Flexible Framework for Assessing Water Resource Sustainability in River Basins

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Abstract

As the anthropogenic footprint increases on Earth, the wise use, maintenance, and protection of freshwater resources is key in the sustainability of development. Borne from efforts to promote sustainable development of water resources, integrated water resource management (IWRM) was advanced. Methodologies supporting IWRM implementation have largely focused on the overall process, but have paid limited attention to evaluation methods of ecologic, economic, and social conditions. To assist in assessing water resource sustainability, the River Basin Analysis Framework (RBAF) has been developed. The RBAF merges the UN GEO4 DPSIR approach, UN Millennium Ecosystem Assessment approach, and principles of sustainable development to enable users to better understand spatiotemporal interactions between hydrologic, socio-economic, and ecologic systems and evaluate impacts of disturbances on ecological goods and services and human well-being (HWB). The RBAF provides new methods and tools to identify and employ analytical processes for conducting assessments of sustainability and policy alternatives.

The RBAF is comprised of a Conceptual Template (RBAF-CT), for assessing the situation and guiding indicator selection, and an Analytical Interface (RBAF-AI) for organizing and processing analytical results. The RBAF-CT connects constituents of HWB directly, or through EGS, to the relevant hydrologic cycle components. Associated with these constituents/components are relevant pressure, state, and impact indicators for use in assessing conditions and analyzing ecological, economic, and social conditions. Disturbance Templates for eight pressure types (e.g. population growth) guide users on the potential changes to the hydrological cycle and associated systems. The RBAF-AI organizes the output data from hydrologic, ecologic, economic, and social analyses and, with respect to time and space, computes the reliability, resilience, and vulnerability of the impact indicators for various water use scenarios. Results are presented in a timeline of sustainability indicators in ecologic, economic, and social conditions and a star plot for the overall conditions for easy comparison. The RBAF was applied to the Lemhi River Basin, Idaho, and the Upper Bhima River Basin, India (RBAF-CT only). The RBAF supports the IWRM process by providing a structured means to frame and analyze water related issues and select appropriate indicators to assess the sustainability of water programs and policies in river basins.

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Chapter 1. Introduction

Water influences both natural processes in a river basin and associated human activities and responses. As the Earth's population and the resulting anthropogenic footprint increases, the need to maintain and protect freshwater resources will be a key element in the sustainability of development. In 2011, The World Economic Forum identified the interconnected resource issues of water, energy, and food as a serious global risk (WEF 2011). Indeed, not managing water and natural resources properly has led to the decline or collapse of civilizations. Drought and wars impaired the Mayan irrigation system resulting in the collapse of the Mayan civilization (Peterson and Haug 2005, Diamond 2006). Anthropologist believe that Mashkan-shapir, a typical Mesopotamian city connected to the Tigris River by a network of canals, was abandoned after salt build up in the soil from irrigation rendered the soils infertile (www.learner.org/interactives/collapse/mesopotamia.html). Similarly, a series of droughts triggered food shortage that lead to widespread famine causing Anasazi to abandon dwelling in Chaco Canyon in the southwest of the US (Mays 2007b). In modern times, the significant upstream diversion of water from the Aral Sea watershed has led to a 60% decrease in surface area resulting in hotter local climates, lake salinity to increase from 10 g/l to 45 g/l, dust storms, decreased productivity of agriculture, and the collapse of a once thriving fishing industry (Mays 2007b). In its 2011 Water Security report, the WEF (2011) stated that "water security is the gossamer that links together the web of food, energy, climate, economic growth, and human security challenges that the world economy faces over the next two decades." Given the increased anthropogenic pressures on current water resources coupled with greater uncertainty associated with future climate change, the need is great for evaluating the sustainable use of water resources.

Efforts to promote sustainable and responsible use of water have given rise to Integrated Water Resource Management (IWRM) (GWP 2004, GWP 2008). IWRM involves understanding a system's current conditions, identifying and assessing limiting factors, developing and implementing solutions, and monitoring for success (GWP 2004). Supporting the implementation of IWRM is a broad base of literature covering general concepts, philosophies, methodologies, guidance, and applications. The IWRM methodology and guidance literature has largely focused on the overall process: creating participatory organizations, building institutional capacity, financing programs, developing legal frameworks, outlining components of a plan, and identifying management instruments (GWP 2004, Hooper 2005, GWP 2008, UNESCO 2009a,b). While a significant aspect of

IWRM is participatory and management oriented, analytical tools can assist water managers and participants in assessing the current situation as well as developing solutions to address and mitigate identified limitations.

Water management has traditionally focused on the distribution of water given the available supply and demand of water within a basin (ASCE 1998). Yet, by IWRM principles, assessment of water management decisions sustainability needs to evaluate how water distribution affects ecological, economic, and social conditions (the Sustainability Criterion (SC)) within a basin (GWP 2004, Hooper 2005, GWP 2008). To operationalize IWRM, several questions need be addressed. When evaluating sustainable development with respect to water resources, what defines sustainable ecological, economic, and social systems? How do we assess, either through observations or predictive models, if water resources management strategies are sustainable in the hydrologic, economic, ecologic, and social systems? How are these assessments from the different SC disciplines combined and displayed to illustrate the economic efficiency, environmental conservation, equity in allocation to evaluate the effectiveness of water resources management in achieving pre-established objectives? To address these questions, there is need for a framework to guide and extend the water resource analysis to include evaluation of the SC criterion.

While IWRM guidelines stress the need to evaluate the SC disciplines, there are few resources to provide water managers, decision-makers, stakeholders, and technical staff with a comprehensive overview of how each discipline is analytically evaluated individually and holistically with respect to water management. One of the most comprehensive manuals on the sustainability analysis of water resources is ASCE's (1998) *Sustainability Criteria for Water Resource Systems* monograph. Currently out of print, the monograph offers an overview of assessing water resource sustainability, but is limited in its discussion on the role of ecological economics, environment, and social systems analysis. For guidance on discipline specific analysis with respect to water, other resources are distributed throughout the literature. For evaluating sustainable water resource allocation, resources include ASCE (1998), Cai et al. (2002), Jakeman and Letcher (2003), Loucks et al. (2005), and Sandoval-Solis et al. (2011). Economic and water resource development have historically been interlinked (Lund et al. 2006) and extensive resources are available including Young (2005), Harou et al. (2009), and Booker et al. (2012). Since the late-1980's, attempts to integrate environmental factors more prominently in economic evaluations have employed the use of natural capital valuation and valuation of ecosystems services; methods that have been growing in acceptance and application resources (MA 2005a, Russi et al. 2012). Ecologically, developments in freshwater ecosystems including advancements in aquatic habitat modeling, agent based modeling, systems dynamic modeling, biologic modeling, and integrated modeling frameworks that link discipline specific models into a systems understanding of ecological systems, environmental thresholds such as carrying-capacities, and the role of biodiversity in resilience (World Bank 2000, Russi et al. 2012). Finally, the study of socio-ecological systems is bringing greater clarity of the connections between how humans and the environment interact (Azar et al. 1996, Falkenmark and Folke 2002, Walker and Meyers 2004, Walker et al. 2004, Ostrom 2007, Collins et al. 2010).

The objective of the River Basin Analysis Framework (RBAF) developed herein is to support the IWRM process by providing a structured and transparent means for water managers and stakeholders to understand the full implications of water related issues, to focus the types of studies and analyses that are necessary to conduct, and appropriate indicators to assess the sustainability of water management programs and policies in river basins under different future scenarios. This document provides the background, describes methodology, and illustrates the application of the RBAF with case studies. The content of the chapters in the document are:

1. Introduction: Provides an overview of the problem being addressed and how RBAF addresses this problem. .
2. Assessing the Sustainability of Water Resources in River Basins: An Overview: Definition of sustainability, the assessment of sustainability per discipline, how indicators can assist in the assessment, and a categorized list of indicators for assessing water resources derived from many of the primary literature sources.
3. Flexible Framework for Assessing Water Resource Sustainability in River Basins: Introduction to the RBAF and the theoretical background information on driver-pressure-state-impact-response assessment method (DPSIR), ecological goods and services (EGS), constituents of human well-being (human well-being), and freshwater ecosystems which provides the foundation for the framework. The chapter also includes an overview of the RBAF and how it is applied.
4. Classification of Water Resources Sustainability Indicators: This chapter presents the classification of 550+ indicators that can be mapped to the Pressure, State, Impact framework for guiding analysis and determining the important elements to measure in assessing a basin's water resources sustainability.

5. RBAF-Conceptual Template (CT): a detailed methodology for applying the RBAF-CT as well as case studies in the Lemhi River Basin, Idaho, USA, and Upper Bhima Basin, Maharashtra, India.
6. RBAF-Analytical Interface (AI): a detailed methodology for applying the RBAF-AI with a case study set in the Lemhi River Basin, Idaho, USA.
7. Summary: an overview of how the RBAF components fit together and a discussion on the application of the framework to address water resources sustainability.

This document has been written in partial satisfaction of the requirements for the doctoral degree in Civil Engineering at the University of Idaho. Chapters 5 and 6 are prepared as journal articles and therefore contain some redundancy of concepts and information presented in earlier chapters.

Chapter 2. Water Resource Sustainability

2.1 Sustainable Development Defined

Sustainable development has been defined by several organizations as the implementation of socio-economically viable alternatives that will maintain, if not improve, the ecosystem (Hardi 1997, MA 2003, UNEP 2007). The Brundtland Commission (UN 1987) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The International Institute for Sustainable Development’s (IISD) (Swanson and Pintér 2007) definition of sustainable development, and one adopted for this document, is “development that improves the economic and social well-being of people while maintaining or enhancing environmental integrity for current and future generations”. Sustainable development can further be characterized by its core elements. Modified from the Bellagio Commissions findings in 1997, the IISD (ibid) identified the core elements of sustainable development as:

- *Intra- and inter-generational linkages:* development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- *Inter-dependence:* development that takes account of the inherent connections among our environment, the people living in it, and the economy within which we interact on a daily basis.
- *Multi-stakeholder perspectives:* development that relies on the multiple perspectives of broad participation to adequately understand the complexity of issues and to attain the legitimacy necessary to implement initiatives that advance development.
- *Multi-scale effects:* understanding the inter-relationships between scales for issues and policy responses.
- *Inherent socio-economic and ecologic capacities:* understanding and appreciating the thresholds that exist within our interrelated socio-economic and environmental systems.
- *Adaptive learning and management:* the need for continuous cycles of planning, implementation and adjustment due to the inherent complexity of development.

