to sum to a total weight of 1. This structure (two sub-objectives grouping multiple criteria) was hard coded into the Heatseeker MC-SDSS prototype to suit the parameters of the case study.

The default weighting in the Heatseeker application values each of the two sub-objectives—geologic and economic favorability— equally at 0.5 in the model. Within each sub-objective, each attribute is weighted equally. For example, by default a sub-objective grouping of three attributes would each be given a global weight of 0.165 (0.5*0.33) while a sub-objective grouping of four attributes would each be given a global weight of 0.125 (0.5*-.25). Users can perform sensitivity analysis on the model by manually adjusting the relative weight of each attribute in the model. However, it should be noted that the functionality of the MC-SDSS tool only allows users to evaluate the relationship between attribute weights and the overall alternative scores through either their visual representation or by viewing tabular data. The ability to store and evaluate the degree of change in alternative scores in order to perform more robust analysis is an area for further development. As such, the function of the MC-SDSS tool cannot provide end-to-end support for all analysis functions necessary to complete an MCDA process. It is necessary, therefore, for its use to be supplemented by additional decision aids where appropriate.

Graphical User Interface and Gesture-enabled Capability

The graphical user interface (GUI) is important to the effectiveness of the DSS because it is the delivery mechanism through which scientific information is accessed, model parameters are changed, and user-generated scenarios are generated and stored. Users should be capable of navigating the GUI efficiently and intuitively to access both tabular and graphical representations of the underlying information and model outputs. The main GUI of the Heatseeker application is shown in Figure 10.

The GUI is created for use in Internet Explorer 8.0+ due to the native support within the web browser for touch device gesture recognition. This, in combination with a multi-touch device, allows users to explore spatial data using common gesture controls such as panning (touch and drag the displayed map area with one or two fingers) and zooming (adjust the map scale by pinching fingers together). A global navigation bar allows users to toggle between the spatial data interface, a report generation function, and an export function for storing and retrieving user-create scenarios. A secondary dashboard allows users to adjust the weighting of model attributes, which triggers a recalculation of final multi-attribute scores for each alternative and redraws the choropleth map according to the recalculated utility scores.

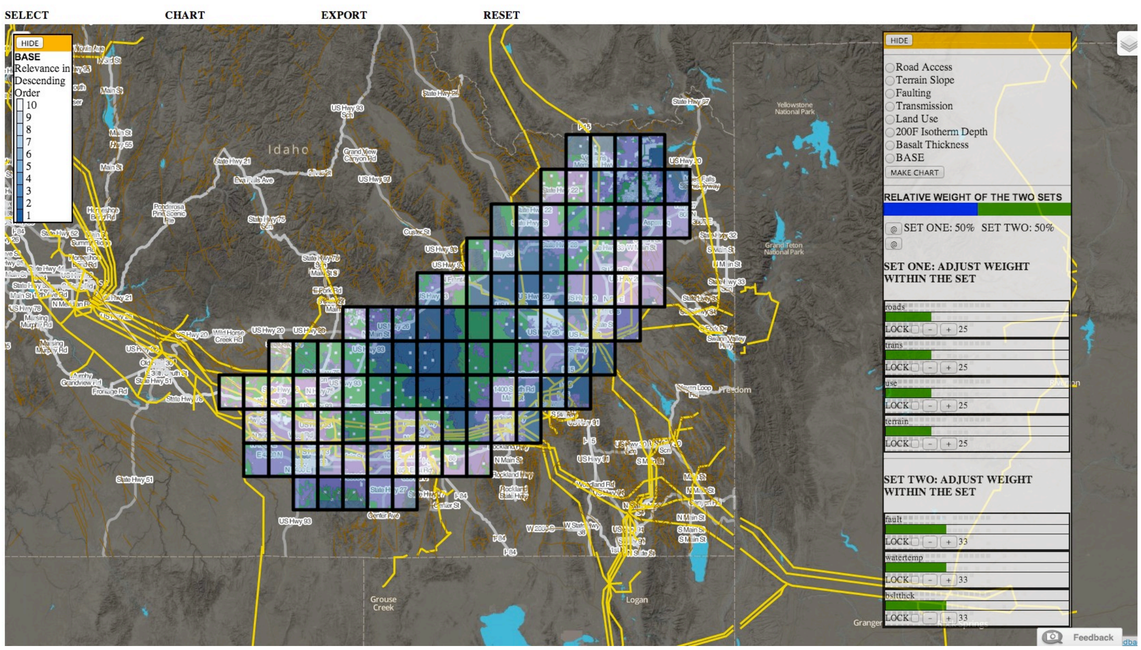

Figure 10: Main GUI of the gesture-enabled Heatseeker MC-SDSS tool

The evolution of human-computer interaction (HCI) is an emerging field of research for information science education (ISE). The 2013 Conference on HCI-ISE presented numerous examples of touch service devices being deployed in education- and research-oriented environments as a tool for enabling education and collaboration (McEver, 2013) The Heatseeker touchscreen serves as an interactive medium for delivering information so that a group can evaluate the combined information and knowledge about a field site simultaneously and the format will support substantive interactions among a team. An alternative example for possible uses of the technology and application may be in the context of stakeholder and public engagement. For example, technical teams from an industry can communicate about the intricacies of a planned development of a natural resource site with community members in an interactive manner that develops shared understanding. Key characteristics supported by the multi-touch device are its ability to:

- Support exploration of multiple alternatives where the process is no longer argumentative and an environment of collaboration is created.
- Allow for the creation of what-if, preference-based scenarios to support an iterative process toward mutual understanding.
- Generate low-cost, modifiable models that assist stakeholders in engaging in an interactive "conversation" with the system.
- Create transparency and credibility of a decision-making process by revealing the relationship between the data, models, and value judgments that influence a final decision outcome.

The code base of the Heatseeker application, including documentation is included in Appendix A. The code is also published under a GPL V2.0 license on GitHub and can be retrieved at http://github.com/djnoll/heatseeker/.

Chapter III: Heatseeker Application to Case Study - Geothermal Project Siting in Eastern Snake River Plain, Idaho

The development of the Heatseeker MC-SDSS tool is performed in support of a case study evaluation of geothermal resource potential in the Snake River Plane, Idaho. To evaluate geothermal favorability, multi-attribute utility theory is used as the primary method for comparing candidate sites across the decision criteria. This choice reflects the heterogeneity of model inputs and the desire to simulate a multi-stakeholder decision process. This chapter includes results and partial excerpts of the final report submitted the 2011 U.S. Department of Energy National Student Geothermal Competition.

BACKGROUND

The Eastern Snake River Plain (ESRP) in Idaho and eastern Oregon is a large, geologically complex, and relatively unexplored area for geothermal development. The definition of objectives and model attributes for the Heatseeker tool implementation is based on an investigation into the geological and socio-economic characteristics of the study area.

The case study is conducted in the eastern portion of the Snake River Plane (ESRP), a geographic area approximately 200 miles long and 60 miles in width (Figure 11). The ESRP has been underexplored for geothermal development with little extant well data and no current advanced geothermal energy projects. The eastern side of the plain is the youngest geologically and is proximate to the Yellowstone volcanic complex—the largest hotspot in the United States.

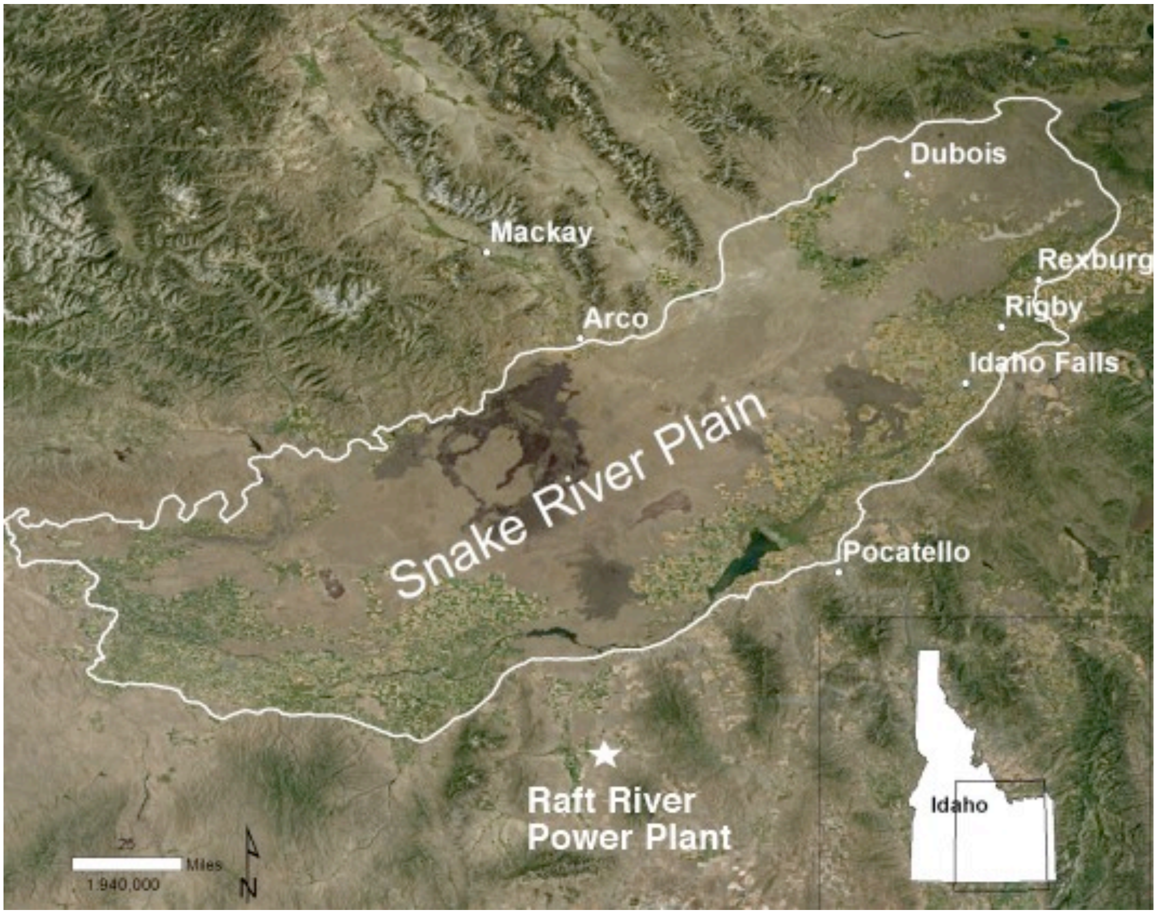

Figure 11: The eastern Snake River Plain, topographic map including boundaries of the SRP aquifer, major population centers, and location of the Raft River River Power Plant.

The ESRP was formed by a deposition of basaltic lava extruded from numerous vents across the plain. A recent study conducted by the Massachusetts Institute of Technology identified the area as a prominent potential geothermal resource while another study by the Western Governors Association Geothermal Task Force concluded that Idaho ranked 3rd behind California and Nevada in near-term geothermal power capacity (MIT 2006, WGA Task Force, 2006). Yet despite its relatively active geological setting, Idaho has not seen major development of geothermal power. The 10MW Raft River power plant, located on the very southern periphery of the eastern Snake River Plane (ESRP), is the sole operational geothermal power project in Idaho (Figure 11). To date, uneconomical conditions have limited characterization of Idaho's geothermal resource potential, but there is renewed interest in exploring geothermal energy for power production in region.

Geological Setting

The ESRP is characterized by two main regional geological characteristics, Basin and Range faulting, and magmatism resulting from the Yellowstone hotspot track. Given the lack of subsurface data available for the Snake River Plain, this case study uses a strategy for identifying geothermal reservoirs by focusing on areas with presently active faulting and fracturing. Using GPS measurements on a regional scale, the rate of extension for different geographic regions surrounding and encompassing the Snake River Plain have been determined (Payne et al, 2008). Strain rates for the normally faulted zones on the periphery of the Snake River Plain have been found to be in the range of $5.6 \pm 1.3*10-9$ yr-1 and $12.2 \pm 4.7*10-9$ yr-1. For the volcanically active region of the Snake River Plain strain rates are $1.6 \pm 4.8*10-9$ yr-1, (Payne et al., 2008). Furthermore, Figure 12 shows that most active faulting occurs along the periphery of the Snake River Plain.

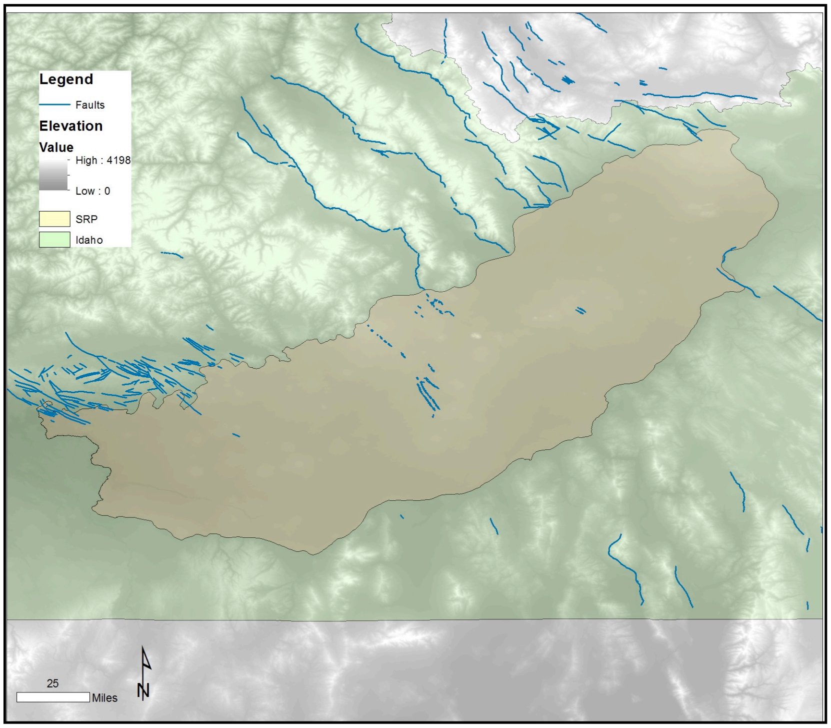

Figure 12: Diagram of Holocene faults from the Idaho Geological Survey database.

One of the key constraints of determining a viable geothermal resource is whether a defined resource has an existing reservoir. In a general sense, it is well known that permeability tends to decrease with greater depth, a relationship that has been discovered through the analysis of global data. This is because of a host of factors including, mineral precipitation, compaction, and hydrothermal alteration (Ingebritsen and Manning, 2010).

The relationship between permeability and depth poses a significant problem for geothermal resources because within crustal rock heat is also, generally, a function of depth. Therefore, to obtain heat from the subsurface one must balance the need for temperature, which will allow a geothermal plant to operate efficiently, and the need to pull significant volumes of water efficiently from depth within the reservoir. However, there are exceptions to this general rule. The most significant exception is an insight made by oil and gas operators as well as geothermal developers. They have discovered that low permeability matrix reservoirs can be efficiently produced if there are critically stressed fractures present. This idea is known as the *critically-stressed-fault hypothesis*, which states that faults and fractures that are hydraulically conductive today are those that are critically stressed in the current stress field (Zoback, 2007).

Given the evidence presented above, the search for conventional geothermal resources is focused on the presently active faults on the periphery of the volcanically active region. As a result, the location of active faulting in areas with high shearing rates is an important attribute considered in the decision model. Exploration in these areas will have a higher probability of containing fractured permeable reservoirs at depth.

Hydrological Setting

The ESRP is associated with a regional aquifer system that is hosted in Pliocene-aged fractured basalt flows. Several losing streams which are fed by snowmelt and runoff from the surrounding mountains provide a catchment and recharge to the aquifer (Roback, 2001). However the majority of recharge comes from irrigation return flow on the plain. Storage values for the aquifer are estimated to be 200 million acre feet, and studies have found the average groundwater residence time to be 50 years (Smith, 2004). The upper unconfined aquifer occurs in a Pliocene-aged fractured basalt layer averaging about 400 feet in thickness, which overlies a Miocene basaltic flow, and older silicic volcanic rocks are at greater depths.

Groundwater flow is generally towards the west-southwest, and the main discharge points are Thousand Springs and American Falls near Twin Falls, Idaho (Figure 13). Thousand Springs discharges about 5,200 cfs, comprising a majority of the total annual discharge. At a less regional scale, storage and flow is highly dependent on the presence of sedimentary interbeds and fractures, respectively (Welhan and Reed, 1997). A conceptual model of the system is shown in Figure 13. The Snake River is the major surface water expression of the hydrologic system. In addition, there is a strong link between surface and groundwater flow due to spring flow contribution in certain stream lengths (Whitehead, 1994).

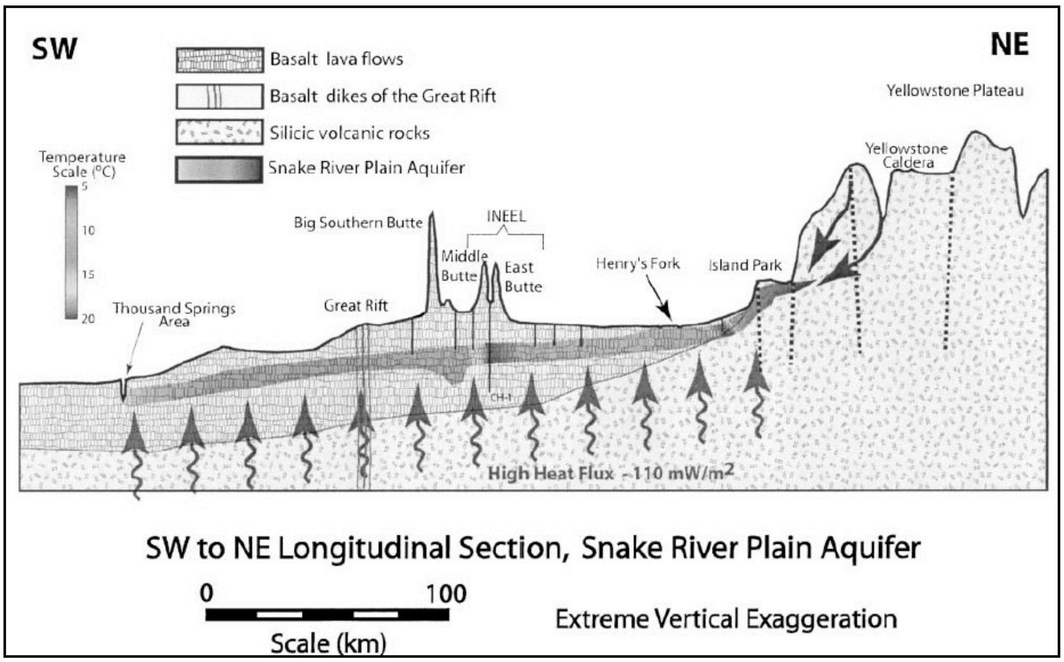

Figure 13: Conceptual model of the ESRP Aquifer showing the thermal gradients along the central axis of the plain (Smith, 2004).

Policy and Economic Analysis

A 2006 study by the Western Governors Association Geothermal Task Force concluded that Idaho ranked 3rd behind California and Nevada in near-term geothermal power capacity. Yet despite its relatively active and hot geological setting, Idaho has not seen major development of geothermal power (WGA Task Force 2006). Instead, electricity production in Idaho has historically been dominated by hydropower. In 2011, more than 80% of Idaho's net electricity production came from hydropower and an additional 8% from wind power. However, as Idaho's electric demand continues to grow it has needed to rely on imported electricity from outside of the state (EIA, 2012). Currently this does not present a major reliability problem, as this imported power comes primarily from coal fired generation in bordering states and the low cost of coal and hydropower have combined to make Idaho residential and commercial electric rates among the lowest in the nation.

Perhaps as a result of historically abundant resources Idaho does not currently have any state-level incentives or major restrictions with regard to development of geothermal energy. The state government has only recently moved to make changes to its state geothermal leasing policies (Streater, 2011). Unlike many western states, Idaho has not yet established Renewable Portfolio Standards (RPS) for its electric utilities. While utilities that operate in neighboring states have become subject to those states RPS, the Idaho state government has not actively promoted renewables through regulatory incentives.

Such incentives are needed by developers to offset the high upfront infrastructure costs associated with developing a geothermal project. Like other renewable resources, such as wind and hydro, geothermal energy is inherently constrained by geography. Its fuel source—geothermal steam—cannot be transported any distance. As a result, proximity to existing electric transmission infrastructure and road access are both critical factors in siting a successful project. With the cost of road construction ranging in the millions of dollars and new 138kv transmission lines costing approximately $400,000/mile developers immediately face major financial constraints before even beginning geological investigations.

Adding to the increased cost is the risk of extended development timeframes due to environmental and federal land use permitting. The Bureau of Land Management (BLM) owns nearly 12 million acres of land in Idaho, much of it within the eastern SRP. The process of winning a concession, leasing, and permitting on BLM land is well defined, but can often take multiple years and extended negotiation with the BLM and the National Forest Service. If at all possible, developers strongly prefer siting projects on private land where the timeframe and costs for permitting and negotiation are much lower.

In addition , surface and groundwater regulation are critical policy issues from a permitting perspective in Idaho. Idaho is an arid state and relies heavily on withdrawals of surface and ground water to fuel its agriculture-based economy. In 2005, Idaho ranked 3rd behind California and Texas in total water withdrawals per day (Barber, 2009). The Idaho Bureau of Water Resources has in the past issued moratoriums on geothermal development near sensitive areas in the southeastern portion of the SRP. While these moratoriums do not preclude geothermal development in the majority of favorable areas, they constitute the primary environmental impact risk for geothermal developers in Idaho.

While there are considerable regulatory and environmental concerns for developers of geothermal resources in the ESRP, these variables are typically difficult to quantify. Although energy project developers are attentive to potential growing regulatory risks, the factors of land use and infrastructure proximity were selected as dominant economic and regulatory variables. These attributes are well-defined risk factors that can greatly decrease project feasibility for a developer.

HEATSEEKER EVALUATION CRITERIA

To evaluate favorability across the ESRP, the study area is divided into 104 equal area land plots measuring 16.2 km by 22.2 km (Figure 10). This size roughly represents the size of a USGS quadrangle map and it was determined, after evaluating the regional geology and infrastructure, that additional granularity provided only limited value to the final analysis. Moreover, input data are received at varying levels of resolution and some of the challenges associated with cell size can be mitigated by aggregating data into mean values for each cell. However, it is acknowledged that there is no simple and satisfactory solution to the modifiable areal units problem for WLC (Goodchild and Quattrochi, 1997)

The objectives and attributes[11] used in the underlying ranking model for the Heatseeker tool are derived from a comprehensive evaluation of academic literature, industry white papers, and informal interviews covering the regional geology of the ESRP and the main drivers of geothermal exploration and siting costs. In the Heatseeker tool, objectives and attributes are arranged in a hierarchy, as shown in Figure 14. The hierarchy emphasizes two main objectives—geological favorability and physical/economic favorability—under which seven attributes are arranged. The attributes scores (measures) for each alternative determine to what extent implementation of an alternative would satisfy each objective. These values (developed in an expert-driven process in the initial phase of Heatseeker design and implementation process), in combination with the weights assigned by users of the Heatseeker application (in the second phase of the process), combine to yield a composite score reflects the overall

[11] In the software package Logical Decisions, objectives and attributes are described as goals and measures, respectively.

desirability of each alternative. The model is constructed so a higher overall score indicates a more desirable alternative on a 100-point evaluation scale.

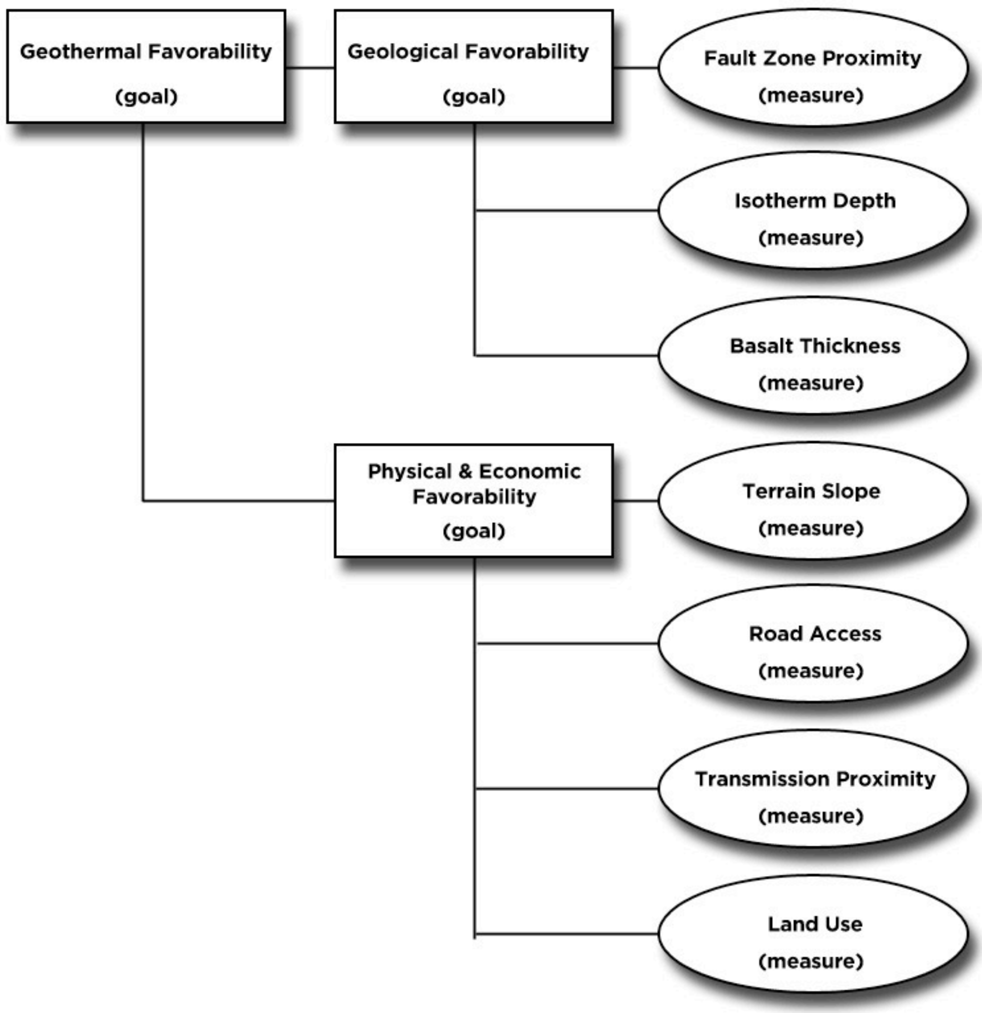

Figure 14: Heatseeker decision model hierarchy displaying objectives (goals) and attributes (measures) for the Eastern Snake River Plain case study.

GENERATING ATTRIBUTE VALUES AND MODEL INPUTS

Seven input variables were selected for use in the Heatseeker MC-SDSS decision model: water temperature at depth, basalt thickness, fault zones, land use, road access, and transmission. A summary of model attributes, including data type, units, min and max values, and sources is provided in Tables 4 and 5, and source information is contained in Appendix B. In some cases, these attributes can be measured on a natural scale, such as depth from surface or travel miles. In other cases, it is necessary to construct scales that required estimates for alternatives based on expert judgment, such as in the case of land use restrictions where judgments must be made about the relative value of differences in land ownership. Spatial analysis using ArcGIS is used to derive initial performance values for each alternative against the set of criteria. Next, to measure the relative attractiveness of each alterative the values for each attribute are normalized onto comparable scales using single-attribute value functions. A combination of linear, step function, and exponential utility curves are used depending on the nature of the attribute being evaluated. Constructing these value functions is accomplished using the software program Logical Decisions™.

Attribute (model abbr.)	Description
Water Temperature (wtr_tmp)	Mean distance to 200 degree Fahrenheit Isotherm
Basalt Thickness (bslt_thk)	Mean vertical thickness of basalt layer within site alternatives
Fault Zones (faults)	Horizontal distance from centroid of site alternative to existing faulting
Land Use (land_use)	Calculated value of land use restrictions and ownership between federal, state, indian country, and private lands.
Road Access (roads)	Existence of built roads within territory of site alternatives
Terrain (terrain)	Calculated value of land availability based upon mean values of terrain slope
Transmission (trans)	Horizontal distance from centroid of site alternatives to 138kV+ Transmission Lines

Table 4: Multi-Criteria Decision Analysis Attributes and Descriptions

Attribute	Datatype	Units	Min Value	Max Value	Utility Function
Water Temp	Spreadsheet	meters (ft)	0	10000	Exponential
Basalt Thickness	Digital Map	feet (ft)	0	4000	Exponential
Fault Zones	Shapefile	feet (ft)	0	56000	Step Function
Land Use	Shapefile	percentage (%)	0	100	Linear
Road Access	Shapefile	binary	0	1	binary
Terrain Slope	Digital Elevation Model	degrees	0	100	Linear
Transmission	Shapefile	feet	0	56000	Step Function

Table 5: Multi-Criteria Decision Attribute Data Types, Value Ranges, Units, and Utility Function Types

Geological Attributes

Water Temperature

Antecedent water data was acquired from three independent archives: Mariner, USGS NAWQWA, and the SMU Geothermal Database[12]. Ultimately, this layer integrates an understanding of groundwater occurrence and flow, as well as thermal gradients in the SRP. One of the main challenges for this layer is to tease out the thermal gradient from a bimodal temperature distribution. The anomalously high temperatures in shallower wells are likely a function of highly fractured and thus permeable rocks near the surface, and wells that bypass this zone show a more typical thermal gradient.

In total 922 well data points were used in the GIS water analysis, which consists of creating pilot points across the plain and selecting the nearest wells (Figure 16a). Using the bottom hole temperature to depth plots, a linear regression established depth to the 200 degree Fahrenheit (93 degree Celsius) isotherm for each of the clusters. The

[12] Detailed source information is included in Appendix B.

isotherm is chosen based on the minimum values for binary cycle power generation. A mean depth to isotherm value is calculated for each cell, after which the relative attractiveness of each alterative is determined by calculating a utility value between 0 and 100. The single-attribute utility function holds an exponential curve, reflecting the decision-makers belief that isotherm depth acts as a function of drilling cost with higher costs associated with greater depths.

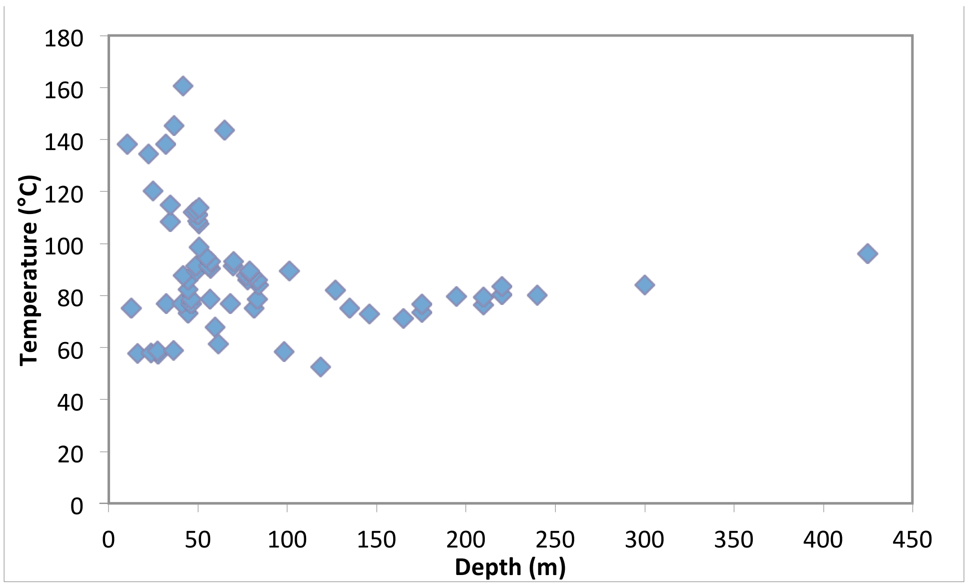

Figure 15**:** Graph of the bimodal temperature depth relationships for a selected cluster of SRP wells.