Thus, assessment of sustainable development should address these core principles in its methodology and analysis. Though these definitions appear straightforward, in practice how sustainable development is defined and evaluated is contextual and subject to the conceptions and beliefs of the implementer (Dresner 2008, Bell and Morse 2008). It is the multifaceted and contextual characteristics of sustainable development that have made operationalizing the sustainability principles difficult (Simonović et al. 1997).

Considering water availability and use is essential in evaluating sustainable development as water influences all facets of human life: from direct consumption to economic livelihoods to cultural practices to the ecological systems upon which humanity relies. Specifically, humans directly use water through personal consumption and sanitation as well as the production of consumer goods and services (e.g. manufactured goods or energy from thermal power plants). Humans indirectly enjoy water's benefits through its support of ecosystems upon which ecological goods and services (EGS) are derived (e.g. fish consumption, storm protection, recreational opportunities, spiritual rituals, aesthetics value of a river or lake) (Daily 1997a,b, MA 2003, Postel and Richter 2003, MA 2005a). Thus, water delivery in sufficient quantity and quality to maintain the function of ecological, economic, and social systems is crucial for sustaining human well-being. Water of insufficient quantity or poor quality limits economic development, leads to adverse health and livelihood conditions, and can even cause the collapse of societies (Mays 2007a).

When considering water resources sustainability, several definitions emphasize the water's importance to human and natural systems as well as the necessity of considering the elements of sustainable development. Rothman's definition states "Water resources sustainability is the ability to provide water managers water quantity and quality so as to meet the present needs of human and environmental ecosystems, while not impairing the needs of future generations" (Mays 2007a). In the ASCE monograph (1998), water resource sustainability is proposed as "water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity". Gleick (1995) defined the core elements of the sustainable water resources as:

- A basic water requirement will be guaranteed to all humans to maintain human health.
- A basic water requirement will be guaranteed to restore and maintain the health of ecosystems.
- Water quality will be maintained to meet certain standards, these standards will vary depending on location and how the water is to be used.
- Human actions will not impair the long-term renewability of freshwater stocks and flows.

- Data on water resource availability, use, and quality will be collected and made accessible to all parties.
- Institution mechanisms will be set up to prevent and resolve conflicts over water.
- Water planning and decision-making will be democratic, ensuring representation of all affected parties and fostering direct participation of affected interests.

In these and other definitions of water resources sustainable development (GWP 2004, Brunner and Starkl 2004, Loucks et al. 2005, Giupponi 2006, GWP 2008, UNESCO 2009a, WEF 2011), the core components of assessing water resource sustainability follow the elements of assessing sustainable development. Analysis should include both intra- and inter-generational considerations as well as evaluate the SC systems with respect to capacities and thresholds in response to disturbances. Thus, the analysis supporting IWRM should be conducted with consideration of these core components and elements.

Though recognized as important in assessing the water resource sustainability, less guidance is available as to how to assess sustainability of the SC systems. In applying the definitions and core elements in the assessment of water resource sustainability, questions arise such as what defines the sustainability in each SC system? How are SC systems analyzed and measured individually as well as integrated to provide a holistic assessment of the system's sustainability? Finally, when concerned with the water resources management, how do decisions and perturbations to the hydrologic system ripple through the SC systems? Though guidance to these questions is disseminated in the literature, to the author's knowledge there is no good single source for obtaining this information. The following text provides an overview as to how sustainability is defined and measured in the SC systems.

2.2 Formulating Sustainability Analyses

When formulating sustainability analyses, three question need to be addressed (Bell and Morse 2008):

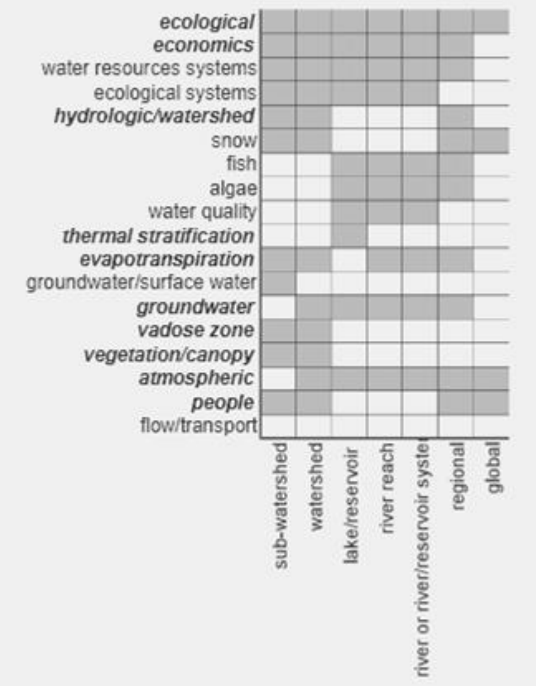
- What defines the domain of the system being analyzed?
- What is the time frame of the analysis?
- What defines the metrics to gage a system's condition?

Combined, addressing these questions will formulate the water resources sustainability analysis of a river basin.

2.2.1 Analytical Domains

Different processes in a river basin operate within different domains (Figure 1). Domains define what is endogenous and exogenous to the system and include the spatial domain as well as non-spatial elements such as demographic groups, economic sectors, government agencies, and species. The domain extent needs to be large enough to encapsulate the relevant processes, but not so large as to render the system insignificant (Bell and Morse 2008). For example, if fish population distribution within a watershed is of interest, a reach analysis would be too small as it does not account for interactions with other reaches and a regional analysis is too large-scale as the watershed population would be lumped into a single figure. Typically, it is more difficult to define domains for smaller systems as exogenous factors have a greater influence on the system processes (ibid).

For natural resource analyses, the analytical domains are often spatially delineated. For example, hydrologic and ecological processes are tied to the landscape and thus are typically delineated within a watershed boundary. Economic and social systems are generally less directly tied to physical location and thus less likely to follow geographic features. In assessing economic and social systems within a watershed, it is important and more challenging to define which elements are endogenous, exogenous, or both to a river basin (ibid). For example, social systems may be defined by governmental borders that may or may not follow geomorphic features such as rivers or watershed boundaries. Thus, defining which government organizations and accompanying policies are operating within the watershed is required for crafting the social system analysis. Similarly, determining the relevant economic sectors and their elements that operate endogenously and exogenously in a watershed is required for developing the economic analysis. Extent of the domain is a function of the question being addressed, analytical method chosen, data availability, computational power required, and time and resources available. The domain is typically determined by scientific experts constructing the analysis.



	sub-watershed	watershed	lake/reservoir	river reach	river or river/reservoir syste	regional	global
ecological	▨	▨	▨	▨	▨	▨	▨
economics	▨	▨	▨	▨	▨	▨	
water resources systems	▨	▨	▨	▨	▨	▨	
ecological systems	▨	▨	▨	▨	▨		
hydrologic/watershed	▨	▨				▨	
snow	▨	▨				▨	▨
fish			▨	▨	▨	▨	
algae			▨	▨	▨	▨	
water quality			▨	▨	▨		
thermal stratification			▨				
evapotranspiration	▨	▨		▨	▨	▨	
groundwater/surface water	▨						
groundwater		▨	▨	▨	▨	▨	
vadose zone	▨	▨					
vegetation/canopy	▨	▨					
atmospheric		▨	▨	▨	▨	▨	▨
people	▨	▨				▨	▨
flow/transport							

Figure 1. Example of spatial scales for hydrologic, ecologic, economic systems (John Tracy personal communication, 2011).

2.2.2 Time Frame

Factors to consider when selecting appropriate temporal scales include the time step, reference point, and duration of the analysis. Processes operate on different temporal and spatial scales in the fundamental process (e.g. computational cell size) and are often linked with finer spatial resolution dictating smaller time steps. Greater variability within a process can also dictate smaller time step length in order to capture rapid change. For example, base flow conditions with constant flows can be simulated on a daily or weekly basis whereas flooding events need to be simulated on minute to hourly basis. In addition, several time scales may be necessary when analyzing multiple processes in a system. For example, in the hydrologic cycle, water movement in a river may be computed on a 5-minute time step, the unsaturated zone on a six-hour time step, and the saturated zone on a daily time step (Figure 2). Likewise, for economic and social systems, the economic production from irrigated crops may be computed seasonally and child mortality rates on an annual basis. Selecting the fundamental process time step is important for the systems' analysis, exchanging data between systems, and computing the sustainability indicators from analysis output.

Choosing a reference point and duration of analysis influences the sustainability assessment of a system (Bell and Morse 2008). In Figure 3, assuming the time series data represents water delivery to a user, the overall trend from periods T1 through T5 is approximately flat thus indicating water delivery is constant over the full period. If analysis of the system's conditions was limited to periods T1, T2, or T5, the trend in the data indicating that water delivery is increasing and thus sustainable. On the contrary, if the periods T3 or T4 represented the system's conditions, water supply appears to be decreasing and thus increasingly unsustainable. Thus, selection of the reference point and duration of analysis is important in evaluating a system's sustainability. This becomes particularly challenging under climate change when some watersheds are experiencing rapid change (Milly et al. 2008).