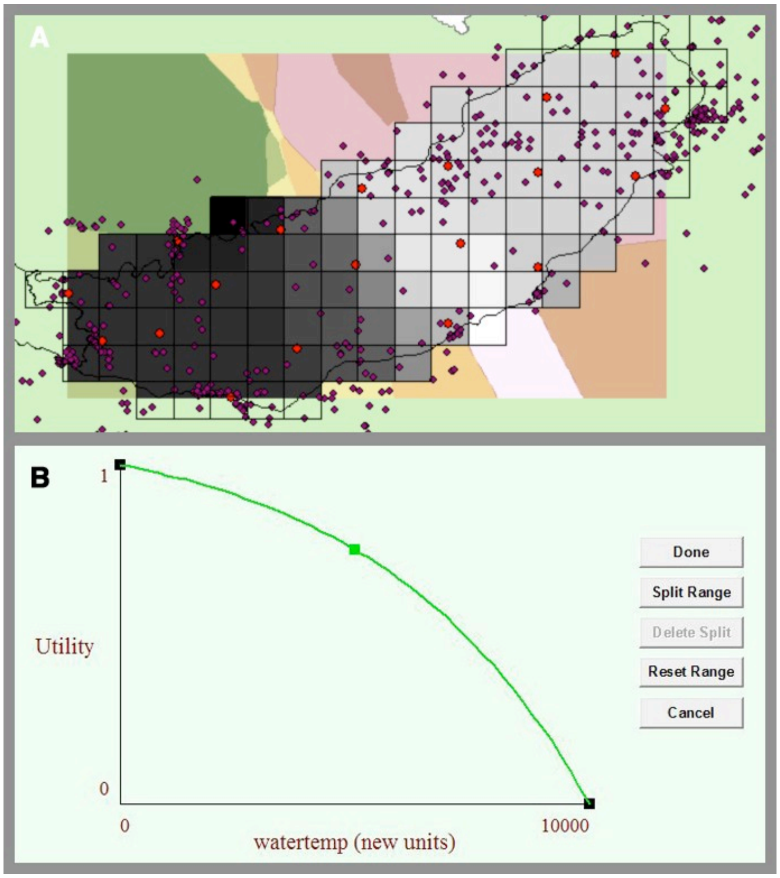

Figure 16: A. Spatial analysis of the well locations (purple), pilot points (red), and relative weighting of depth to the isotherm for each grid cell. B. Single-attribute utility function

Basalt Thickness

The quaternary basalts underlying the SRP have implications for heat flux as well as drilling costs, and so the multi-attribute model incorporates this with a layer ranking the spatial variance in basalt thickness. The basalt thickness is determined by georeferencing mapped contours from a digital map acquired from the USGS online repository. These contours are then interpolated across the plain and a zonal mean is assigned to each model grid cell. The average thickness values are then normalized using an exponential utility curve—consistent with drilling cost curves— and assigned utility values ranging from 0 to 100.

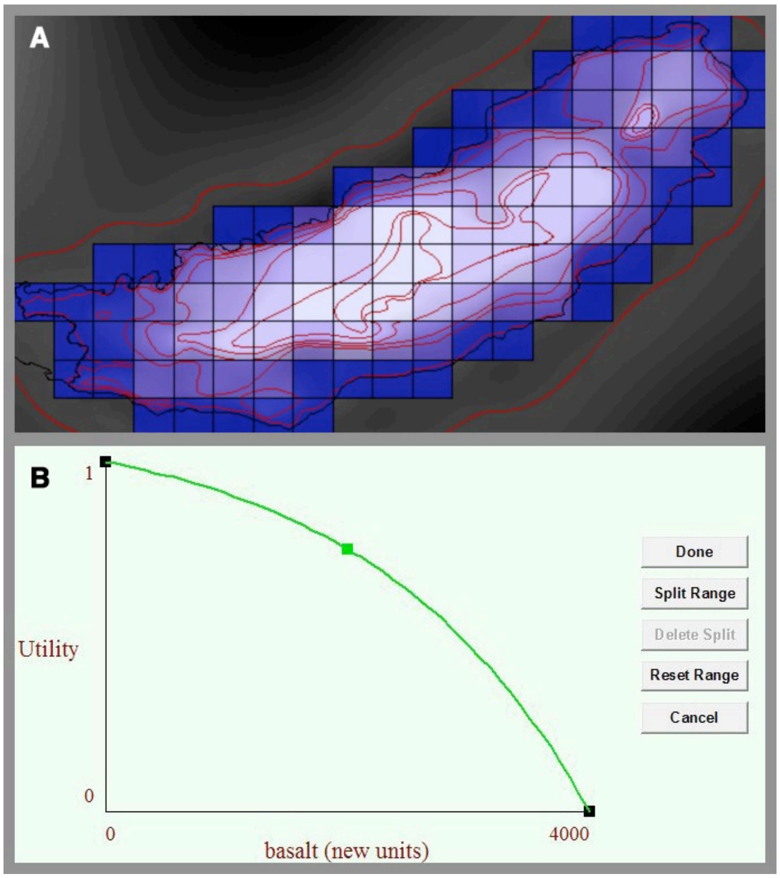

Figure 17: A. Screen capture of Heatseeker showing a schematic of the basalt thickness contours as well as the relative weighting of thickness for each grid cell. B. Utility curve

Faults Zones

For the fault layer, a GIS shapefile of mapped faults in the eastern SRP region was acquired from the Idaho Geological Survey's online database. With this information, an average value for distance in feet to a 100m buffer surrounding fault zones is calculated from the centroid of each of the alternative cell locations. The values are assessed using a utility function that assigns a value of 100 for any distance less than the distance to the corner of a cell plot (e.g. the fault zone intersected with the alternative). Longer distances are assigned values using a linear curve to create a step function.

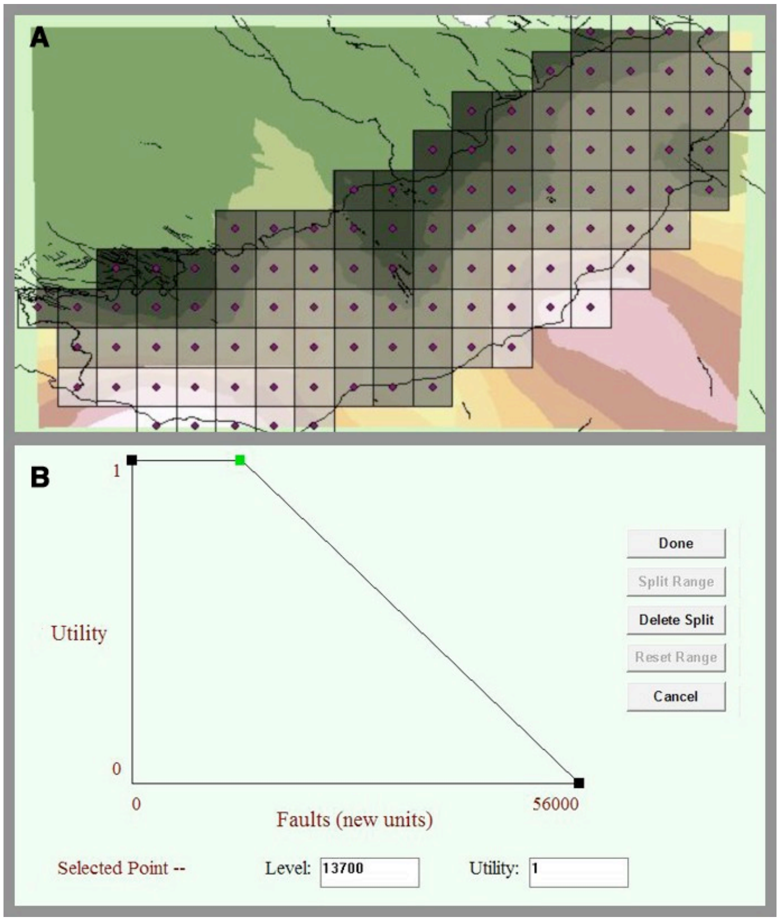

Figure 18. A. Screen capture of Heatseeker showing a schematic of the relative weighting of each grid cell for proximity to mapped faults. B. Utility curve

Physical/Economic Attributes

Land Use

Geothermal resources are subject to various jurisdictions, permitting requirements, and prohibitions according to a land parcel's ownership and relevant state and federal regulations governing the use of the land. Both ownership type and restrictions on land use impact the value of a land parcel's value by increasing transaction costs and reducing the area available for development. In the ESRP, land ownership is divided between Indian Country, federal, state, and private ownership. Using public geospatial data from the Idaho Water Resources Department, the Bureau of Land Management, and the National Park Service, a coverage map was created. Based on interviews with geothermal developers and industry white papers, a value was assigned to areas of land that were either under federal jurisdiction, state jurisdiction, Indian Country, privately held, or off limits for geothermal development due to a moratorium or other factors (urban locations, lakes, etc.). Private land is deemed the most desirable given the lower development timelines and costs for permitting (value = 100), followed by state land (value = 75), federal (value = 50), Indian Country (value = 25), and areas unavailable for development (0). These values are multiplied by the percentage of each land coverage contained within each alternative to calculate a composite score. This score is in turn normalized on a 100-point scale using a linear value function.

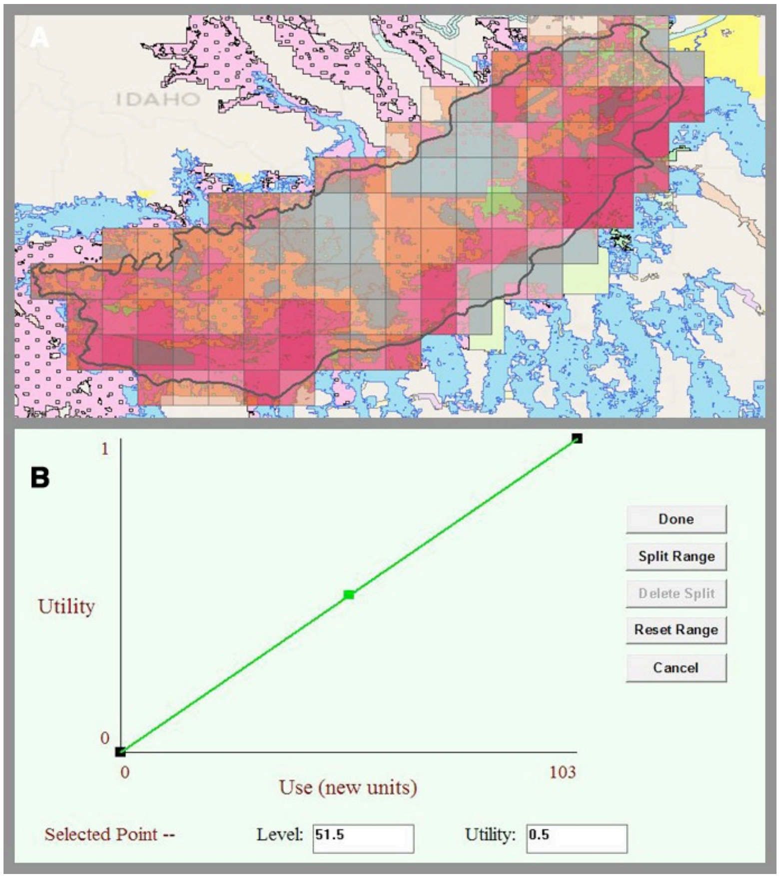

Figure 19. A. Screen capture of MC-SDSS tool showing a schematic of the relative weighting of each grid cell for land use. B. Utility curve

Road Access

Access to and use of existing road infrastructure is critical to the economic viability of a new power development project. Generic estimates for road construction predict a per mile cost of between 1 and 5 million dollars, making the need to construct new road infrastructure over large geographic areas a prohibitively expensive barrier to project siting. Using CENSUS MAF/TIGER data on existing Idaho road infrastructure, a binary determination is made to assign values of 1 and 0 to cells with and without intersecting road infrastructure. These are converted into utility values of 100 and 0.

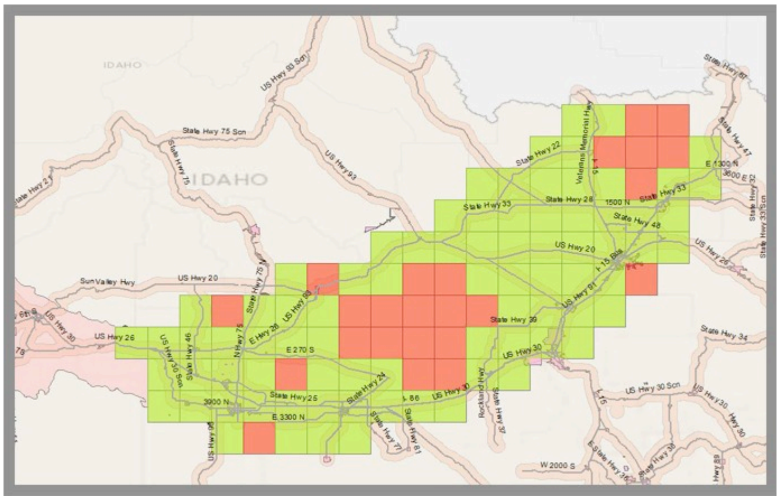

Figure 20. Screen capture of MC-SDSS tool showing a schematic of the binary weighting of grid cells containing roads

Terrain

Terrain refers to the steepness of the land surface. Higher slope values limit the viability of geothermal siting because it increases the cost of construction, transportation, as well as obstructing subsurface water pathways. Using geospatial data from the USGS National Elevation Dataset, a mean terrain (slope) value is calculated for each alternative. These values are then normalized by assigning a utility score on a scale for theoretical slope values between 0 and 100.

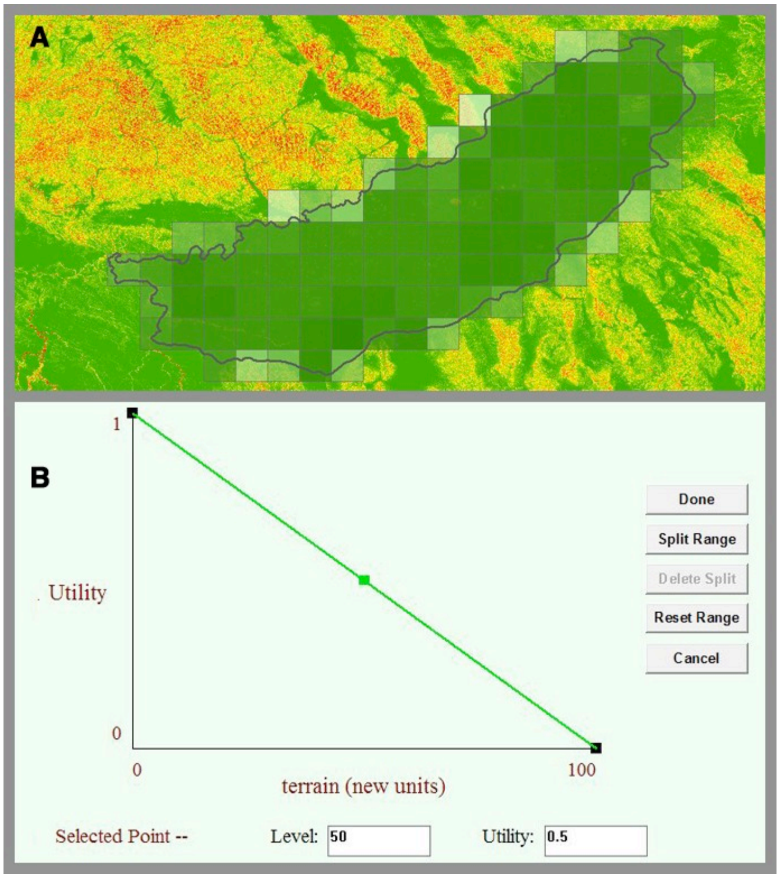

Figure 21: A. Screen capture of MC-SDSS tool showing a schematic of the relative weighting of each grid cell for terrain. B. Utility curve

Transmission

Resources best-situated for siting new geothermal developments are located adjacent to existing transmission lines since the need to build new transmission capacity adds substantially to the overall cost of a power project (Hurlbut, 2012). While the cost for a new transmission line depends on many factors, the cost increases in proporation to the distance over which new transmission must be built. One estimate for the construction of a 138 kV overhead line in Idaho suggests a cost of approximately $350,000 to $400,000 per mile. Data from the Federal Emergency Management Agency (FEMA) is used to create a schematic representation of existing transmission routing. A distance between the centroid of each cell and the nearest line is calculated to provide an absolute value in meters. The values are then normalized using a utility function to assign a value of 100 for any absolute distance value less than the distance from a centroid to the corner of a cell plot (e.g. the line crosses the alternative boundary). Higher attribute values are then assigned utility values using a linear curve to create a step function.

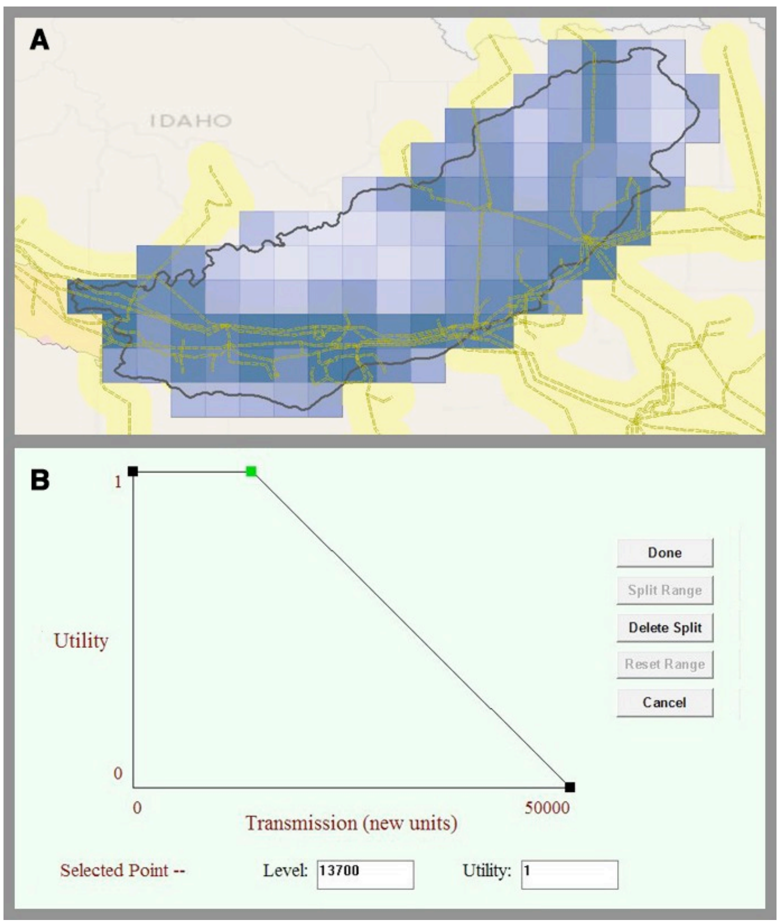

Figure 22: A. Screen capture of MC-SDSS tool showing a schematic of the relative weighting of each grid cell for transmission infrastructure. B. Utility curve

Heatseeker Integration

After constructing single-attribute utility functions for each attribute, a base case final assessment of geothermal favorability in the ESRP is determined using default weights for model inputs specified in the prototype version of the Heatseeker application (see Chapter 2). The application is displayed on a 32-inch multi-touch surface and run from an accompanying laptop computer with spatial data hosted on a remote server (Figure 23).

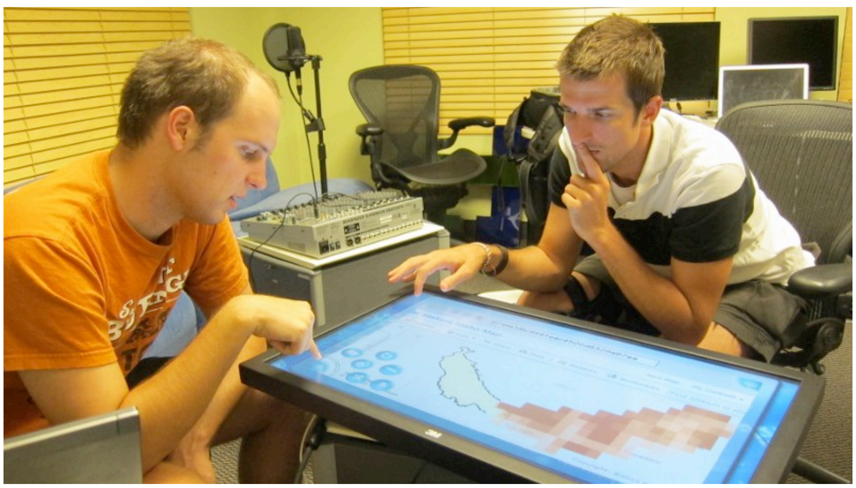

Figure 23: Team members using the multi-touch display

Using the device, members of the research team navigated the spatial environment using gesture controls. Elements of the GUI include a navigation panel to select features in the Heatseeker application, a dashboard to toggle between map base layers and model attribute layers, a slider to manipulate the weighting of attributes within the model, and an index that displays color values for the choropleth maps. Team members are also capable of evaluating individual site alternatives through map markers that displayed attribute data (Figure 24).

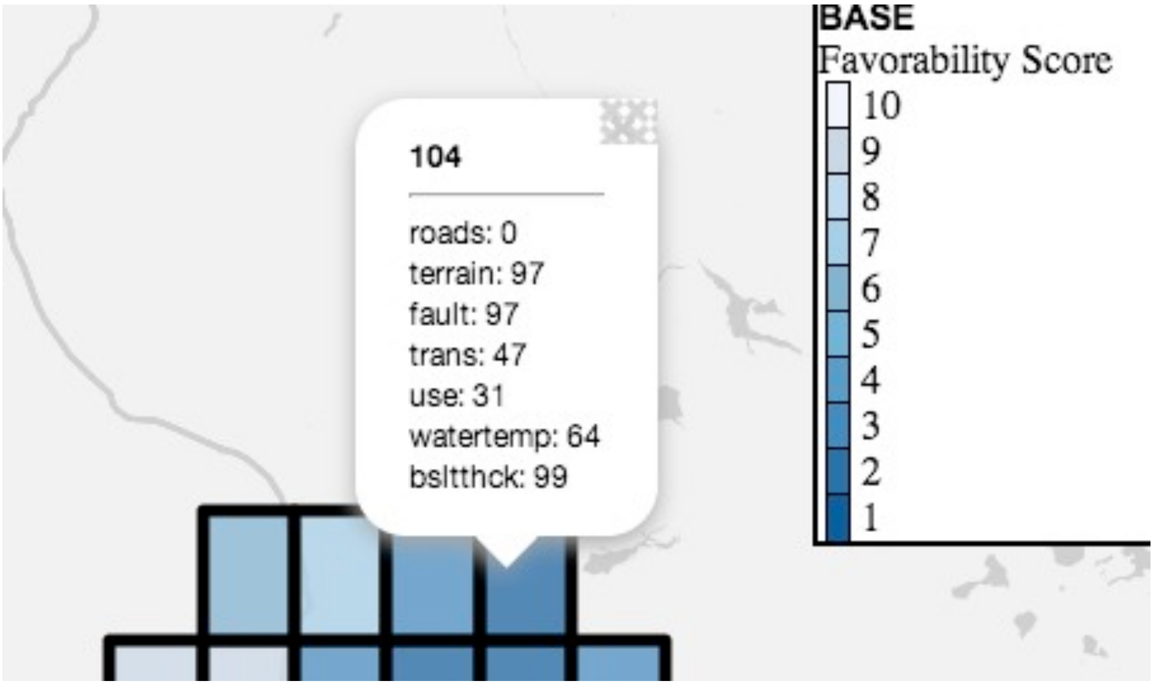

Figure 24. Map marker displaying attribute values for a single alternative.

Evaluation of the model output using the Heatseeker application identified five clusters of high geothermal favorability within the study region. A natural break in the performance scores between the 22 sites divided between these five areas and the rest of the alternatives led to a favorability minimum value of 85 as a threshold for selecting sites for further evaluation. The 5 regional zones that met these conditions were labeled as “High Potential Zones” and are displayed in Figure 25 along with the final attribute scores of all alternatives.

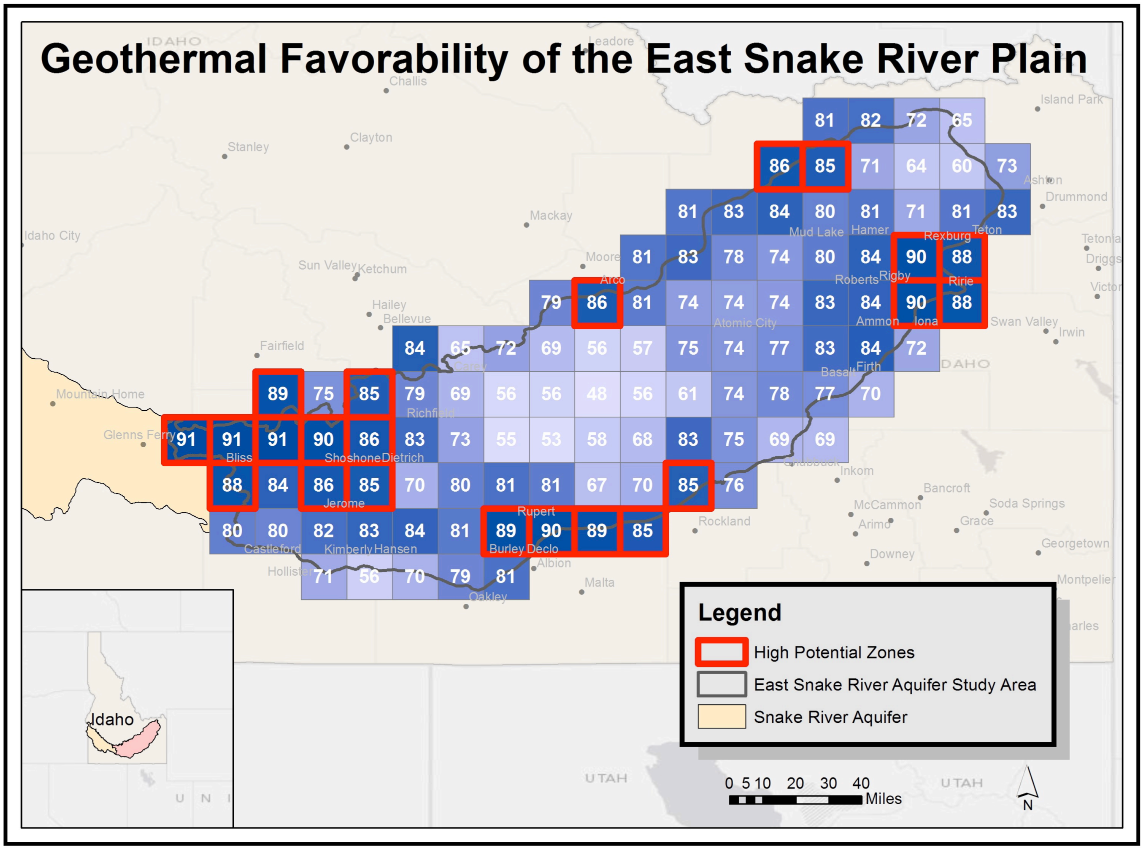

Figure 25: Geothermal development favorability map of the ESRP representing base case performance values for all 104 site alternatives.

SECONDARY ANALYSIS

After evaluating the ESRP using the Heatseeker application, it was determined that a secondary analysis was required to evaluate each High Potential Zone in greater detail. Each region was evaluated using a new set of non-compensatory criteria to identify between one and ten development areas to be marked as potential development zones. These criteria joined buffer zones in geologic and infrastructure requirements (transmissions, roads, and fault zones) and removed exclusionary zones (land use limitations, municipal boundaries, terrain suitability, and lakes and rivers). The remaining coverages represent the development areas with the highest potential for lowest cost project development. This process is represented in the following categorical equation and described in Figure 26

$$D⍰ = (a_! \cap a_! \cap a_!) \cap (b_! \cap b_! \cap b_! \cap b_!) \qquad \text{(Eq.8)}$$

DA = Development Area , a_n = Required criteria, b_n=Exclusionary criteria

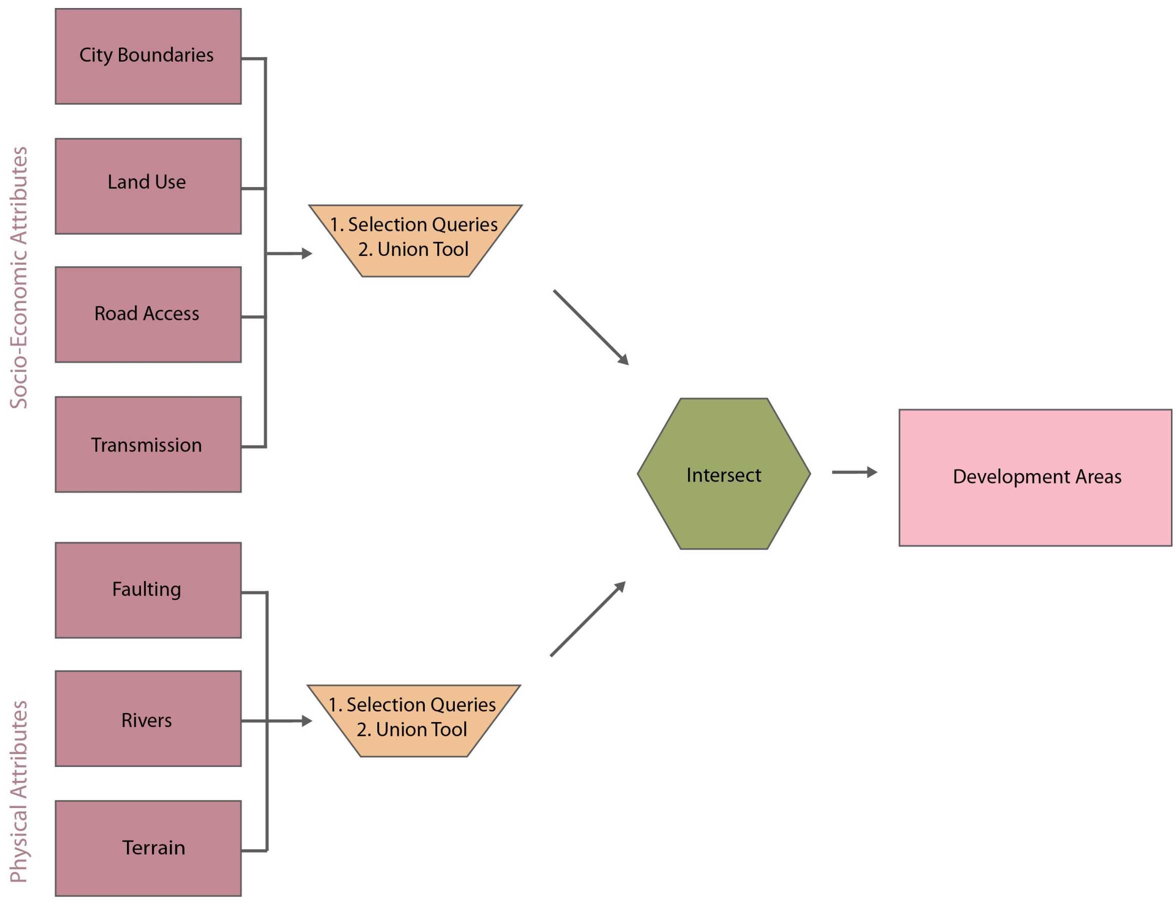

Figure 26: Diagram of the secondary analysis geospatial union process

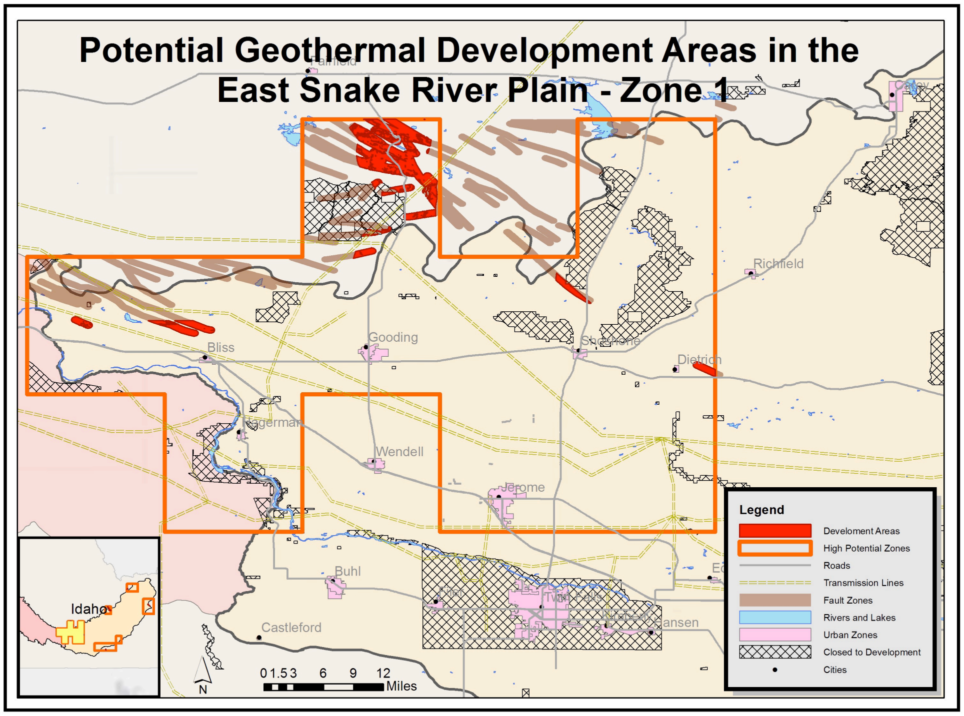

Figure 27: Zone 1 in the ESRP depicted potential areas for development based on modeled results.