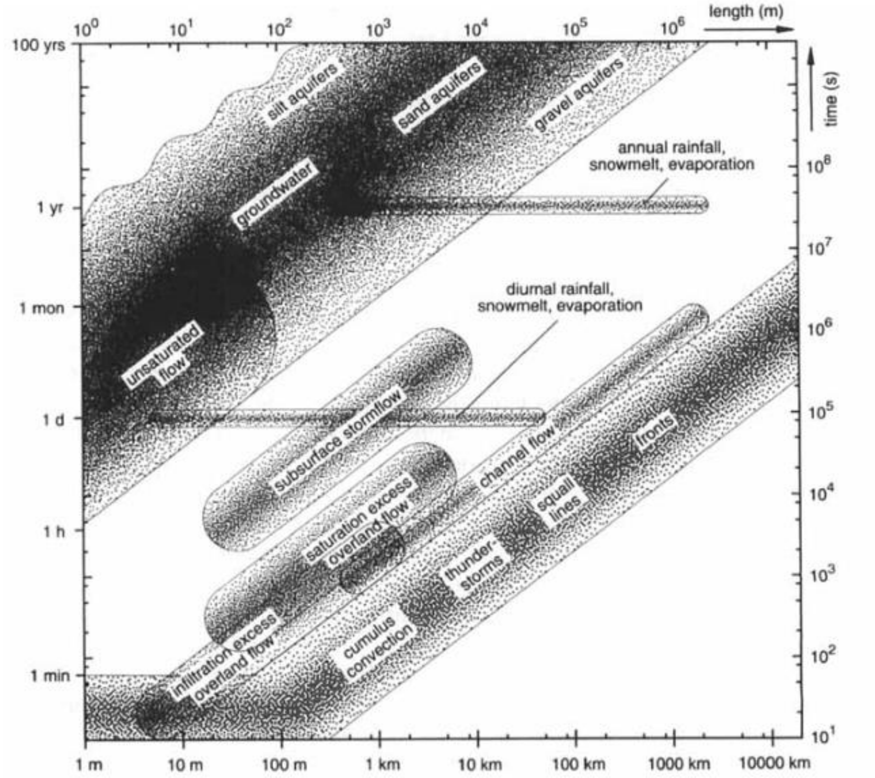


Figure 2. Spatial and temporal scale of meteorological and hydrological systems (Bloschl and Sivapalan 1995).

Additional factors to consider in determining the duration of analysis period include the disturbance being evaluated and variability of the system. The analysis period needs to encompass both the occurrence and propagation of a disturbance as well as the potential recovery of systems that have been affected (Bell and Morse 2008). For example, the lag time associated with pumping from a well in an aquifer may not affect river flows until the following year. To account for different conditions that systems may encounter, the analysis period should consider the internal and external variability in driving forces and system behavior. Variability to be considered includes random drivers (e.g. annual precipitation amounts) and cycles of processes (e.g. decadal cycles in weather patterns). According to the Principles of Sustainable Development Assessment, the analysis period should extend over several generational periods, though additional data and predictions of future conditions are needed to support extended analysis.

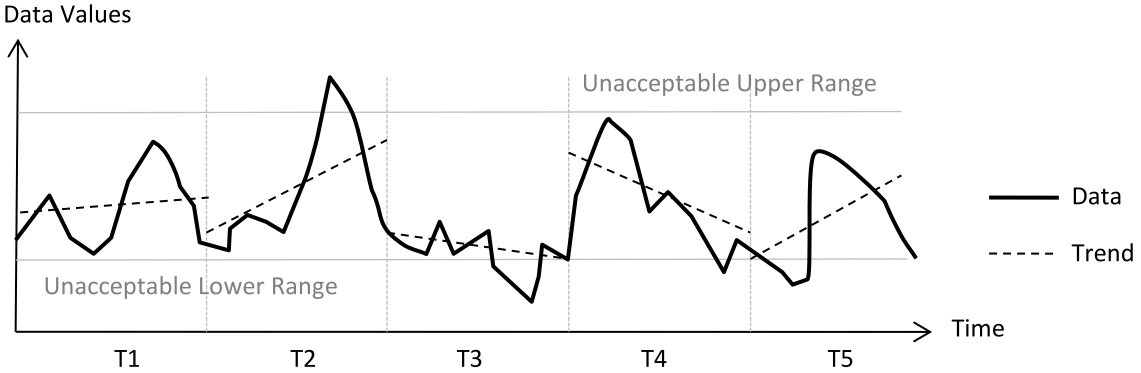


Figure 3. Example time series of typical variability in water availability illustrating the importance of the period of trends. Adapted from Bell and Morse (2008) and ASCE (1998).

Finally, the period being evaluated relative to the present affects if the analyses are a 'sustainability analysis' or 'program evaluation' (Bateman et al. 2010). Sustainability analyses involve examining past data to find trends in order to determine if a system's current status is sustainable. These analyses are more deterministic in nature as they are looking for root causes of problems. Program evaluation is forward looking, predicting the impact to future drivers and pressures of change on a system. Program evaluation involves assessing a system's response to change in future scenarios from drivers and pressures such as climate, landuse, demand, infrastructure, environment, economic, society, or policy (institutional). These analyses tend to incorporate stochastic and probabilistic solutions to reflect the uncertainty of the future.

2.2.3 Measuring Impacts

Indicators are an effective means of analyzing the data characterizing a system and have been widely applied in assessing sustainable development. To this end, they are effective tools in communicating technical information between scientist and decision-makers to understand SC systems and assist in formulating management decisions (Malkina-Pykh 2002). Furthermore, indicators are applicable for a multitude of disciplines, can represent different data types and sources and provide a powerful tool in diagnosing problems, understanding underlying causes, identifying solutions, defining future goals, and monitoring progress towards sustainability

(Winograd et al. 1999, Segnestam 1999, Malkina-Pykh 2002, Pintér et al. 2008, Bell and Morse 2008, Winograd and Farrow 2011). For river basin management, indicators are used to assess the health of resources and the hydrologic system through the development, implementation, and monitoring of water management decisions (UNESCO 2009b). Indicators are limited, however, in that they are a measurement and do not include the cause and effect processes of the systems they describe and therefore cannot be used in a predictive capacity (Bell and Morse 2008).

Indictor selection for assessing a system's condition must consider what it is measuring in the system and how the results will influence the findings (MA 2006, Bell and Morse 2008). Common selection criteria includes: easily understandable, relevance towards policy, theoretically well founded, sensitive to change in time, measurable both scientifically and practically, appropriate in scale, wider in significance than its immediate meaning, and accessible (Malkina-Pykh 2002, Cap-Net 2008, Winograd and Farrow 2011). To support the interdisciplinary analysis required for assessing sustainability management, the indicators selection criteria should also reveal interrelated connections between disciplines, whether a system is sustainable or unsustainable (Winograd and Farrow 2011) and be able to be linked with mathematical models (Malkina-Pykh 2002). Note, when selecting indicators, Rogers et al. (2008) observed that science is good at measuring physical and chemical properties, but falls away when measuring biological, social, and cultural aspects. In reviewing the state of economic assessments, Stiglitz et al. (2009) suggests a shift is required from assessing economic to human well-being noting the gap between GDP and common peoples' well-being starting with living standard (material well-being). He further calls for not just measuring average well-being, but looking at variety of community members over time to determine the equity in societies. Considering biological, social, and cultural indicators that describe well-being and equity could provide greater relevance to assessment of the water resources sustainability.

George Miller (1956) experimentally determined that, when making decisions, a typical person is able to conceive only 5-9 independent factors. In line with that, the 5th Bellagio Principle for Sustainable Development Assessment states that a limited number of indicators or analytical factors should be used in an assessment (http://www.iisd.org/measure/principles/progress/bellagio_full.asp). Given the wide array of disciplines being addressed in assessing sustainability, the number of applicable indicators can be extensive. To limit the number of indicators that water managers and stakeholder need to consider, indexes are used. Indexes are aggregations of indicators that provide an additional level of analysis.

Often they are used to analyze larger scale issues such as regional or national trends (Segnestam 2002). Methods of developing indexes include multivariate analysis, normalizing indicators, weighting indicators, and aggregating indicators (OECD 2008). *The Handbook on Constructing Composite Indicators* (ibid) provides a comprehensive methodology for developing indexes. The effort to operationalize sustainable develop has resulted in many indexes and indicators suites for determining sustainable development. The IISD Compendium of Sustainable Development Indicators Initiatives (http://www.iisd.org/measure/compendium/) provides a worldwide directory of activities in the field of sustainability indicators. While indexes are an effective means of summing results from multiple indicators, their use can hide important aspects of the system and make it more difficult to analyze casual links to individual indicators (ibid).

Indicator suites and indexes have been developed for assessing the sustainability of water resources. The Sustainable Water Resources Roundtable (SWRR) compiled a list of 386 indicators that relate to water to social, economic, and ecological conditions (SWRR 2005). Other indexes to assess the sustainability of water resources include the Arctic Water Resource Vulnerability Index (Alessa et al. 2009), Canadian Water Sustainability Index (Government of Canada 2007), Water Poverty Index (Sullivan et al. 2003), Watershed Sustainability Index (Chaves and Alipaz 2007), and West Java Water Sustainability Index (Juwana et al. 2010a,b). These frameworks offer useful insights but are geared towards specific applications and do not provide a generic framework for broader application.

2.3 Assessing the Sustainability of Systems

Indicators of a system describe qualities and conditions, but do not in themselves provide insight into a system's sustainability and therefore performance criteria are employed. Performance criteria by which systems are judged sustainable include trend, resilience, reliability, and vulnerability of an indicator (Table 1) (Loucks 1997, Simonović et al. 1997, ASCE 1998, Sandoval-Solis et al. 2011). Resilience is a measure of a system's ability to withstand and recover from changes from drivers or pressures (ASCE 1998, Sandoval-Solis et al. 2011). Reliability is defined as the probability that an indicator is within an acceptable range during the time period considered (ASCE 1998). Vulnerability is the extent to which change from a driver or pressure may damage or harm a system (ibid) and reflects on a system's sensitivity to perturbations and ability to adapt to new conditions. In other words, a system's vulnerability is evidence of the buffering capacity to adjust to perturbations or susceptibility to tipping points or thresholds of harmful change. In general, with greater reliability and resilience and lower vulnerability, a system becomes increasingly sustainable.

Table 1. Performance criteria used to determine the sustainability of a system.

Criteria	Equation	Equation No.	Source
Trend	$= \Delta D/\Delta t$	(1)	ASCE 1998
Reliability	$=\Sigma\#D_A/\Sigma\#D$ where $D_A = T_L < D < T_U$	(2)	ASCE 1998
Resilience	$=\Sigma\#C/\Sigma\#D_U$ where $C = 1$ when $D_{U\,t}$ and $D_{A\,t+1}$	(3)	ASCE 1998
Vulnerability	$=(\Sigma D_u/\#\, D_u)/\Sigma D_T$	(4)	Sandoval-Solis et al. 2011
Equity	$= \Sigma\lvert E(i,g) - A(i,g)\rvert$	(5)	ASCE 1998
Given:	• D – data, • #D - number of occurrences • D_T – target value • D_A, D_U - acceptable, unacceptable data, respectively • C - a tag for counting the occurrences given certain criteria • T_L ,T_U - lower, upper threshold • E(i,g), A(i,g) – excepted, actual beneficial impact across all groups		

The use of a system's resilience, reliability, and vulnerability are not universally agreed upon as fully comprehensive performance criteria for evaluating systems (Simonović et al. 1997). When used in a predictive manner, dependence on these terms implies that the systems and interactions between systems are known, with a degree of certainty, to be able to predict future conditions. If the prediction is wrong, then these criteria do not account for the effectiveness of corrective measures. Introducing reversibility, robustness, and risk are means to address this shortcoming (ibid). Reversibility is the degree to which adjustments are possible in practices, processes, or structures of systems to predicted or actual changes from drivers or pressures (Loucks 1997, Fanai and Burn 1997). Robustness is defined as the ability of the system to recover to all or a portion of the desired state from unforeseen changes (ibid). Risk is defined as the possibility of negative social, environmental, or economic impacts on a system (Kroeger and Simonović 1997, Simonović et al.

1997). In general, with greater reversibility and robustness and lower risk, a system becomes increasingly sustainable.

Finally, following the social equity component for sustainability, equity or fairness are also considered. Matheson et al. (1997) suggest that following the definition by the Brundtland Commission, equity is balanced spatially as well as within an intragenerational and intergenerational time period. In evaluating the sustainability of water resources in the Syr Darya Basin, Cai et al. (2002) implemented a modeling framework that computed equity by evaluating if water benefits are non-decreasing each year during the simulation period and that agricultural users have equitable shares of the irrigation water. Greater equity leads to greater social well-being and a sustainable system through the acceptance of stakeholders (Simonović et al. 1997).

Generally, these criteria are statistically computed from data or indicators used to evaluate a system. Examples of data and indicators include water delivery, groundwater depth above a threshold, economic output, and number of species located in an ecosystem. Typically, experts define the acceptable thresholds and boundaries for the variables from which criteria are then calculated from the analysis results. For example, if the data in Figure 3 represents the daily delivery of water to a city, then the lower bound represents when the system would be in deficit. If the criterion for reliability was that water delivery dropped below the lower threshold for no more than two days, then based on the data stream and the criteria, it is likely that periods T3 and T5 would have failed and the system reliability is 3 out of 5 time periods.

These sustainability criteria can be viewed individually, within a multi-criteria analysis, or combined into a single indicator of relative sustainability (ASCE 1998, Sandoval-Solis et al. 2011). When viewing multiple sustainability criteria, increasing one criterion may decrease the value of another, thus a project or policy should be viewed in light of a suite of sustainability criteria. Furthermore, decision-making becomes increasingly more complex with growing recognitions of the complex linkages between human and natural systems (Simonović et al. 1997), although indicators can be selected that evaluate performance of complex connections of between systems with respect to tradeoffs. It is this concept that the RBAF Analytical Interface assesses sustainability of water resources in river basins.

2.4 Discipline Analyses

Assessing water resources sustainability implies determining the sustainability of the SC systems in a river basin. The definition of sustainability for each SC discipline includes elements of time and consideration of ecosystem health and human well-being (Table 2). When assessing sustainability for each SC systems, general principles are followed and metrics employed. The following text provides a general overview principles for each SC discipline as well as the general metrics employed in assessments of their systems. Indicators for each SC discipline are further discussed in Chapter 4.

Table 2. Sustainable development classification criteria.

Discipline	Sustainable Development Definition
Hydrologic	Water resources sustainability is the ability to provide water in sufficient quantity and quality so as to meet the present needs of human and environmental ecosystems, while not impairing the needs of future generations (Mays 2007a).
Ecological	Sustainable development is about the maintenance of essential ecological processes and life support systems, the preservation of genetic diversity and the sustainable utilization of species and ecosystems (IUCN, WWF, UNEP 1987).
Economic	(*Weak*): Resource use by a generation should not exceed a level that would prevent subsequent generations from achieving a level of well-being at least as great (Tietenberg 2006). (*Strong*): The value remaining of a stock of natural capital should not decrease. This definition places special emphasis on preserving natural (as opposed to total) capital under the assumption that natural and physical capital offer limited substitutions possibilities (Tietenberg 2006).
Social	Sustainable development involves a process of deep and profound change in the political, social, economic, institutional, and technological order, include the redefinition of relations between developing and more developed countries (Rogers et al. 2008).

2.4.1 Hydrological Sustainability

Hydrologic analyses are concerned with the spatial and temporal distribution of water given the meteorological and physical conditions, as well as the anthropogenic activities, in a basin. Their purpose is to provide water managers and stakeholders with a common understanding of the major hydrologic processes active in the study area; illuminate spatial and temporal magnitude of water related issues; forecast the state of water given pressures and drivers such as climate change or water management strategy scenarios; act as a repository for existing data and identify data gaps to guide further collection; provide input data for other system analyses (e.g. ecological, economic, and social); and to target where future, more in-depth research is required. The hydrologic analyses that support the IWRM are intended for planning, thus they are generally applied over a basin, simulated over longer periods to capture meteorological variability, and have output that is easily understood by water managers and stakeholders. Typical issues addressed by hydrologic planning analyses include surface water distribution considering supply and demand, land-use change impacts, quantification and development of surface water supply, climate change impacts, drought management, water quality, and groundwater and conjunctive use studies. An overview of relevant hydrologic analyses is given in Loucks et al. (2005).

Hydrologic sustainability is determined by evaluating the availability of water supply to water demand and equitability of water distribution with respect to both humans and ecosystems use (Table 2). Rothman's definition states "Water resources sustainability is the ability to provide water managers water quantity and quality so as to meet the present needs of human and environmental ecosystems, while not impairing the needs of future generations" (Mays 2007a). In the USGS Circular 1186, groundwater sustainability is defined as the "development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences" (Alley et al. 1999, Alley and Leake 2004). Thus, the hydrologic analyses supporting the assessment of water resources needs to inform on water quantity and quality distribution as well as provide data to the other SC systems' analyses.

Output from hydrologic analyses includes time series and maps of water distribution and use within a basin. A few examples of time series output include river flow, reservoir water levels, water delivery to users, hydropower production, groundwater pumping, catchment runoff, and water quality. To assess hydrologic sustainability, time series of these results are used to compute trend, reliability, resilience, and vulnerability on the water distribution and quality (Loucks 1997, ASCE 1998, Sandoval-Solis et al. 2011), safe yield (Alley et al. 1999, Alley and Leake 2004), and equity of distribution (Cai et al. 2002).

2.4.2 Ecologic Sustainability

Ecological system sustainability typically involves maintaining or rehabilitating ecological function, species populations, and biodiversity when facing natural or anthropogenic pressures and disturbances (Table 2) (IUCN, WWF, UNEP 1987). A sustainable ecosystem is robust in its ability to absorb disturbance and is resilient in its recovery. Ecological function with respect to thresholds and carrying capacity are two criteria by which to evaluate ecological systems (Bell and Morse 2008), but these should be put in context as ecosystems are dynamic, continuous and adaptive, self-organizing, hierarchically organized, and have developed within an environment with a specific disturbance pattern in space and time (Bremer 2000, World Bank 2000). Similarly, species have evolved to take advantage of natural resources and conditions within their environment. Thus, greater biodiversity leads to greater ability to adapt to disturbances as there are more opportunities for a species to capitalize on use new or limited access to natural resources. Thresholds and carrying capacity of ecological functions are commonly used to evaluate the robustness and resilience of an ecosystem (Bremer 2000).

2.4.3 Economic Sustainability

Economics is essential in informing policy makers about resource use and development. Economic analyses evaluate the efficient use of scarce resource and equity of resource allocation to provide the maximum well-being (World Bank 2000). With respect to economic analysis involving water resources, "water management problems involves choices as to how water should be combined with other resources so as to obtain the greatest public return from scarce resources" (Young 2005). Generally, questions addressed using economics analyses include what to produce, how much to produce, who is producing/consuming resources, and how efficiently resources are being used. These questions are then used to evaluate and develop policy, infrastructure, or better management strategies.

For evaluating human well-being, value is one factor to consider. Value is multifaceted being defined by individual and societal norms. In assessing sustainable development, both the natural capital and the built capital need to be considered (Tietenberg 2006). Built capital is value derived from manmade goods and services whereas natural capital is value derived from EGS (a more in depth discussion of EGS is provided in Chapter 3). Value of goods and services are context and culturally dependent, involving both monetary (economic welfare) and non-monetary benefit (social values and ecological sustainability) to individuals and societies (MA 2006). In economics, monetary units are generally used as a proxy for value. Given the limited role played by market forces in water allocation, both monetary and non-monetary valuations need to be considered (Young 2005).