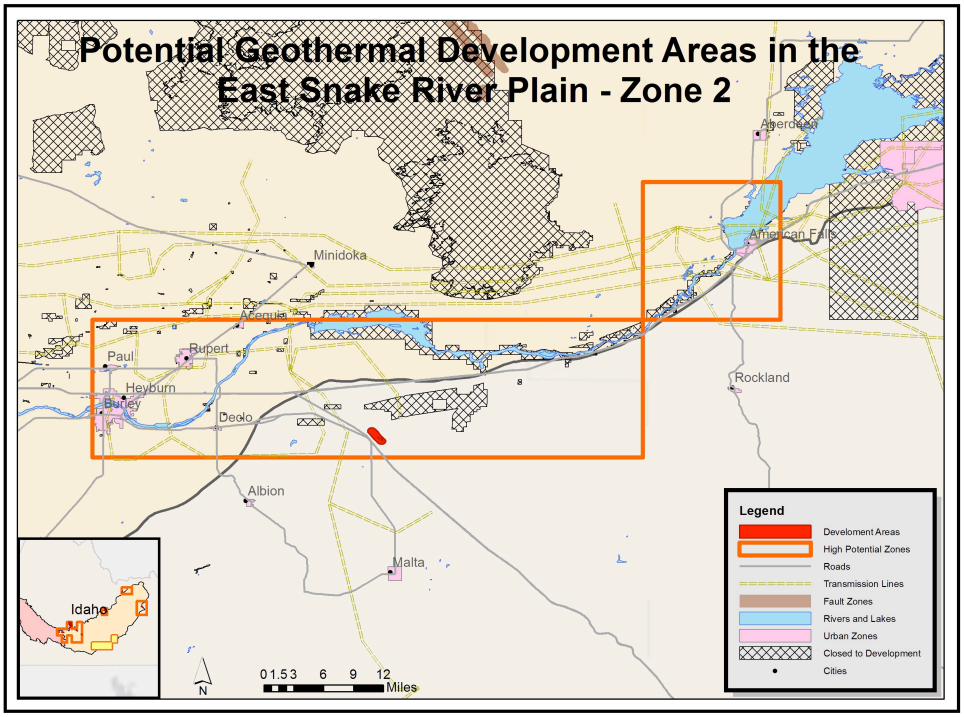

Figure 28: Zone 2 in the ESRP depicted potential areas for development based on modeled results.

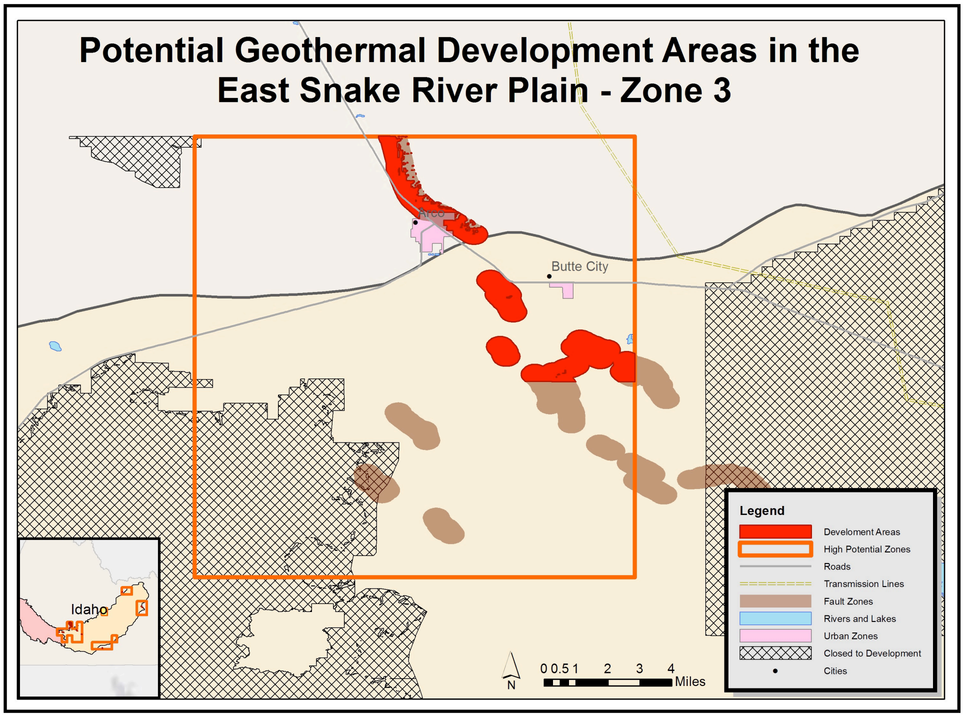

Figure 29: Zone 3 in the ESRP depicted potential areas for development based on modeled results.

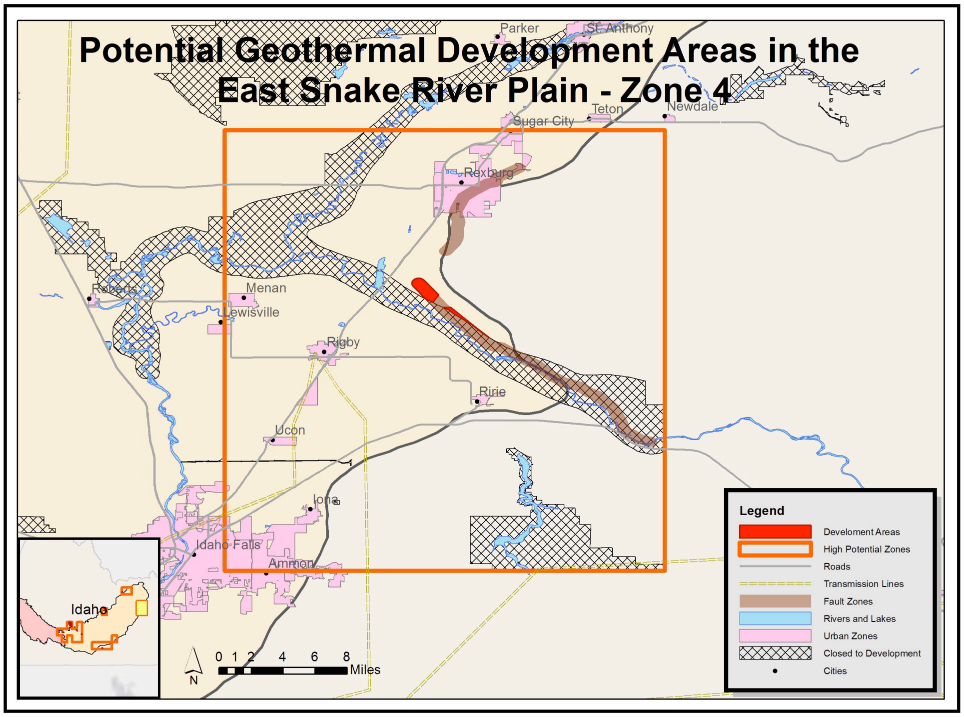

Figure 30**:** Zone 4 in the eastern SRP depicted potential areas for development based on modeled results.

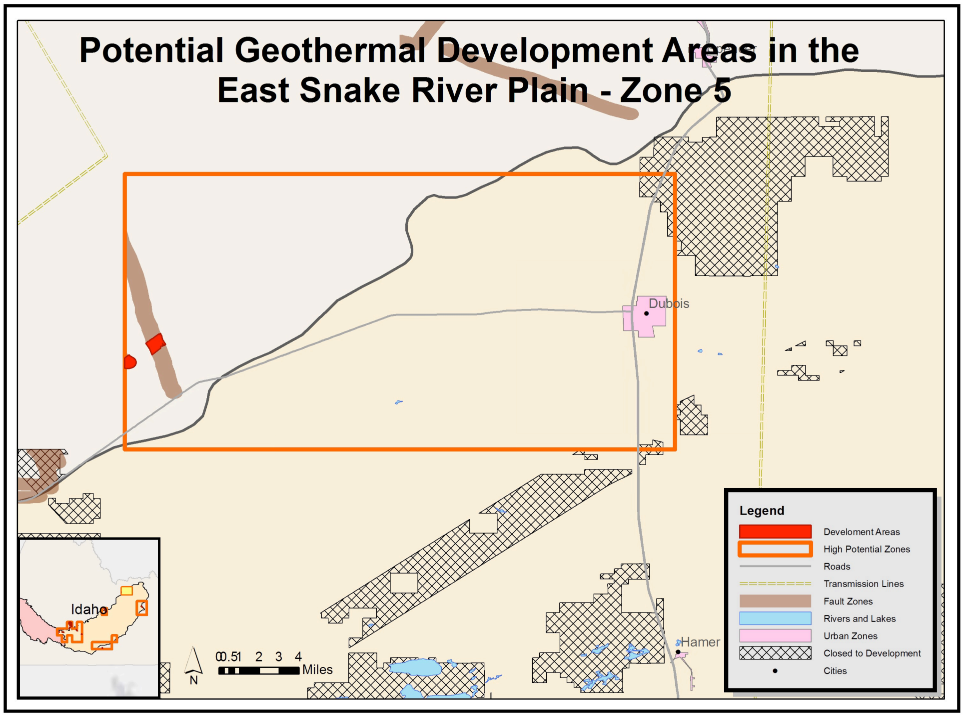

Figure 31: Zone 5 in the eastern SRP depicted potential areas for development based on modeled results.

The above results are based on specified weighting for the prototype case study by research team members, however future iterations of the model can be modified based on the user-defined weighting. Ultimately, the model worked as a proof of concept, which will continue to develop by improving functionality and further exploring the integration of open source software.

Geothermometry results proved to correlate with the initial strictly geological assessment of the high potential zones, in that the two highest reservoir temperature estimates—Heise and Milford Sweat—are located in the high potential zones (Malin et al. 2012). This validates the use of geothermometry as a final calibration step of the multi-attribute model, where the initial geological and economic assessment can delineate zones of feasible exploration and geothermometry can quantify the associated resource.

Conclusions and Future Work

The Heatseeker application provides a proof-of-concept for the use of gesture-enabled multi-touch devices in support of natural resource decision-making. The use of the Heatseeker application supported geothermal favorability mapping by improving the decision process in three meaningful ways. First, the spatial representation of a case study area and decision model data created an efficient visual tool for identifying areas of high values where further investigation was warranted. Second, the ability to modify attribute weights and automatically generate new performance scores that updated the choropleth map allowed for multiple scenarios to be tested in an efficient manner. For the research team, the value of this functionality was to provide a quick method of understanding the sensitivity of the model to changes in attribute weights. For a multi-stakeholder process, this feature provides an even greater benefit of allowing users to generate their own preference-based scenarios that can be exported and compared in real time. Third, Heatseeker created an interactive platform for communicating the underlying information of a technical analysis to outside groups. By allowing individuals to manipulate model weights and to use the gesture-based functionality of the touch device, individuals are able to intuitively understand the underlying dependencies and assumptions of a multi-criteria decision process. In this way, Heatseeker provides an accessible format for information and data presentation that is useful to subject matter experts and also accessible to lay people.

The technology and functional advantages of the Heatseeker application endeavor to assure the application is easy to adapt for future uses in a wide range of contexts. The application can be easily deployed across a variety of technology platforms with minimal technical expertise. Additionally, the application offers advantages for future implementation and transferability due to the small file size of its dependent components and use of freely available and open source web tools that are well-documented

As a proof-of-concept application, Heatseeker affords a cornerstone up which future applications and functionality can be built. For example, during testing it was determined that although the visual representation of alternatives on a choropleth map was intuitive to the research team, additional functionality was necessary to help communicate the relationship between final alternative performance scores and the underlying spatial data layers for individuals who were not part of the research group. For that reasons, a method of overlaying a second window onto the Heatseeker application was developed. This enabled a magnifying glass-style effect where a base layer, such as land use restrictions, could be overlayed on top of the choropleth and resized using drag-and-drop gesture controls (Figure 32). In this manner, the relationship between attribute values and the underlying data became more intuitive. Integrating this functionality directly into the Heatseeker application is an area for future development.

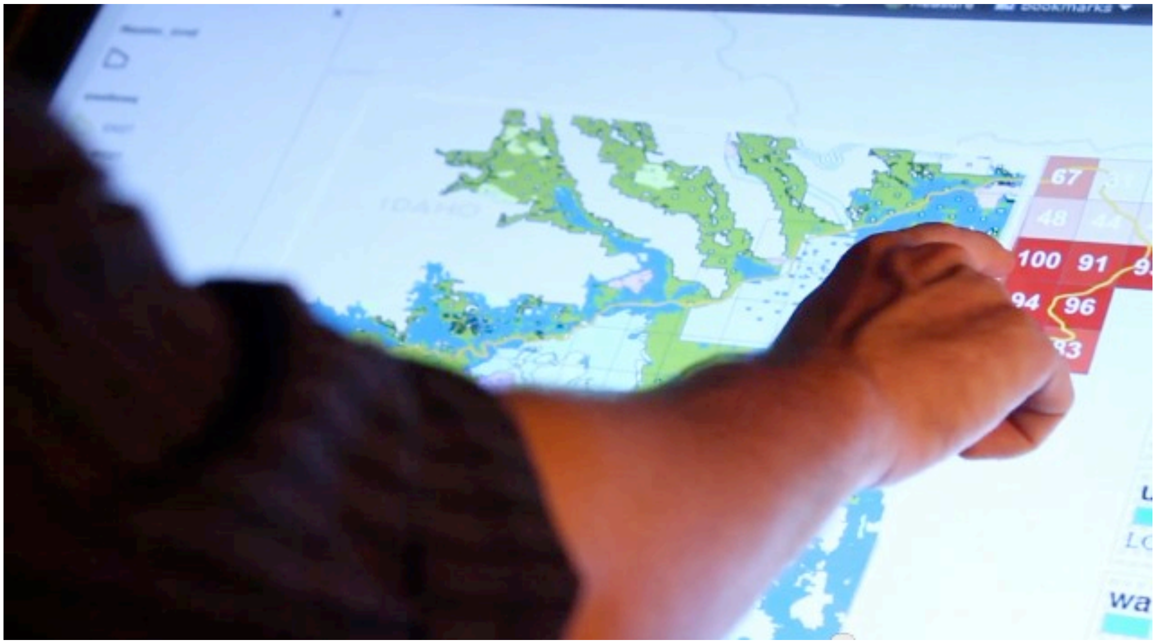

Figure 32. Pinch and Zoom Window Overlay displaying single attribute spatial data.

Heatseeker is a decision aide that can be used to support a decision making process across a variety o settings, particularly where there is conflict among interested parties. The utility of the tool is expected to aid dialogue dramatically in situations more in line with its intended use—as a boundary object to facilitate multi-stakeholder negotiation in scenarios where conflict between competing interests is likely. Future testing of the Heatseeker application within a real-world multi-party conflict or negotiation setting is recommended to further evaluate the value of the device and proposed decision support methods.

Appendix A – Heatseeker Application Code

README.TXT

DATA

The actual data establishing the grid and their geometry and attributes is found in the mastergrid.js file which creates a global data structure named mastergrid. So long as this format is preserved different data sets pertaining to different regions can be used, and the attribute data can be changed, both as to the attributes themselves (adding or deleting) as well as the values for each and any feature in the set. Currently it will only deal with "features" that are of type "Polygon," but the code could be modified fairly easily to deal with other feature types recognized by the leaflet.js API.