Assessing the sustainability of economic systems involves accounting of flows and stocks of environmental resources, produced assets, and human resources through time. Economic sustainability can be defined as 'strong' or 'weak', depending on if natural capital is considered to be substitutable (Tietenberg 2006). Weak economic sustainability implies that resource use by a generation should not exceed a level that would prevent subsequent generations from achieving a level of well-being at least as great (ibid). It also assumes that natural capital is generally substitutable with built capital and provided that the system as a whole does not lose value, then the system is deemed sustainable. Strong economic sustainability indicates that the value remaining of a stock of natural capital should not decrease. This definition places special emphasis on preserving natural (as opposed to total) capital under the assumption that natural and built capital offer limited substitution possibilities (ibid). The most appropriate method for evaluating this form of sustainability is debated amongst economists.

In assessing the future value of flows and stocks across multiple periods, discount rates also need to be considered. Discount rates determine how the benefits and costs of a service will be valued into the future. High discount rates favor consumption today, as future stocks will have relatively less value. Conversely, low discount rates promote conservation as stocks maintain value into the future. When evaluating renewable natural resources across multiple periods, the analysis needs to consider the regeneration in flow and stock of resources (Tietenberg 2006). Selection of discount rates is a judgment based decision but should consider intergenerational equity (Bateman 2010).

Typical outputs from hydroeconomic studies include standard economic performance determined for time series of water availability and water system operations (Harou et al. 2009). These outputs include, but are not limited to, benefit cost ratio, internal rate of return, incomes, revenues, costs, pricing, asset value, and equity of allocation amongst groups. Metrics for evaluating economic sustainability with respect to natural resources include trends in marginal shadow value, resilience, safe minimum standards (Bateman 2010), and equity of distribution (Baumgärnter and Quaas 2010). Further information on valuing water is given by Young (2005), Harou et al. (2009) and Booker et al. (2012).

2.4.4 Social Sustainability

Parameters that define human well-being include safety, health, cultural, access to make a living, and freedom of choice (MA 2003). Social sustainability involves social homogeneity, with equitable income and access to goods, services and employment (Vallance et al. 2011). Socio-ecological systems (SES) examine the complex linkages between environmental and social systems. In evaluating the sustainability of SES, investigations center on the resilience, robustness, and vulnerability of both systems (Walker et al. 2006, Bélair et al. 2010). Typical outputs from social analysis are indicators of human health, household income, institutional programs, educational level, and cultural and spiritual events.

Chapter 3. Flexible Framework for Assessing Water Resource Sustainability in River Basins

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."
John Muir 1911

Freshwater is a resource crucial to man's existence, affecting all human life. Human need for freshwater resources includes the basic consumption such as drinking water and sanitation for good health and combating disease; assisting in the production of food and goods humans consume; providing for a foundation for cultural services such as community connectivity, spirituality, and recreation; and supporting the ecosystems upon which humans rely (Daily 1997a,b, Postel and Richter 2003, MA 2003, MA 2005a). Despite the importance of water, the freshwater resources are on the decline. The MA (2005a) reports about 5-25% of global freshwater use exceeds long-term accessible supply and that freshwater availability is declining due to severe, anthropogenic pollution. An estimated 50% of inland waterways have been degraded in the 20th century, and the decline of inland waterways has led to a decrease in the ecosystem goods and services (EGS) for supporting human well-being.

The decline in the availability and access to freshwater resources will "lead to problems with food production, human health, and economic development" (MA 2005a). In 2011, the World Economic Forum (WEF) identified the interconnected resource issues of water, energy, and food as a serious global risk. The WEF stated:

> *"The "water-food-energy" nexus: A rapidly rising global population and growing prosperity are putting unsustainable pressures on resources. Demand for water, food and energy is expected to rise by 30-50% in the next two decades, while economic disparities incentivize short-term responses in production and consumption that undermine long-term sustainability. Shortages could cause social and political instability, geopolitical conflict and irreparable environmental damage. Any strategy that focuses on one part of the water-food-energy nexus without considering its interconnections risks serious unintended consequences."* WEF, Global Risks 2011, 6th Edition.

In its 2011 Water Security report, the WEF (2011) also described that "*water security is the gossamer that links together the web of food, energy, climate, economic growth, and human security challenges that the world economy faces over the next two decades*." Underscoring this view, frameworks addressing water-energy-food security have placed water as a primary pillar in the assessment methodology (Hoff 2011, WEF 2011, ICIMOD 2012, Bizikova et al. 2013).

Recognizing the decline in freshwater resources, the World Summit on Sustainable Development in Johannesburg 2002, brought forth the initiative to develop Integrated Water Resource Management (IWRM); to promote the holistic and sustainable development of water resources (Hooper 2005). The IWRM process was created in order to "*promote the coordinated development and management of water and land resources in an equitable manner in order to maximize socio-economic benefit to mankind and minimize damage to the environment*" (GWP 2008). The IWRM concept is the cross-sectoral integration of water for people, food, nature, and other uses by using institutions and management tools and creating enabling environments (GWP 2008). The objective of IWRM is to promote wise governance of water management by improving the three e's: <u>e</u>conomic development, social <u>e</u>quality, and <u>e</u>nvironmental sustainability. The core themes of IWRM are (GWP 2004, GWP 2008):

- moving toward an enabling environment of appropriate policies, strategies, and legislation for sustainable water management,
- establishing an institutional framework for implementing policies, strategies, and legislation, and
- instituting the management instruments to support the IWRM.

Thus, the IWRM process seeks to provide a balance between the benefits/services received by different sectors (including the environment) in the short- and long-term sustainability (Ramsar 2007), thus one of the goals of IWRM is the sustainable development of water resources.

Having a solid foundation for the risks and impacts of decisions as they impact the sustainability criterion is key to developing adaptive and sustainable institutions, policies, and regulations for sustainable water use (Hooper 2005, GWP 2008, UNESCO 2009a, Stiglitz et al. 2009). Not addressing these core themes in water management can lead to unsustainable water availability and supporting ecosystems. A few examples include the demise of the Aral Sea due to dewatering for upstream irrigation (UNEP 2009), the potential ecological ineffectiveness of piece-meal river rehabilitation projects in California (Kondolf 2000), and loss of the water quality and biodiversity and increase in invasive species in Chilika Lake, India due to upstream diversions (UNEP 2009).

Due to the complexity of the hydrologic cycle and socio-economic and ecological systems, establishing analytical frameworks to assist water managers in understanding risks and developing sustainable alternatives could greatly add to the implementation of IWRM.

> *"Modelling at the sub-catchment or river basin level can integrate the hydrological, technical, ecological, environmental, economic, social, institutional and legal aspects of water problems into a coherent framework. Presently hydrological models simulating water balance elements (such as river run-off, groundwater and evapotranspiration) are quite well developed. So are water quality models for rivers, groundwater and lakes. However, models for most other water aspects (ecological, environmental, economic, social, institutional and legal) need significant improvement.* (C1.5)" (GWP Toolbox: C1.03 Modeling in IWRM).

UNESCO (2009b) identifies the benefits of an analytical framework as: 1) guidance for which multi-disciplinary tools can assist integration, and 2) guidance on which tools are appropriate for different settings.

Supporting the implementation of IWRM is a broad base of literature covering general concepts, philosophies, methodologies, guidance, and applications. The IWRM methodology and guidance literature has largely focused on the overall process, creating participatory organizations, building institutional capacity, financing programs, developing legal frameworks, components of a plan, and management instruments (Hooper 2005, GWP 2004, GWP 2008, UNESCO 2009a,b). Approaches for scientific methods and analytical frameworks to support the IWRM process are limited.

IWRM analysis needs to be supported by frameworks and decision support software (DSS) which conceptualize, analyze, and evaluate water resource management in basins. Important elements of effective frameworks and DSS include the ability to frame water resource issues and related factors in the participatory setting; identify analyses and indicators to represent key water resource issues; and be capable of evaluating a range of decisions, from simple to complex (Millington et al. 2011). The framework should support the organization of data in evaluating alternatives; provide a flexible structure to accommodate evolution of decisions, issues, data, scenarios, and models (ibid); and produce reliable and transparent output that is linked to relevant indicators used in the evaluating policies and decisions directly or indirectly affecting water resources in a basin. Types of tools available to assist in the analysis include sustainable development assessment frameworks (UN GEO4 DPSIR Framework (UNEP 2007), Millennium Ecosystems Approach (MA 2003)), conceptual models (DRERIP, (Nobriga 2008)), systems models (STELLA, Powersim, Versim), coupling complex models (SWAT, WEAP, MIKE BASIN), ecosystem service valuation programs (InVEST (Natural Capital Project 2011), MIMES (UVM 2011), ENVISION (OSU 2012)), and indicators frameworks (Arctic Water Resource Vulnerability Index (Alessa et al. 2009), Canadian Water Sustainability Index (Government of Canada 2007), Water Poverty Index (Sullivan et al. 2003), Watershed Sustainability Index (Chaves and Alipaz 2007), West Java Water Sustainability Index (Juwana et al. 2009)). Sustainable development assessment frameworks and conceptual models provide a foundation for conceptualizing the links between pressures and drivers acting on the complex systems found in river basins. A conceptual foundation guides the analyses to be performed and the metrics and indicators used to evaluate management decisions. In addition, sustainable development assessment frameworks also link potential impacts to policy drivers (Pintér et al. 2008). While important in framing the factors related to the water resource issues, these frameworks lack a means of analyzing and producing output for evaluating water resource management decisions.

Analytical tools such as systems, hydrologic, and discipline specific models provide a means to quantitatively test and evaluate the concepts and management strategies developed in the sustainable development assessment frameworks and conceptual models. Given the appropriate data and algorithm employed, management decisions can be quantitatively tested from simple to complex. Systems models provide a powerful method of examining connections and feedback loops in complicated systems comprising different types of elements, effectively demonstrating trade-offs in management decision. For more complicated analyses, systems models require relationships to be known which need to be addressed by physically based process models (e.g. spatial extent of drawdown from groundwater pumping in an aquifer) or economic and ecological models (e.g. production rate given varying prices as determined in an economic partial equilibrium model). For determining these relationships, more detailed hydrologic, economic, and ecological models are used. However, In general, hydrologic, economic, and ecological models are more complex, taking more computational time to develop and simulate conditions, and are more difficult to couple together in determining the interdisciplinary results. In developing any analytical model, development without a solid conceptual foundation of the important processes, knowledge of the issues to be addressed, potential management scenarios to analyze, and metrics to evaluate projects will likely lead to subpar or erroneous predictions, therefore analytical models alone are not sufficient to support the IWRM analysis process.

Ecosystems provide services that are often undervalued or not considered in policy decision, thus leading to decisions that are detrimental to the natural systems (Daily 1997a,b, Costanza et al. 1997, MA 2003). Forslund et al. (2009) reports that the "*marginalization of ecosystems in water resource management, and the associated degradation or loss of ecosystems services, have resulting in economic costs in terms of declining profits, remedial measures, damage repair, cost of healthcare and sick days . . . , and lost opportunities*". As a tenet of IWRM is ecological sustainability, the ecological impacts need to be evaluated. Ecosystem service valuation programs provide a structured means of illustrating and quantifying the impacts and trade-offs that decisions have on the ecosystems and the goods and services they provide. The InVEST Tool maps and values ecological goods and services that are essential to sustaining human life, including freshwater ecosystems (Natural Capital 2012). MIMES and ENVISION are suites of models for evaluating changes in natural, human, social, and built capital resulting from the environmental alteration associated with land use change (UVM 2011, OSU 2012). As these tools focus on valuation of ecosystem services, they do not provide the full range of factors to consider in IWRM.

Frameworks for indicators provide system information to water managers and stakeholder, translate data into trends and communicate the results of implementing objectives (Cap-Net 2008). The value of indicator frames for policy making is providing feedback on system behavior and policy performance, improving adaption, moving towards common goals, improving implementation, and increasing accountability (Woerdon et al. 2008). Furthermore, indicator framework help understanding how different issues are interrelated (Segnestam 2002). With regards to the IWRM analysis, the limitation with indicator frameworks are that they are products of the processes and therefore cannot be used independently to conceptually understand the interlinking of systems or predict a systems response to a driver or pressure.

Currently, general conceptual frameworks and highly deterministic methods are available to aid in IWRM, but no framework exists that provides comprehensive guidance on the important water resources related factors to consider in a basin, emphasizes the importance of the environment through ecosystem services and their impact on human well-being, guides selection of appropriate analyses and relevant indicators to use, and organizes and post-processes the analytical output from discipline models such that managers, stakeholders and the technical can evaluate water resource issues. The River Basin Assessment Framework (RBAF) has been developed to provide a structured manner for understanding and framing the analysis of the water related issues as well as testing the sustainability of proposed water management decisions in river basins. The RBAF incorporates the principles of sustainable development, the UN GEO4 DPSIR Framework (UNEP 2007, Jager et al. 2008, Pintér et al. 2008), and the Millennium Ecosystems Approach (MA 2003, MA 2005a) to develop a holistic understanding of the pressures causing changes in hydrologic cycles, as well as the impacts to the sustainability criterion. The framework contains two components: a conceptual component to guide water managers and stakeholders in realizing and selecting the ecological, social, and economic factors and analysis methodologies to consider in evaluating a management alternative, and a software tool to collect and present the results of analytical solutions involving multiple discipline analyses. Coupling the conceptual with the analytical aspects of IWRM analysis assists interested parties in identifying the water resource issues and potential impacts from pressures, identifying the important analyses to perform and identify relevant indicators of measure, and then organizing and displaying the output from hydrological and SC system analyses to evaluate management decisions. The RBAF is intended to be applicable in a wide variety of river basins, supporting differing analytical methods and demonstrating the impact of water management decisions or pressures to stakeholders.

This document outlines the theory supporting the framework, the framework structure and use, and the conceptual component of the RBAF. Background information on definition of sustainability, analysis, and relevant indicators for each discipline are presented in Chapter 2. The methodology, application, and case study of the RBAF's Conceptual Template (RBAF-CT) and Analytical Interface (RBAF-AI) are presented in Chapter 5 and Chapter 6, respectively.

3.1 Background

3.1.1 IRBM and the Sustainability Criterion

Integrated River Basin Management (IRBM), a subset of IWRM, embodies the same principles but focuses on water resource management in freshwater river basins. The IRBM implementation literature has been largely focused on practicalities of IRBM, defining basin management systems, roles of basin organization, involving stakeholders, creating basin action plans, establishing information and communication systems, and financing the IRBM organizations (Burton 2003, Hooper 2005, Cap-Net 2005, Cap-Net 2008, GWP 2009). Hooper (2005) provides a definition of IRBM guidance on the methodology of government, frameworks for establishing, and overview of policy measures. A good online resource for the IWRM definitions, guidelines, and case studies is the GWP's Toolbox (http://www.gwptoolbox.org/). UNESCO (2009b) has laid out a detailed, step-by-step process for developing an integrated river basin plan.

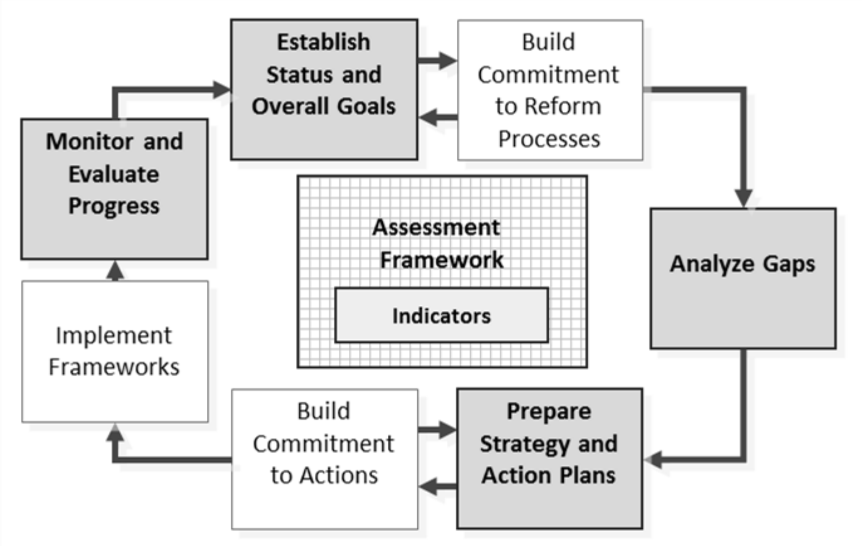


Figure 4. IWRM framework cycle with grey boxes representing steps where technology can support the IWRM process. The assessment framework and indicators are located in the center depicting support of the full cycle. Modified from GWP 2004.

The IRBM process follows the adaptive management cycle of assessing the problem, building awareness, quantifying the impact, developing a solution, implementing the solution, and monitoring the outcomes (Figure 4) (GWP 2004). As stated, the literature outlines the development of the institutions, funding, and participation in such a cycle, but does not provide much guidance on how analytical tools can augment the process. The use of technical solutions can be very helpful in the IRBM process by:

- Developing awareness of water related issues. Informing and building collective awareness including indicating how systems operate and connect, data availability to support analysis, and where disagreements lie between stakeholders (Hooper 2005, UNESCO 2009b, GWP 2009),
- Organizing existing data to recognize what is known and highlight areas where greater information is needed to address uncertainty or lack of understanding,
- Providing quantitative assessments of the potential outcomes for water management decisions (GWP, 2008).

- Creating output from scenario modeling that educates both members of the stakeholder group as well as the wider public on the impacts of water management decisions (UNESCO 2009b).

The RBAF is intended to support the IRBM process in assessing the problem, building awareness, and quantifying the impacts of water issues in a basin.

As sustainable development is a key element of IRBM, defining the term and outlining its core elements is important. Sustainable development has been defined by several organizations as the implementation of socio-economically viable alternatives that will maintain, if not improve, the ecosystem (Hardi 1997, MA 2005a, UNEP 2007). The IISD definition of sustainable development, and the one adopted herein, is "*development that improves the economic and social well-being of people while maintaining or enhancing environmental integrity for current and future generations*" (Swanson and Pintér 2007). The core elements of sustainable development include Intra- and inter-generational linkages; inter-dependence of ecological, economic, and social systems; multi-stakeholder perspectives; multi-scale effects; inherent socio-economic and ecologic capacities; and adaptive learning and management. Thus, frameworks established for assessing sustainable development should address these core principles in its methodology and analysis.

3.1.2 Frameworks for Assessing Sustainability

Because of the multiple spatiotemporal scales as well as the multi-discipline components of natural and anthropogenic systems, assessing the sustainable development of a region or nation is complicated. To assist in assessment of sustainable development, frameworks have been developed. These frameworks can be classified into six general categories: issue or theme based, index based, sectoral based, capital based, DPSIR based, and ecosystem services based (UNEP 2007, Pintér et al. 2008). These frameworks use indicators to define current conditions and are used to evaluate change, determine the natural variability and anthropogenic activities that will change the system, predict the effects resulting from system changes, and convey pertinent information to the interested stakeholders. However, these approaches differ in focus (concentrating on different elements of the systems), indicators, spatial scale, evaluation parameters, and relevance to policy makers and stakeholders. Of the six categories, the RBAF incorporates two: the UN Global Environmental Outlook 4 (GEO4) DPSIR Framework (UNEP 2007, Jager et al. 2008, Pintér et al. 2008) and the Millennium Ecosystem Assessment (MA) Framework (MA 2003, MA 2005a,b,c). Both frameworks were developed specifically to assess the Sustainability Criterion, evaluate policy steps, and provide guidelines for engaging stakeholders.