CONFIGURATION

Altering the settings is accomplished by editing the file config.js. It creates a global variable named 'config' that contains the information needed to dynamically build the components. The actual data is contained in the file 'mastergrid.js.' Use caution in editing it. If syntax errors are made when editing the file the entire application may abort itself upon load.

config.sought --This is an array containing the names of all attributes that are to be used in any calculations. The data in the JSON structure in mastergrid.js may contain other attributes, but unless they are listed in this array they will be ignored.

config.alias --This array contains "English translation" which directly correspond in place with the entries in config.sought. They can be anything, but the size of this array must match that in config.sought in number. The alias will be the name that appears with the layer selection panel and the popups.

config.key --The name of the attribute that distinguishes a data entry's unique identity. The primary key for the data set.

config.set1 --This is an array of the attributes that will appear in slider set one.
config.set1alias--This performs the same function as config.alias above. Because the selectors may be styled to be small, this allows shorter aliases to be used.
config.set1dest--This is the id of the HTML element that the selectors in this set will be created in.

config.set1Weight -- The sum of all values in the set. LEAVE IT AT 100.

config.set2* --the same as the set options above except it applies to set two.

config.exportUrl --this doesn't work, this file name is hard-coded into the export.js module. Maybe its merely a bug in the browser version, but it seemingly won't allow a variable for use as the url in creating an xmlHttpRequest object.
This should enable one to specify the application to which exported data goes.

config.sum --This specific the name of the field where a block's weight will be stored. This field should NOT ALL READY EXIST in the data. It will be created. Here it is called 'Weight,' but it can be called "Score" or anything one desires.

config.color --This is an array of the color scheme used to visually display the results of a calculation. If for example only three colors were used, the top 33% would display as the first color in the array, the next highest as the second color, and so forth.

config.opacity -- A single value between 0 and 1 that can be used to modify the opacity of config.color.

config.makeDraggable --This is an array listing the ID's of the components that one wishes to make draggable. If you don't want this feature, comment this line out.

layerFill is a global array of objects that are used to set the color scheme for the individual layers such as 'roads'.

Each object in the array has three properties:

- name--This should be the name of the attribute.
- colors --This is an array of all the colors used to display the values for the layer.
- opacity--This is an array of opacity values for the corresponding colors. Even if the values are identical DO NOT omit this array.

OVERVIEW

Upon page load the setUp function in master.js is called. This function builds the various components and provides the event bindings that allow users to interact with the components. Besides the global variables defined in mastergrid.js and config.js, there are: map, grabber, slider1, slider2, sorter, slate, recorder, and master.

- -- map is created by leaflet.js
- --slate is a generic object used for storing miscellaneous data
- -- grabber is an object that basically handles all data storage and visual manipulation of the actual map. Upon creation it extracts, processes and stores

information from 'mastergrid' and 'layerFill.' It has four properties:
(1) It stores the attribute data in an array named 'data'.
(2) It adds the features to the leaflet map and stores a reference to them in 'shape'
(3) It calculates the color schemes for individual layers and stores them in 'layers'
(4) Creates content for the 'legend' component and stores them in 'legend'

It also creates a set of radio buttons which allows the user to toggle "layers," upon calling its makeButtons() function. Toggling the layers also causes the object to change the innerHTML of the "legend" component to match the layer. It also has a method called setGradient, which is used to "paint" the blocks to their appropriate color to indicate their relative weight after a selection/calculation has been made.

slider1 and slider2 are balancer objects. Each controls a set of selectors that allows the user to set the relative importance of the factors. It merely reacts to the user and stores data. When a calculation is made, each slider's giveSet method is called, which returns an object with the structure where the name of each property is the name of an attribute and its value is that of the percentage as indicated by its selector.

master controls the widget that allows the user to set the relative weights of the two sets vis a vis one another. After the two objects have been received, each is run through this object. It adjusts their values so that the sum of both sets' properties will be 100 so that they can then be combined into a single object, which is the formula for the calculation.
=====================

Example:

set1 produces this object: {roads: 50, terrain: 25, fault: 25}
set2 produces this object: {trans: 20, use: 20, watertmp: 60}
--Note that the sum of each object's properties is 100.

set1 was given a weight of 70% leaving 30% for set2
Everything in set 1 is multiplied by 0.7, and everything in set2 by 0.3.

This yields:
set1: {roads: 35, terrain: 17.5, fault: 17.5}
set2: {trans: 6, use: 6, watertmp: 18}

They can now be combined into a single object:
result:{roads: 35, terrain: 17.5, fault: 17.5,trans: 6, use: 6, watertmp: 18}
--The sum of all properties values is 100.
===========================

---sorter is the object that controls the actual calculations, sorts the results from greatest to least in terms of "Weight", and generates the html table.

It makes its calculations by going through the data array and multiplying the corresponding attributes actual value by the factors in the object described in the example above.

Given a data object k and a formula object f

k.weight = (k.roads * f.roads) + (k.terrain * f.terrain) + ...

STARTING THE CALCULATION

What binds all this together is the global 'calculate' function. It pulls the data from the selectors and uses the resultant formula object as an argument along with a reference to grabbers' data array. The calculations are made, the html table is generated and put inside the HTML 'chart' div, and grabber's setGradient method is called to color the blocks to reflect their respective rankings. A copy of the formula object is also stored with the recorder object, so that it can export that along with the other data if requested to do so.

EXPORTING DATA

The object (global var recorder) is very simple, but it relies upon server side applications to make it run. Assuming that a calculation has been made and the user has entered a description/filename, this creates a data structure having the following format:
{description: (user's input), date: (timestamp), formula: (see formula object above), chart: (the html from the table generated)
}

It sends this via POST through an xmlHttpRequest object as an url-encoded JSON string. It will report back on the status code, if any, of the request made to the server.

It should be directed at "exporter.php" on the server. Currently this is hardwired into export.js.

There are three files involved. They should be placed on the server in the same directory as index.html. They are:
exporter.php
import.php
mapData.src

mapData.src is a data file. Its empty. Keep a copy of it so you can overwrite it when it gets too full. At some point you may want to switch to a database rather than a flat file.

As it is, exporter.php must be able to both read and write to that file on the server. Import.php must be able to read mapData.src on the server.

If you use the newest version of export.js I have sent, you will find that it dynamically adds an 'import' button to the list. This will allow you to look at the data you have exported up to the server.

MISCELLANEOUS

You don't have to use all the attributes from a data file for the process. If you don't want a particular attribute weighed then simply don't include it in any of the slider sets. This is covered in the section dealing with config. And if the attribute is not ready for prime time don't include it in the 'config.sought' array.

INDEX.HTML

```
<!DOCTYPE html>
<html>
<head>
<link rel="stylesheet" type="text/css" href="widget.css" />
<link href='http://api.tiles.mapbox.com/mapbox.js/v1.0.0/mapbox.css' rel='stylesheet' />
<link rel="stylesheet" href="http://cdn.leafletjs.com/leaflet-0.6.4/leaflet.css" />
<!--[if lte IE 8]>
<link rel="stylesheet" href="http://cdn.leafletjs.com/leaflet-0.4.4/leaflet.ie.css" />
<![endif]-->
<script src='http://api.tiles.mapbox.com/mapbox.js/v1.0.0/mapbox.js'></script>
<script type="text/javascript" src="vkboardsc.js"></script>
<script type="text/javascript" src="config.js"></script>
<script type="text/javascript" src="master.js"></script>
<script type="text/javascript" src="slideSet.js"></script>
<script type="text/javascript" src="sorter.js"></script>
<script type="text/javascript" src="export.js"></script>
<script type="text/javascript" src="mastergrid.js"></script>
<script type="text/javascript" src="process.js"></script>
<title>Daniel Noll Thesis - MCSDSS</title>
<meta charset="utf-8" />
<meta name="viewport" content="width=device-width, initial-scale=1.0">
<style>
#map { position:absolute; top:2.5em; bottom:0; width:100%; }
```

```
.info {
padding: 6px 8px;
font: 14px/16px Arial, Helvetica, sans-serif;
background: white;
background:   rgba(255,255,255,0.8); box-
shadow: 0 0 15px rgba(0,0,0,0.2); border-radius:
5px;
}
.info h4 {
margin: 0 0 5px;
color: #777;
}
.legend {
text-align: left; line-
height: 18px; color:
#555;
}
.legend i {
width: 18px;
height: 18px;
float: left;
margin-right: 8px;
opacity: 0.7;
}
</style>
</head>
<body>
<div id ="topBar" class="top">
<span id ="s1" class= "bars"> SELECT</span>
<span id="s2" class="bars"> CHART </span>
<span  id="s4"  class="bars">EXPORT</span>
<span id ="s5" class="bars">RESET</span><hr>
</div>
<link rel='stylesheet' href='leaflet.draw.css' />
<!--[if lte IE 8]>
<link  rel="stylesheet"  href="/mapbox.js/assets/leaflet.draw.ie.css"  />
<![endif]-->
<script   src='leaflet.draw.js'></script>
<div id='map'></div>
<script>
```

```
var map = L.map('map').setView([43.5, -111], 8);
L.control.layers({
'Base   Map':   L.mapbox.tileLayer('examples.map-zgrqqx0w').addTo(map),
'Grey   Map':   L.mapbox.tileLayer('dnoll.g7i1h04g')
}, {
'Land   Use':   L.mapbox.tileLayer('dnoll.nkkxzuxr'),
'Raod   Access':   L.mapbox.tileLayer('dnoll.qohnz5mi'),
'Transmission   Lines':   L.mapbox.tileLayer('dnoll.7xzp8pvi'),
'Fault   Zones':   L.mapbox.tileLayer('dnoll.qga7zaor')
}).addTo(map);
var featureGroup = L.featureGroup().addTo(map);
var drawControl = new L.Control.Draw({
edit: {
featureGroup:   featureGroup
}
}).addTo(map);
map.on('draw:created', function(e) {
featureGroup.addLayer(e.layer);
});
</script>
<!--DIV CONTAINING CHART-->
<div id="chartCont">
<div id="chartDrag" class="dragBar">
<input type="button" id="chartFade" class = "hideIt" value="HIDE">
</div>
<hr>
<div id="chart">
<h3>No Chart Currently Exists</h3>
</div>
</div>
<!--FOR   EXPORTING-->
<div id="export" >
<div id="exportDrag" class="dragBar">
<input type="button" id="exportFade" class = "hideIt" value="HIDE">
</div>
<hr>
<p   id="ExMessage"></p>
<input type = "text" id="textBox" class="keyboardInput" ><br>
<div   id="keyboard"></div>
<input type="button" id="exSend" value="SEND">
```

```
<input type="button" id="exClear" value="CLEAR">
</div>
<!--SEARCH   SELECTION-->
<div id = "dashB">
<div id="dashDrag" class="dragBar">
<input type="button" id="selectFade" class="hideIt" value="HIDE">
</div>
<hr>
<!--FOR TOGGLING LAYERS-->
<div   id="radio"></div>
<!--FOR THE SLIDERS-->
<div id="slideDiv">
<input type="button" value="MAKE CHART" id ="doCalc" class="butCalc"><hr>
<div id ="masterSet">
<h3>RELATIVE WEIGHT OF THE TWO SETS</h3>
</div>
<div id="slide1Div"><h4>SET ONE: ADJUST WEIGHT WITHIN THE SET</h4></div>
<div id="slide2Div"><h4>SET TWO: ADJUST WEIGHT WITHIN THE SET</h4></div>
</div>
</div>
<!--LEGEND DIV-->
<div id ="legendWrapper">
<div id="legendDrag" class="dragBar">
<input type="button" id="legendFade" class="hideIt" value="HIDE">
</div>
<div id="Legend">
</div>
</div>
<script   type="text/javascript">
var _usersnapconfig = {
apiKey:    '1d4650f1-8120-4a7b-9bea-f98fae1eab20',
valign: 'bottom',
halign: 'right',
tools: ["pen", "highlight", "note"],
lang: 'en',
commentBox: true,
emailBox: true
};
(function() {
```

```
var s = document.createElement('script');
s.type = 'text/javascript';
s.async = true;
s.src = '//api.usersnap.com/usersnap.js';
var x = document.getElementsByTagName('head')[0];
x.appendChild(s);
})();
</script>
</body>
</html>
```

CONFIG.JS

```
/*Configuration for all the custom javascript objects*/


var config = {};
config.sought = ['roads', 'terrain', 'fault', 'trans', 'use', 'watertemp', 'bsltthck'];
config.alias = ['Road Access', 'Terrain Slope', 'Faulting', 'Transmission', 'Land Use', '200F
Isotherm Depth', 'Basalt Thickness'];
config.key = 'OBJECTID';
config.set1 = ['roads', 'trans', 'use', 'terrain'];
config.set1weight = 100;
config.set1dest = "slide1Div";
config.set1alias = ['roads', 'trans', 'use', 'terrain'];
config.set2weight = 100;
config.set2 = ['fault', 'watertemp', 'bsltthck'];
config.set2dest = "slide2Div";
config.set2alias = ['fault', 'watertemp', 'bsltthck'];
config.sum = 'Weight';
config.color = ['#EEF2FE', '#BFCFE0', '#B3D3EC', '#96C4E3', '#6FA5C7', '#60A4D0',
'#488CBF', '#3479B4', '#215F99', '#0B4C8F'];
config.opacity = 1;
config.makeDraggable = ['dashB', 'legendWrapper', 'export', 'chartCont'];
config.exportUrl = ['http://dnoll.com/thesis/new/export/']

var layerFill = [{
  name: 'roads',
  colors: ['#EEF2FE', '#0B4C8F'],
  opacity: [1, 1]
},

{
```

```
  name: 'terrain',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'fault',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'trans',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'use',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'watertemp',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'bsltthck',
  colors: ['#FF0000', '#00FF00', '#0000FF', '#FF00FF'],
  opacity: [1, 1, 1, 1]
},

{
  name: 'BASE',
  colors: ['#CCCCCC'],
  opacity: [1]
}];
```

MASTER.JS

```
// This sets up the application
//global variables--'config' and 'style' were set in config.js
var map, grabber, slider1, slider2, sorter, slate, recorder, master;

window.onload = function() {
  setUpMain();
}




//---------GENERAL UTILITY FUNCTIONS-----------------------------
//sets z-index of main containers to bring the one whose id is the arg to the top
function adjustZ(id) {
  var set = ["chartCont", "export", "dashB", "legendWrapper"];
  var ref, i, start = 1000,
    len = set.length;
  for (i = 0; i < len; i++) {
    ref = document.getElementById(set[i]);
    if (set[i] == id) {
      ref.style.zIndex = 10000;
    } else {
      ref.style.zIndex = start;
      start = (start * 1) + 100;
    }
  }
}


function calculate() { //calculates from present settings--makes chart and sets colors by
rank
  sorter.purify(grabber.data, config.sum);
  grabber.setVisible('BASE');
  slate.graphics_exist = 'yes';
  //put data in original order
  grabber.data = sorter.sortObj(grabber.data, config.key);
  grabber.data = grabber.data.reverse();
  var prime, minor, i, out;
  prime = slider1.giveSet();
  prime = master.adjustOne(prime);
  minor = slider2.giveSet();
  minor = master.adjustTwo(minor);
```

```
  //merge into prime
  for (i in minor) {
  prime[i] = minor[i];
  }

  grabber.data = sorter.calc(grabber.data, config.sum, prime);

  recorder.buffer = prime;
  out = sorter.makeTable(grabber.data);
  document.getElementById('chart').innerHTML = out;
  grabber.setGradient();
}

//instantiates the objects needed to run the program
function setUpMain() {
  //set up slate to provide status data and general info storage
  //this is actually a relic from the esri map--retained but of little use
  slate = {
    graphics_exist: "no",
    iframe: null,
    current: null,
    width: null,
    height: null
  };

  //========create the controller objects
  grabber = doMap(masterGrid, map, config, layerFill);
  grabber.makeButtons('radio'); //create layer toggle buttons

  //create MASTER selector for sliders
  master = makeMaster("masterSet");


  //create slider sets
  slider1 = balancer(config.set1dest, config.set1weight, config.set1, config.set1alias);
  slate.temp = document.getElementById(config.set1dest);
  //create hr between them
  slate.el = document.createElement('hr');
  slate.el.id = "divider1";
  slate.temp.appendChild(slate.el);
  //
  slider2 = balancer(config.set2dest, config.set2weight, config.set2, config.set2alias);
```

```
//now the sorter
sorter = chartMaker();
sorter.init(config.key, config.sum, config.sought);

//now export
recorder = exporter();


//========set listeners for top bar
//SHOW CONTROLS
var ref = document.getElementById('s1');
ref.onclick = function() {
  document.getElementById('dashB').style.display = 'block';
  adjustZ('dashB');
}
//make it hide upon request
ref = document.getElementById('selectFade');
ref.onclick = function() {
  document.getElementById('dashB').style.display = 'none';
}


//SET UP CHART DIV
ref = document.getElementById('s2');
ref.onclick = function() {
  document.getElementById('chartCont').style.display = 'block';
  adjustZ('chartCont');
}
ref = document.getElementById('chartFade');
ref.onclick = function() {
  document.getElementById('chartCont').style.display = 'none';
}


// EXPORT ACTION
ref = document.getElementById('s4');
ref.onclick = function() {
  document.getElementById('export').style.display = 'block';
  adjustZ('export');
}
ref = document.getElementById('exportFade');
ref.onclick = function() {
  document.getElementById('export').style.display = 'none';
```

```
}



//RESET
ref = document.getElementById('s5');
ref.onclick = function() {
slate.graphics_exist = 'no';
grabber.setVisible('BASE');
recorder.buffer = '';
  var tar = document.getElementById('chart');
  tar.innerHTML = '<h3>No Chart Currently Exists</h3>';
}

//LEGEND
ref = document.getElementById('legendFade');
ref.onclick = function() {
  var k = document.getElementById('legendWrapper');
  k.style.display = "none";
}

//BIND BUTTON IN SLIDER BOX TO CALCULATE function
ref = document.getElementById('doCalc');
ref.onclick = function() {
  calculate();
}
//================================== if indicated in config.js, make divs
draggable
//create function to make divs draggable
var makeDrag = function(el) {
    var x = {};
    x.motion = false;
    x.init = false;
    x.xoff = 0;
    x.yoff = 0;
    x.left = 0;
    x.top = 0;
    x.el = document.getElementById(el);

    x.pos = function(e) {
      var par, el;

      el = x.el;
```

```
  do {
    x.left += el.offsetLeft;
    x.top += el.offsetTop;
    el = el.offsetParent;
  } while (el != null);
  x.el.style.top = x.top + 'px';
  x.el.style.left = x.left + 'px';
  x.xoff = e.clientX - x.left;
  x.yoff = e.clientY - x.top;
  x.init = true;
}

x.el.onmousedown = function(e) {
  x.motion = true;
  adjustZ(x.el.id);
  if (!x.init) {
    x.pos(e);
    x.el.style.position = 'absolute';
  }
  x.xoff = e.clientX - x.left;
  x.yoff = e.clientY - x.top;
  return false;
}

x.el.onmousemove = function(e) {
  if (!x.motion) {
    return false;
  }
  x.left = e.clientX - x.xoff;
  x.top = e.clientY - x.yoff;
  x.el.style.top = x.top + 'px';
  x.el.style.left = x.left + 'px';
  return false;
}

x.el.onmouseout = function() {
  x.motion = false;
  return false;
}

x.el.onmouseup = function() {
  x.motion = false;
  return false;
```

```
    }

    return x;
  }

  //if indicated in config.js, make the controllers and stick them in an array in slate
  // so the divs in the array will be draggable
 if (config.makeDraggable && config.makeDraggable.length > 0) {
  slate.drag = [];
  var i, obj, len = config.makeDraggable.length;
  for (i = 0; i < len; i++) {
    obj = makeDrag(config.makeDraggable[i]);
    slate.drag.push(obj);
  }
 }

}
```