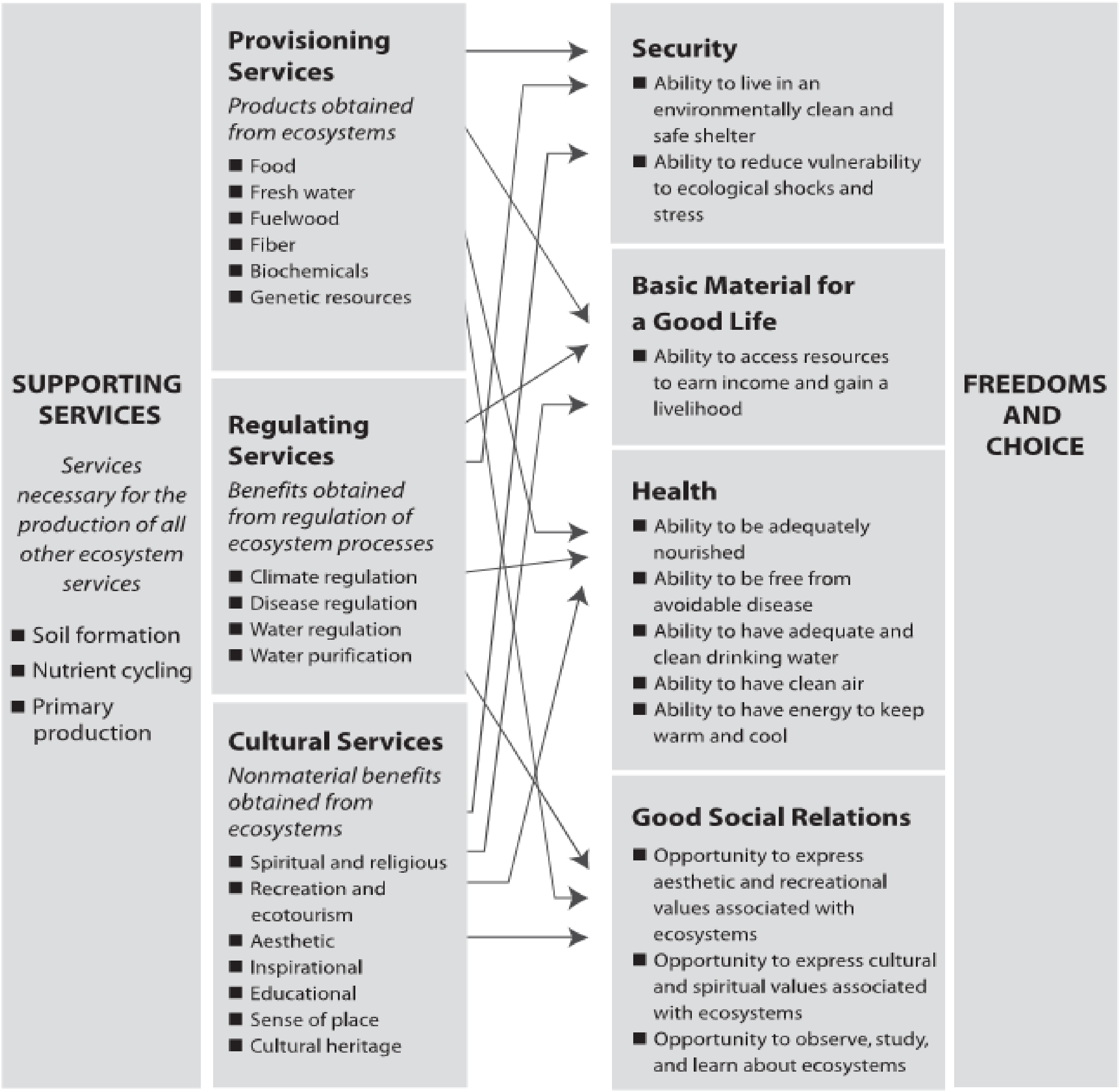


Figure 5. Connection of ecosystem services and the constituents of well-being (MA 2003).

The UN GEO4 DPSIR Framework clearly lays out the connection between the drivers, pressures, state, impacts, and responses of the system (Pintér et al. 2008). The framework is straightforward and intuitive for stakeholders to understand the integrated and complex ecological and socio-economic issues within a system. However, the limits of the framework include the difficulty of assessing the extent of impacts to human well-being and defining connections between multiple environmental issues (UNEP 2011).

The MA Framework (MA 2003, MA 2005a) provides a systematic link between the ecosystems, the goods and services they provide, and human well-being (Figure 5). While the framework also uses the DPSIR framework, it is more narrowly focused on ecosystem services analysis and has been criticized as being more difficult to understand the connections between drivers-pressures and the impact and response (UNEP 2007). The goals for the MA Framework include: i) conservation, ii) sustainable use of the natural resources, and iii) equitable share of the benefits of the EGS (CBD 2000). The RBAF uses the strength of both frameworks; the clarity of the UN GEO4 DPSIR Framework in linking causal effects and the MA Framework's strength in linking impacts to EGS and human well-being. Below is a more in-depth description of both frameworks.

3.1.3 DPSIR Overview

The European Environmental Agency (1997) applied the DPSIR Framework for a causal framework to describe the interactions between society and the environment (EEA 1997), which was later adopted as the base for integrated environmental assessments in the UN GEO4 DPSIR Framework (UNEP 2007, Pintér et al. 2008). Table 3 provides definitions for each term in the DSPIR per the UN GEO4 DPSIR Framework (ibid).

3.1.4 Ecological Goods and Services (EGS)

Humans derive goods and services from ecosystems which contribute to their well-being. Historically, when making decisions, direct ecological services such as food production and freshwater supply have been considered as they are easily valued, but the indirect ecological services (e.g. wetlands mitigating flood risks or enhancing water quality) are seldom considered and less often valued (Daily 1997, MA 2005a). "*The concept of an ecosystem provides a valuable framework for analyzing and acting on the linkages between people and the environment*" (MA 2003). Since the 1980's, the EGS concept has been developed to elucidate the value of the ecosystem when making decisions (Brauman et al. 2007). The major concept is that human and environmental well-being are inseparable, so to maintain a good existence, the natural systems which humans rely on must be maintained (Daily 1997, MA 2003, MA 2005a). By identifying the importance of EGS used by humans, decisions can be evaluated with a more holistic understanding of their impacts to well-being.

While the concept of the ecosystem structure and process supporting human well-being is easy to comprehend, application has proven inconsistent due to the variable distinction between ecological function and EGS (de Groot 2002, Jax 2005, Cook and Spray 2012). De Groot et al. (2002) defined ecosystem function as “the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly”. EGS are benefits arising from ecosystem functions that contribute towards well-being. An ecosystem can provide multiple EGS such as a wetland that provides the local community fish for food, fodder for cattle, purification of water, attenuation of flood waters, and recreational use by bird watchers or anglers. The value of the benefits derived from of the EGS, both monetary and non-monetary, depend on the receiver’s geographical location and societal values (Haines-Young and Potschin 2010). In the MA Framework, EGS are grouped into provisioning, regulating, cultural, and supporting services (MA 2003). The MA (2003) has identified 30 EGS contributing to human well-being (Table 4), though de Groot et al. (2002) suggest that more may be identified in the future.

Table 3. DPSIR classification criteria related to water use (UNEP 2007, Pintér et al. 2008).

Categories	Description	Example
Drivers	Drivers refer to fundamental processes in society, which initiates activities having a direct impact on the environment (the state of water). Drivers are sometimes referred to as indirect or underlying drivers or driving forces.	The need for additional water supply to support a city’s growing population.
Pressures	Pressures include human or natural interventions causing environmental change, or could be an intentional or un-intentional by-product of other human activities.	The proposed development of a dam to increase reliable water supply.
State	The environmental condition of a system including trends, often referred to as environmental change, which are naturally and/or human induced. In regards to the RBAF, the state of water resources describes the supply, movement, storage, and use of the water in the river basin.	The change in water supply, downstream river flows, and reliability of delivery to downstream users.
Impact	The change of state environment that positively or negatively influence the availability of EGS.	Increased water supply during low flow periods decreases water use deficits. However, changes in the hydrograph downstream of the proposed dam adversely affect recreational fisheries.
Response	Responses (interventions in the MA Framework) consist of elements among the drivers, pressures and impacts which may be used for managing society in order to alter human–environment interactions. Drivers, pressures, and impacts that can be altered by a decision-maker are referred to as endogenous factors: those that can’t are exogenous factors	Securing the funding to develop the dam.

The connection between ecosystem structure and process, ecosystem function, EGS, and human well-being (a.k.a. benefits) is illustrated by the ecosystem services cascade model (Figure 6) (Haines-Young and Potschin 2010). By the cascade model, ecosystem function emanates from ecosystem structure and process, with EGS and benefits following in a similar fashion. Liquete et al. (2011) extended the cascade model by adding the "value" category following "benefits" category. The cascade model incorporates a feedback loop with benefits affecting pressures acting on the ecosystem structure and process. To change the cycle, policy action is identified between pressures and ecosystem structure and process. Haines-Young and Potschin (2010) noted that in reality, the linear connection is more complicated, but the diagram is useful for illustrating the theoretical connection between each category.

Table 4. Ecosystem services (MA 2005a).

	Ecosystem Services	**Ecosystem Services Description**
Provisioning	Food and fiber	This includes the vast range of food products derived from plants, animals, and microbes.
	Fiber	Materials such as wood, jute, hemp, silk, and many other products derived from ecosystems.
	Fuel	Wood, dung and other biological materials serve as sources of energy
	Genetic resources	This includes the genes and genetic information used for animal and plant breeding, and biotechnology.
	Biochemicals, natural chemicals, and pharmaceuticals	Many medicines, biocides, food additives such as alginates, and chemicals and biological materials are derived from ecosystems.
	Ornamental resources	Animal products, such as skins and shells, and flowers are used as ornaments, although the value of these resources is often culturally determined.
	Fresh water	Fresh water is another example of linkages between categories—in this case, between provisioning and regulating services.
Regulating	Air quality maintenance	Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.
	Climate regulation	Ecosystems influence climate both locally and globally. For example, at a local scale, changes in land cover emitting greenhouse gases play an important role in climate by either sequestering carbon. At the global scale, ecosystems can affect both temperature and precipitation.