SLIDESET.JS

/*builds an individual selector widget--the set is controlled by balancer (below)--args are: id= HTML id of container in which they go, txt--text that will describe them at the top of the widget, qual--actual name of attribute, value--original starting value, master --the callback function to the balancer so it can report to it, and factor-which represents the 'weight' the set is to have*/

```
 function buildWidget(id, txt, qual, value, master, factor) {
  var x = {};
  x.val = value;
  x.isLocked = false;
  x.qual = qual;
  x.off = 0;
  x.max = 100;
  x.trans = 0;
  x.width = 1;
  x.callBack = master;
  x.trigger = false;
  x.factor = factor;


  var target = document.getElementById(id);

  var inner = '';
```

```
//build widget structure here here
inner += '<div id="descriptq" class="descript">';
inner += '<span id="descSpanq" class="descSpan">';
inner += txt;
inner += '</span>';
inner += '</div>'; //end of description
inner += '<div id="holderq" class="holder">';
inner += '<div id="barq" class="bar">';
inner += '</div>';

inner += '</div>'; //end of holder
inner += '<div id="controlq" class="control">';
inner += '<span id="lockq" class="lock">LOCK';
inner += '</span>';
inner += '<input type ="checkbox" id="checkq" class="check" />';
inner += '<button id="minusBq" class="minusB">-</button>';
inner += '<button id="plusBq" class = "plusB">+</button>';
inner += '</span>';
inner += '<span id="counterq" class ="counter">0</span>';
inner += '</div>'; //end of control area



//append to parent
x.out = document.createElement('div');
x.out.className = "slider";
target.appendChild(x.out);
x.out.innerHTML = inner;

//get the refs and store them in x.l object
x.l = {};
var div = x.out.getElementsByTagName('div');
x.l.sign = div[0].firstChild;
x.l.holder = div[1];
x.l.bar = div[2];
var ctr = div[3];
var button = ctr.getElementsByTagName('button');
x.l.minus = button[0];
x.l.plus = button[1];
var inp = ctr.getElementsByTagName('input');
x.l.check = inp[0];
var display = ctr.getElementsByTagName('span');
x.l.display = display[1];
```

```
  //

  //get true cords
  x.trueCords = function() {
  x.off = 0;
    /*
var node = x.l.holder;
do{
    x.off += node.offsetLeft;
    node = node.parentNode;
} while(node.nodeType == 3);

x.off = x.l.holder.parentNode.offsetWidth;
*/
    //KLUDGE
    x.off = document.getElementById('dashB').offsetLeft;
    x.width = x.l.holder.offsetWidth;

    //get translation factor
    var divW = x.l.holder.offsetWidth;
    x.trans = divW / 100;
  }


  x.l.holder.onclick = function(e) {
    if (x.isLocked) {
      return false;
    }

    x.trueCords();
    var xx = e.clientX - x.off;
    xx = xx / x.trans;
    xx = Math.round(xx);
    if (xx == 99) {
      xx = 100;
    }
    if (xx == 1) {
      xx = 0;
    }
    x.sendData(xx);


    //x.l.display.innerHTML = val;
```

```
  //x.l.bar.style.width = val + '%';
}

x.setVal = function(val) { //how the balancer sets the value
  x.val = val;
  var alt = val * x.factor;
  alt = Math.round(alt);
  var r = Math.round(x.val);

  x.l.display.innerHTML = alt;
  x.l.bar.style.width = r + '%';

}

x.l.plus.onclick = function() { //when + button is clicked
  if (x.val == 100) {
    return;
  }
  var tmp = x.val + (1 / x.factor);
  x.sendData(tmp);
}

x.l.minus.onclick = function() { //when minus button is clicked
  if (x.val < 1) {
    return;
  }
  var tmp = x.val - (1 / x.factor);
  x.sendData(tmp);

}


//locking
x.l.check.onclick = function() {
  if (x.l.check.checked) {
    x.isLocked = true;
  } else {
    x.isLocked = false;
  }


}
/*whenever user interacts with the slider (other than to lock/unlock, it sends data
```

```
   to the balancer through x.sendData*/

  x.sendData = function(request) {
   var m = {};

   m['name'] = x.qual;
   m['request'] = request;
   m['val'] = x.val;

   x.callBack(m);
  }

  x.message = function(txt) { //used to send error messages to replace description text
   var fnc, m = x.l.sign.innerHTML;
   x.l.sign.innerHTML = txt;
   fnc = function() {
    x.l.sign.innerHTML = m;
   }
   setTimeout(fnc, 3000); //replaces original text after 3 seconds
  }

  x.setText = function(txt) { //"manual" setting of description text for the widget
   x.l.sign.innerHTML = txt;
  }


  x.setVal(value);
  return x;
 }

/*=================================================================
===*/
 //The brain for the selector widgets
 function balancer(a, b, c, d) {
  var x = {};
  x.data = {};
  x.numLocked = 0;
  x.quantity = 0;
  x.locked = 0;
  x.factor = 1;

  /*put in here to harmonize with amended geothermal app
   'set1dest, set1weight, set1, set1alias' is order of args */
```

```
x.doTrans = function(destination, weight, attArr, alArr) {
  var out, value, tmp, i, len = attArr.length;
  value = len / 100;
  value = Math.round(value);
  out = {};
  out.id = destination;
  out.factor = weight;
  out.obj = [];

  for (i = 0; i < len; i++) {
    tmp = {};
    tmp.qual = attArr[i];
    tmp.txt = alArr[i];
    tmp.val = value;
    out.obj.push(tmp);
  }
  return out;
}


var input = x.doTrans(a, b, c, d);
//end of insert
var name, i, z, len = input.obj.length;
var target = input.id;
x.factor = input.factor / 100;

//this function is invoked whenever someone clicks on a slider--unless its locked
//in which case the slider ignores the user--the balancer decides how to adjust
//the values of the sliders in the set
x.info = function(m) {

  var request = m.request,
    name = m.name,
    value = m.val;
  var i, tmp, taken = 0,
    direction, empty = 0,
    active = 0,
    available = 0;

  if (request == value) { //no change from present setting--ignore
    return;
  }
```

```
  direction = "push"; //shrinking or expanding a current value?
  if (request > value) {
    direction = "pull";
  }

  for (i in x.data) { //determine number of points that are locked
    if (x.data[i].isLocked) {
      taken += x.data[i].val;
      continue;
    }
    if (x.data[i].val == 0) {
      empty++;
    }
    active++;

  }

  if (active < 2) { //nothing to push to  or pull from
    return;
  }

  if (direction == "push" && ((active - empty) < 2)) {
    x.data[name].message("NO ACTIVE BOXES TO PUSH TO");
    return;
  } //pushing to empties is not allowed
  available = 100 - taken;

  if (request > available) { //special case--sucks the others dry
    x.data[name].setVal(available);
    for (i in x.data) {
      if ((x.data[i].isLocked) || (i == name)) {
        continue;
      }
      x.data[i].setVal(0);
    }
    x.data[name].message("NOT ENOUGH UNLOCKED POINTS");
    return false;
  }

  available = 100 - (taken + request);;
  x.data[name].setVal(request);
  x.synchSet(name, available);
}
```

```
//
x.synchSet = function(name, goal) {
  //identify non-zero non-locked properties
  var i, len, box = [],
    total = 0,
    ratio, tmp, off;
  for (i in x.data) {
    if (x.data[i].isLocked || x.data[i].val == 0 || (i == name)) {
      continue;
    }
    box.push(i);
    total += x.data[i].val;
  }

  ratio = goal / total;
  len = box.length;

  for (i = 0; i < len; i++) {
    off = box[i];
    tmp = x.data[off].val;
    tmp = tmp * ratio;

    if (tmp > 100) {
      tmp = 100;
    }
    x.data[off].setVal(tmp);
  }
}


//object generated when a calculation is made--returns object consisting
// of keys as attribute names and value as currently set by slider
x.giveSet = function() {
  var i, out = {};
  for (i in x.data) {
    out[i] = (x.data[i].val * x.factor);
  }
  return out;
}


//will change text in description box
```

```
 x.alterText = function(prop, txt) {
  if (x.data[prop]) {
  x.data[prop].setText(txt);
  }
 }


 // create the widgets from the info in var input
 for (i = 0; i < len; i++) {
  z = input.obj[i];
  name = z.qual;
  x.data[name] = buildWidget(target, z.txt, name, z.val, x.info, x.factor);
  x.quantity++;
 }

 // set initial values of the slider set to the same value
 var www = 100 / len;
 www = Math.round(www);

 for (i in x.data) {
  x.data[i].setVal(www);
 }
 return x;
}


//=================================master slide
makeMaster = function(id) {
 var x = {};

 var html = '<div class="masterHolder" style="width: 100%">';
 html += '<div class="masterSelect" id = "masterSelect" style="width: 100%">';
 html += '</div></div>';
 html += '<input type="button" value="@" id = "set1">';
 html += '<span id="leftSet">SET ONE: 50%</span>';
 html += '<span id="rightSet">SET TWO: 50%</span>';
 html += '<input type="button" value="@" id = "set2">';


 var target = document.getElementById(id);
 var cont = document.createElement('div');
 cont.id = "masterSlide";
 cont.className = "masterSlide";
```

```
target.appendChild(cont);
cont.innerHTML = html;
var slide = document.getElementById('masterSelect');
slide.style.height = '100%';
slide.style.width = '50%';


x.value  =  50;
x.left  =  false;
x.right = false;
x.displayL = document.getElementById("leftSet");
x.displayR = document.getElementById("rightSet");


//user presses button for first set preference
document.getElementById('set1').onmousedown = function() {
if (x.value == 0) {
   return;
  }
  x.left = true;
  x.shiftLeft();
}

document.getElementById('set1').onmouseup = function() {
  x.left = false;
}
document.getElementById('set1').onmouseout = function() {
  x.left = false;
}

x.shiftLeft = function() {
  if (x.value === 0 || x.left === false) {
    return;
  }
  x.value--;
  x.flash();
  document.getElementById('masterSelect').style.width = x.value + '%';
  setTimeout(x.shiftLeft, 100);
}

document.getElementById('set2').onmousedown = function() {
  if (x.value == 100) {
    return;
```

```
  }
  x.right = true;
  x.shiftRight();
}
document.getElementById('set2').onmouseup = function() {
  x.right = false;
}
document.getElementById('set2').onmouseout = function() {
  x.right = false;
}

x.shiftRight = function() {
  if (!x.right || x.value === 100) {
    return;
  }
  x.value++;
  x.flash();
  document.getElementById('masterSelect').style.width = x.value + '%';
  setTimeout(x.shiftRight, 100);
}

x.flash = function() {
  x.displayL.innerHTML = 'SET ONE: ' + x.value + '%';
  x.displayR.innerHTML = 'SET TWO: ' + (100 - x.value) + '%';
}

x.adjustOne = function(obj) {
  var i, val = x.value / 100;
  for (i in obj) {
    obj[i] = obj[i] * val;
  }
  return obj;
}

x.adjustTwo = function(obj) {
  var i, val = (100 - x.value) / 100;
  for (i in obj) {
    obj[i] = obj[i] * val;
  }
  return obj;
}

return x;
```

```
}
```

SORTER.JS

```
function chartMaker() {
  var x = {};
  x.order = [];

  //data is the array of objects containing the data
  //order is an array of the field names
  x.makeTable = function(data) {
    var order = x.order;
    var i, j, len, table, field = order.length;
    table = '<table border = "1" id="resultTable"><tr>';
    for (i = 0; i < field; i++) {
      table += '<th>' + order[i] + '</th>';
    }
    table += '</tr>';

    len = data.length;
    for (i = 0; i < len; i++) {
      table += '<tr>';
      for (j = 0; j < field; j++) {
        table += '<td>' + data[i][order[j]] + '</td>';
      }
      table += '</tr>';
    }
    table += '</table>';

    return table;
  }



  //data is an array of objects, storageField is a field name
  //in the object that will hold the value, factor is an
  //object with the same field names as the ones in data array
  //
  x.calc = function(data, storageField, factor) {
    var i, j, num, tmp, rd, total, len, field = [],
```

```
    con = [];
  for (i in factor) {
    field.push(i);
    con.push(factor[i]);
  }

  len = data.length;
  num = field.length;

  for (i = 0; i < len; i++) {
    total = 0;
    for (j = 0; j < num; j++) {
      tmp = data[i][field[j]];
      tmp = tmp * con[j];
      total += tmp;
    }
    data[i][storageField] = data[i][storageField] + total;
    rd = data[i][storageField];
    rd = rd * 100;
    rd = Math.round(rd);
    rd = rd / 100;
    data[i][storageField] = rd;
  }
  data = x.sortObj(data, storageField);
  return data;

}

//gets an array of objects and sorts by the value of specified property
//returns the array in order of greatest-least with property values
//should only be used to sort numeric properties
x.sortObj = function(arr, prop) {
  var i, tmp, there, len, keys = {},
    val = [],
    ret = [],
    done = [];
  len = arr.length;
  for (i = 0; i < len; i++) {
    tmp = arr[i][prop];
    if (!keys[tmp]) {
      keys[tmp] = [];
    }
    keys[tmp].push(i); //this will hold the offsets to orig. array
```

```
    if (val.indexOf(tmp) == -1) {
      val.push(tmp);
    }
  }
  val.sort(function(a, b) {
    return b - a
  }); //sort the values
  len = val.length;
  for (i = 0; i < len; i++) { //put indices of arr array in order
    ret = ret.concat(keys[val[i]]);
  }

  len = ret.length;
  for (i = 0; i < len; i++) { //load them into the array
    done.push(arr[ret[i]]);
  }
  return done;

 }
 //==========================
 x.purify = function(arr, storageField) {
  var i, len = arr.length;
  for (i = 0; i < len; i++) {
    arr[i][storageField] = 0;
  }
  return arr;
 }

 //==========================
 x.init = function(key, storageField, fieldArr) {
  x.order.push(storageField);
  x.order.push(key);
  x.order = x.order.concat(fieldArr);
 }

 return x;
}
```

EXPORT.JS

/*The application that gets the information on the server side must be specified in
the 'config' structure as 'config.exportUrl'. It will be sent an url-encoded JSON structure

```
that consists of:
description: [user input--a title, a comment, whatever]
date: number of milliseconds since 1970/01/01
formula: JSON structure used to make the calculation--{attribute: weight for att, attribute
...}
chart: html for the chart produced
*/

function exporter() {
  var x = {};
  x.messageBox = document.getElementById('ExMessage');
  x.textBox = document.getElementById('textBox');
  x.send = document.getElementById('exSend');
  x.clear = document.getElementById('exClear');
  x.buffer = ''; //the calculate function places the search set in here
  x.http = null;
  x.timer = null;
  x.kb = null;


  x.sendMessage = function(txt) {
    x.messageBox.innerHTML = txt;
  }

  //create the callback func for keyboard
  x.keyb_callback = function(ch) {
    var text = x.textBox,
      val = x.textBox.value;

    switch (ch) {
    case "BackSpace":
      var min = (val.charCodeAt(val.length - 1) == 10) ? 2 : 1;
      text.value = val.substr(0, val.length - min);
      break;

    case "Enter":
      text.value += "\n";
      break;

    default:
      text.value += ch;
    }
  }
```

```
x.kb = new VKeyboard("keyboard", x.keyb_callback);


//clear button
x.doClear = function() {
  x.messageBox.innerHTML = '';
  x.textBox.value = '';
}

x.clear.onclick = x.doClear;

//send button
x.send.onclick = function() {
  var data, cont = x.textBox.value;
  data = {};
  if (cont == '') {
    x.sendMessage("YOU MUST ENTER SOME TEXT");
    return;
  }
  if (x.buffer == '') {
    x.sendMessage("NO RESULTS HAVE BEEN SAVED");
    return;
  }
  if (x.http !== null) {
    x.sendMessage("WAIT--PRIOR CALL STILL PENDING");
    return;
  }
  if (config.exportUrl == (null || undefined)) {
    x.sendMessage("THE DESTINATION HAS NOT BEEN CONFIGURED");
    return;
  }
  x.textBox.innerHTML = ''; //no double hits
  data.description = cont;
  data.date = new Date();
  data.date = data.date.getTime();
  data.formula = x.buffer;
  data.chart = document.getElementById('chart');
  data.chart = data.chart.innerHTML;


  data = JSON.stringify(data);
  data = escape(data);
```

```
  data = 'mapData=' + data;


  x.http = new XMLHttpRequest();
  var fix = "'" + config.exportUrl + "'";
  x.http.open("POST", "exporter.php", true);
  x.http.setRequestHeader("Content-type", "application/x-www-form-urlencoded");
  x.http.setRequestHeader("Connection", "close");
  x.http.onreadystatechange = function() {
    if (x.http.readyState == 4 && x.http.status == 200) {
      x.incoming;
    }
  }
  x.timer = setTimeout(x.error, 10000);
  x.http.send(data);
}

x.incoming = function() {
  if (x.http.responseText == 'ACK') {
    x.sendMessage('EXPORT WAS SUCCESSFUL');
  } else {
    x.sendMessage("THERE WAS AN ERROR-ATTEMPT FAILED");
  }
  clearTimeout(x.timer);
  x.http = null;

}

x.error = function() {
  if (x.http.readyState != 4) {
    x.sendMessage("THERE HAS BEEN NO RESPONSE FROM THE SERVER");
  } else {
    x.sendMessage(x.http.statusText);
  }
  x.http = null;

}
//alterations to let user view exported data
var newB = document.createElement('input');
newB.type = "button";
newB.value = "IMPORT";
//stick it in the row
x.clear.parentNode.appendChild(newB);
```

```
  newB.onclick = function() {
    x.makeFrame();
  }

  x.makeFrame = function() {
    var html = document.createElement('div');
    html.id = "impDiv";
    html.innerHTML = ' <input type="button" value="CLOSE" id="closeF"><br><iframe
src="import.php?query=t" id ="impF"></iframe></div>';
    html.style.width = "100%";
    html.style.height = "100%";
    html.style.position = 'absolute';
    html.style.top = '0px';
    html.style.left = '0px';
    html.style.zIndex = '20000';

    document.body.appendChild(html);
    x.frame = document.getElementById('impDiv');
    document.getElementById('closeF').onclick = function() {
    x.frame.parentNode.removeChild(x.frame);
    }
  }

  return x;
}
```

PROCESS.JS

```
//main is the object that contains the data, map is the ref to map, config is global in
config.js
// and layers is the array that holds the color schemes for the layers
function doMap(main, map, config, layers) {
  var x = {};
  x.data = [];
  x.shape = {};
  x.layer = {};
  x.legend = {};

  var obj, block, geo, i, j, key, len = main.features.length;
  key = config.key;
  var alen, k, arr;
```

```
  for (i = 0; i < len; i++) {
    //extract the data
    block = main.features[i].properties;
    obj = {};
    for (j in block) {
      obj[j] = block[j];
    }
    x.data.push(obj);
    // now create the block on the map and record ref in x.shape
    geo = main.features[i].geometry.coordinates[0];
    //TAKE THIS OUT LATER--LATITUDE AND LONGITUDE ARE REVERSED IN
THE DATA
    alen = geo.length;
    for (k = 0; k < alen; k++) {
      geo[k] = geo[k].reverse();
    }
    //END OF ADJUSTMENT
    x.shape[obj[key]] = L.polygon(geo).addTo(map);
    x.shape[obj[key]].setStyle({
      color: '#000',
      fillColor: '#CCC',
      fillOpacity: 0.5
    });
  }

  //now build the colors for the layers based upon values
  var current, off, glob, cut, total, name, colors, val, id, op, clr, dataLen = x.data.length;
  //build function creates object to store info about a block's color for a specific layer
  var build = function(id, clr, op) {
      var obj = {};
      obj.color = clr;
      obj.id = id;
      obj.opacity = op;
      return obj;
    }


  len = layers.length;

  for (i = 0; i < len; i++) {
    name = layers[i].name;
    if (name == 'BASE') { //special case here for BASE
      x.layer['BASE'] = [];
```

```
    for (j = 0; j < dataLen; j++) {
      glob = build(x.data[j][key], layers[i].colors[0], layers[i].opacity[0]);
      x.layer['BASE'].push(glob);
    }
    continue;
  }
  colors = layers[i].colors;
  x.layer[name] = [];
  total = colors.length;
  cut = 100 / total;
  for (j = 0; j < dataLen; j++) {
    off = 0;
    val = cut;
    while (x.data[j][name] > val) {
      off++;
      val += cut;
    }
    if (off == total) { off-
      -;
    }
    op = layers[i].opacity[off];
    clr = layers[i].colors[off];
    id = x.data[j][key];
    glob = build(id, clr, op);
    x.layer[name].push(glob);
  }
}

//colors schemes are built for the layers

//now create the popups
len = x.data.length;
var str, j;

for (i = 0; i < len; i++) {
  str = '<b>' + x.data[i][key] + '</b><hr>';
  for (j in x.data[i]) {
    if (j == key) {
      continue;
    }
    str += j + ': ' + x.data[i][j] + '<br>';
  }
  x.shape[x.data[i][key]].bindPopup(str);
```

```
}

//now create the legends for the various layers

//==========TRANSIENT FUNCTIONS NEEDED TO BUILD THE LEGENDS
//--------convert rgb/opacity to rgba---leflet.js takes opacity as a separate value
var toRGBA = function(hex, opacity) {
    hex = hex.replace('#', '');
    hex = hex.toUpperCase();
    var ret, r, g, b, ret = "rgba( *r, *g, *b," + opacity + ')';
    r = hexToDec(hex.substring(0, 2));
    g = hexToDec(hex.substring(2, 4));
    b = hexToDec(hex.substring(4, 6));
    ret = ret.replace('*r', r);
    ret = ret.replace('*g', g);
    ret = ret.replace('*b', b);
    return ret;
  }

var hexToDec = function(inp) {
    var first, second, conv = '0123456789ABCDEF';
    first = inp.substring(0, 1);
    first = conv.indexOf(first) * 16;
    second = inp.substring(1, 2);
    second = conv.indexOf(second);
    return (first + second);
  }
  //retrieve alias from attribute name
var getAlias = function(name) {
    var off = config.sought.indexOf(name);
    return config.alias[off];
  }
  //====================
var div, curr, clen, clr, alias, start = 0;
len = layers.length - 1; //do not include BASE in this loop
for (i = 0; i < len; i++) {
  alias = getAlias(layers[i].name);
  str = '<h3>' + alias + '</h3>';
  clen = layers[i].colors.length;
  div = 100 / clen;
  curr = div;
  start = 0;
  for (j = 0; j < clen; j++) {
```

```
      str += '<span class="cBlock"';
      str += 'style="background-color:';
      clr = toRGBA(layers[i].colors[j], layers[i].opacity[j]);
      str += clr + '">  </span>' + start + '-' + curr + '<br>';
      start = curr + 1;
      curr += div;
    }
    x.legend[layers[i].name] = str;
  }
  //build one for the BASE--its different
  str = '<h3>BASE</h3>';
  str += "Relevance in Descending Order<br>";
  len = config.color.length;
  var tag = len;
  for (i = 0; i < len; i++) {
    str += '<span class="cBlock"';
    str += 'style="background-color:';
    clr = toRGBA(config.color[i], config.opacity);
    str += clr + '">  </span>' + tag + '<br>';
    tag--;
  }
  x.legend['BASE'] = str;

  //============================== legacy function from esri map--interface to
showLayer()
  x.setVisible = function(arg) {
    if (slate.graphics_exist == 'yes' && arg == 'BASE') {
      x.setGradient();
      var doc = document.getElementById('Legend');
      doc.style.display = "block";
      doc.innerHTML = x.legend[arg];
    } else {
      x.showLayer(arg);
    }
  }

  //========================colors grids to show "layers"
  x.showLayer = function(inp) {
    var i, len, off, fc, op, doc, focus = x.layer[inp];
    len = x.data.length;
    for (i = 0; i < len; i++) {
      op = focus[i].opacity;
      fc = focus[i].color;
```

```
    off = focus[i].id;
    x.shape[off].setStyle({
    fillColor: fc,
      opacity: op
    });
   }
   doc = document.getElementById('Legend');
   doc.style.display = "block";
   doc.innerHTML = x.legend[inp];
  }

  //==============================create radio buttons to toggle layers upon
request
  x.makeButtons = function(contId) {
   var target = document.getElementById(contId);
   config.sought.push('BASE');
   config.alias.push('BASE');
   var i, bt, len = config.sought.length;
   for (i = 0; i < len; i++) {
    bt = document.createElement('input');
    bt.type = "radio";
    bt.name = "layerToggle";
    bt.className = "layerToggle";
    bt.onclick = function(arg, but) {
      return function() {
        but.checked = false;
        x.setVisible(arg);
        document.getElementById('legendWrapper').style.display = "block";
      }
    }(config.sought[i], bt);
    target.appendChild(bt);
    sp = document.createElement('span');
    sp.className = 'layerSpan';
    target.appendChild(sp);
    sp.innerHTML = config.alias[i];
    br = document.createElement('br');
    target.appendChild(br);
   }
   config.sought.pop();
   config.alias.pop();
  }
```

```
  //========================sets colors of blocks in BASE in accordance with
search criteria
  x.setGradient = function() {
    var counter, i, off, feature, color, clrOff, interval;
    var len = x.data.length,
      clen = config.color.length;

    counter = 0;
    clrOff = 0;
    interval = len / clen;
    interval = Math.round(interval);

    //color them according to rank in array--x.data has been sorted already
    for (i = 0; i < len; i++) {
      color = config.color[clrOff];
      off = x.data[i][key];
      x.shape[off].setStyle({
      fillColor: color,
      opacity: config.opacity
      });
      counter++;
      if (counter == interval) {
        if (clrOff < (clen - 1)) {
        clrOff++;
        }
        counter = 0;
      }
    }
  }


  //end
  x.showLayer('BASE');
  adjustZ('dashB');
  return x;
}
```

WIDGET.CSS

```
/*  This is the class for the div which holds each widget --the main container
*/
.slider{
margin-left: 0px;
width: 98%;
```

```
font-size: small;
border:2px solid black;
margin-top: 0px;
background-color: #fff;
background-image: url(sliderbg.png); background-
repeat: no-repeat; background-position: top left;
}
/*   class=descript the top div that holds the description  --empty here                    */
.descript{
}
/* The span that holds the actual text in the top div   */
.descSpan{
}


/* This is the div that is the background for the selection bar   */
.holder{
   height: 1em;
   width: 100%;
   border:1px solid black;
}
/*  This is the div that is currently red--displays value as bar
across the widget  */

.bar{
   height: 100%;
   width: 10%; background-
   color:green;
}
/* The entire bottom div that contains the buttons and numerical display*/
.control{
}
/* class for the span which contains the word LOCK      */
.lock{
}
/* class="check" input of type checkbox*/
.check{
}
/* class for button element that displays the minus sign   */
.minusB{
}
/* class for button element that displays '+' sign  */
```

```
.plusB{
}
/* span that contains numerical display of value*/

.counter{
}
/* bars are the span elements in the nav bar */
.bars{
cursor:   crosshair;
font-weight:   800;
font-size:  normal;
margin-right: 10%
}

/* This is the HR that separates the two sets of sliders*/
#divider1{
/*height: 20px;
color: black;
background-color:blue;*/
}

/*---master slider---*/
#masterSlide{
height: 4em;
width: 100%;
/*border: 2px black solid;*/
}

/*---non-moving (blue) bar */
.masterHolder{
height: 30%;
width: 100%;
background-color: green;
margin-bottom: .5em;
}

.masterSelect{
height: 100%;
background-color: blue;
}

/*-----------spacing between spans  */
#rightSet{
```

```
margin-left: 10px;
}



/*---------------------------Playing around with positioning "floats"  */

#dashB{

position: absolute;
width: 275px;
background-color:#fff;
border: 2px black solid;
right: 0px;
margin-right: 50px;
opacity:0.75;
filter:alpha(opacity=40);

}

/*
#export{
position: absolute;
width: 75%;
background-color: white;
border: 2px black solid;
}

#chartCont{
background-color:white;
position: absolute;
width: 75%;
border: 2px black solid;
}

*/

#legendWrapper{
background-color:white;
position: absolute;
left: 0px;
margin-left: 50px;
width: 5%;
```

```
border: 2px black solid;
}

----set styles for "hide" buttons and drag bars */

.hideIt{
width: 20%;
background-color:white;
font-weight: 600;
}

.dragBar{
min-width: 100%;
min-height: 1.5em;
background-color:orange;
}

.cBlock{
margin-left: 3px;
margin-right: 4px;
margin-bottom: 4px;
width: 16px;
min-height: 16px;
border: 1px black solid;
}

#slideDiv {width: 275px;}
#legendWrapper {position: absolute; left: 0px; margin-left: 10px;}
/*#leg2 {position: absolute; float: right; top: 0px; right: 0px;}*/
/*#legend{position: absolute; float: right;}*/
/*#radio { float: left; }*/
/*#export {position: absolute; top: -5000px; left: -5000px;}
#chartCont {position: absolute; top: -5000px; left: -5000px;}*/

#export{
position: absolute;
width: 50%;
background-color: white;
border: 2px black solid;
}

#chartCont{ background-
color:white;
```

```
position: absolute;
width: 35%;
border: 2px black solid;
}


h3{ font-family:Arial, Helvetica, sans-serif; font-weight: bold; font-size: 14px; margin:
0px; padding: 0px;}
```

Appendix B – GIS Data Sources

Data Source	URL
Mariner Database	http://hotspringchem.wr.usgs.gov/
USGS NAWQA	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:0
SMU Geothermal Database	http://smu.edu/geothermal/georesou/resource.htm
USGS	http://earthquake.usgs.gov/regional/qfaults/
USGS	http://imnh.isu.edu/digitalatlas/geo/snkrvpln/basalt/srpbslt.htm
BLM	http://www.blm.gov/
NPS	https://irma.nps.gov/App/Portal/Home
IDWR	http://maps.idwr.idaho.gov/PLSookup/Map
FEMA	http://www.pasda.psu.edu/uci/FullMetadataDisplay.aspx?file=NREL_FEMATransmission.xml
Census MAF/TIGER	http://www.census.gov/geo/www/tiger/tgrshp2012/tgrshp2012.html
USGS National Elevation Dataset	http://cloud.insideidaho.org/data/anonymous/elevation/ned/1999_30m_idaho/metadata.xml

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