Ecosystem Services		Ecosystem Services Description
	Water regulation	The timing and magnitude of runoff, flooding and aquifer recharge can be strongly influenced by changes in land cover, in particular alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
	Erosion Control	Vegetative cover plays an important role in soil retention and the prevention of landslides.
	Water purification and waste treatment	Ecosystems can be a source of impurities in fresh water, but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems.
	Regulation of human disease	Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.
	Biological control	Ecosystem changes affect the prevalence of crop and livestock pests and diseases.
	Pollination	Ecosystem changes affect the distribution, abundance and effectiveness of pollinators.
	Storm Protection	The presence of coastal ecosystems, such as mangroves and coral reefs, can dramatically reduce the damage caused by hurricanes or large waves.
Cultural	Cultural diversity	The diversity of ecosystems is one factor influencing the diversity of cultures.
	Spiritual and religious values	Many religions attach spiritual and religious values to ecosystems or their components.
	Knowledge systems	Ecosystems influence the types of knowledge systems developed by different cultures.
	Educational values	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
	Inspiration	Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture and advertising.
	Aesthetic value	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives” and the selection of housing locations.
	Social relations	Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.
	Sense of place	Many people value the “sense of place” that is associated with recognized features of their environment, including aspects of the ecosystem.

Ecosystem Services		**Ecosystem Services Description**
	Cultural heritage values	Many societies place high value on the maintenance of either historically important landscapes (cultural landscapes) or culturally significant species.
	Recreation and ecotourism	People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.
Supporting	Supporting services are those that are necessary for the production of all other ecosystem services	These services differ from provisioning, regulating and cultural services in that their impacts on people are either indirect, or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. Some examples of supporting services are primary production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling and provisioning of habitat.

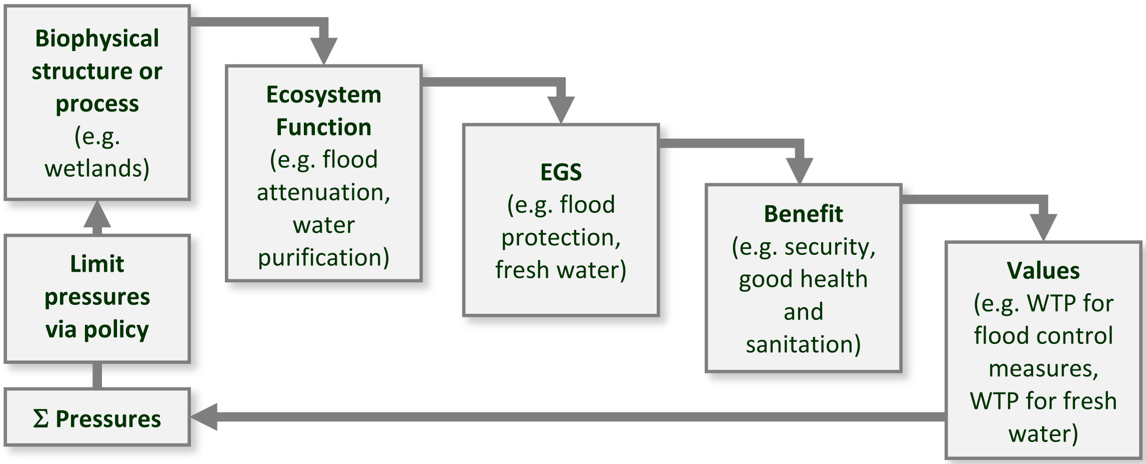


Figure 6. The ecosystem services cascade model, showing the relationship between ecosystem structure and process, ecosystem function, EGS, and human well-being (Benefit) (Haines-Young and Potschin 2010). Liquete et al. (2011) extended the conceptual models modified to include value. WTP is "willingness to pay".

3.1.5 Human Well-Being

The OECD (2013) defines human well-being as "good mental states, including of the various evaluations, positive and negative, that people make of their lives and the affective reactions of people to their experiences". Poverty, existing on the opposite of the continuum from well-being, is the scarcity of resources or lack of a good mental state (MA 2006). Human well-being is experienced and perceived on a personal and social scale as a function of geography, ecology, age, gender, and culture (Prescott-Allen 2001, MA 2003). According to the MA (2005a), "The components of well-being are experienced and perceived differently across cultures and socio-economic gradients". Furthermore, perceptions and values change over time and as human well-being is context specific.

Stiglitz et al. (2009) defined the dimensions of human well-being as i) material living standards, ii) health, iii) education, iv) personal activities including work, v) political voice and governance, vi) social connections and relationships, vii) environment (present and future), and viii) physical and economic insecurity. The MA (2003) identified that EGS have a direct bearing on various aspects of human well-being, which they classified as *Security* (personal safety, resource access, security from disasters), *Basic Material for a Good Life* (adequate livelihoods, sufficient nutritious foods, shelter, and access to goods), *Health* (strength, feeling well, access to clean air and water, energy for comfortable temperature control), *Good Social Relations* (social cohesion, mutual respect, realization of aesthetic and recreational values, expression of cultural values, and ability to help others and avoid tension), and *Freedom of Choice and Action* (the opportunity to be able to achieve what an individual values doing and being) (Figure 5, Table 5). In evaluating human well-being, both objective and subjective dimensions of human well-being need to be addressed (Stiglitz 2009, OECD 2013).

Table 5. Constituents of human well-being (MA 2003).

Components	**Sub-Element**
Security	a safe environment resilience to ecological shocks or stresses such as droughts, floods, and pests secure rights and access to ecosystem services
Basic material for a good life	access to resources for a viable livelihood (including food and building materials) or the income to purchase them
Health	adequate food and nutrition avoidance of disease clean and safe drinking water clean air energy for comfortable temperature control
Good social relations	realization of aesthetic and recreational values ability to express cultural and spiritual values opportunity to observe and learn from nature development of social capital avoidance of tension and conflict over a declining resource base
Freedom and choice	the ability to influence decisions regarding ecosystem services and well-being

3.1.6 Linking EGS to Human Well-Being

While not exclusively contributing to human well-being, EGS are required for human existence and the benefits derived from EGS improve human well-being. The MA (2003) indicates that provisioning, regulating, and cultural services directly influence safety, basic materials, health, and good social relations, though the influence varies in intensity (Figure 5). The relationship between EGS and human well-being is context specific and involves a complex interplay over multiple spatial and temporal scales (MA 2006). As such, greater EGS does not necessarily equate to greater, long-term human well-being for the following (MA 2005a):

1. Human well-being is multifaceted with EGS only part of the equation. Gains or losses of human well-being may or may not be attributed to a change in EGS,
2. The loss of one EGS contributing to human well-being could be replaced through substitution with another EGS or constituent of human well-being,
3. Similarly, widening geographic reach of communities enables them to obtain constituents of human well-being from non-local sources, and
4. Immediate improvement in human well-being may be at the expense of deferred environmental costs.

In addition the EGS-human well-being link goes both ways. As humans strive to increase well-being, their interaction with and use of ecosystems transforms the ecosystem's processes and functions, thus altering the EGS delivered which increases or decreases the benefits to society (MA 2006).

3.1.7 Valuing EGS

The value of EGS to human well-being is context and culturally dependent, involving both monetary (economic welfare) and non-monetary benefit (social values and ecological sustainability) to individuals and societies (MA 2006). Historically, when using economics to evaluate the feasibility of projects or policies, EGS has been undervalued in the decision-making process, thus the EGS approach has evolved to increase the consideration of ecosystem health (Costanza et al. 1997, MA 2003). In assessing EGS valuation with respect to a management decision, de Groot et al. (2010) state the following aspects need to be considered:

- Clear understanding of the ecological function, service, and benefits is important when evaluating the benefits/costs of EGS,
- Assessments of EGS should be made on a spatial and temporal scale meaningful to policy formation as well as the ecological functions affected by the decision,

- Valuation should be viewed as trade-offs of the ecological, socio-cultural, and economic benefits in scenarios,
- Valuation should be viewed with regards to bundles of EGS provided by the ecosystems effected as EGSs interact in complex ways, both negatively and positively,
- Assessment of trade-offs need to consider both the benefits and the costs of EGSs affected by the decision including opportunity costs, and
- EGS assessment needs to look at the risk and uncertainties of knowledge in the valuation process.

De Groot et al. (2010) further notes that the EGS valuation should be divided into potential, actual use, and the actual benefit.

When evaluating a decision monetarily, the total economic value (TEV) of EGS (or natural capital) need be included. EGS provide both use and non-use values (Figure 7). In general, provisioning (drinking water, fish, crops, and timber) and some cultural EGS (recreation use) have direct methods of valuing the services through *revealed willingness to pay methods*: direct estimation of producer and consumer surplus, productivity method, hedonic pricing method, travel cost method; *survey methods*: contingent valuation, contingent choice; and *benefit transfer*: extrapolating from valuations undertaken in other regions with similar socio-economic and ecologic characteristics (Bateman et al. 2010). Regulating, other cultural and supporting EGS have non-use value (e.g. option, bequest, and existence value) and thus must be evaluated using other methods of assessing monetary value such as damage cost avoided and replacement cost. Cost-benefit analysis is a typical tool used to assess the feasibility of projects and policies. Popular approaches for assessing EGS include payment for ecological services (PES), marketing ecological goods and services (MEGS) (UNEP 2005), and ecosystem services valuation (ESV) (Liu et al. 2010).

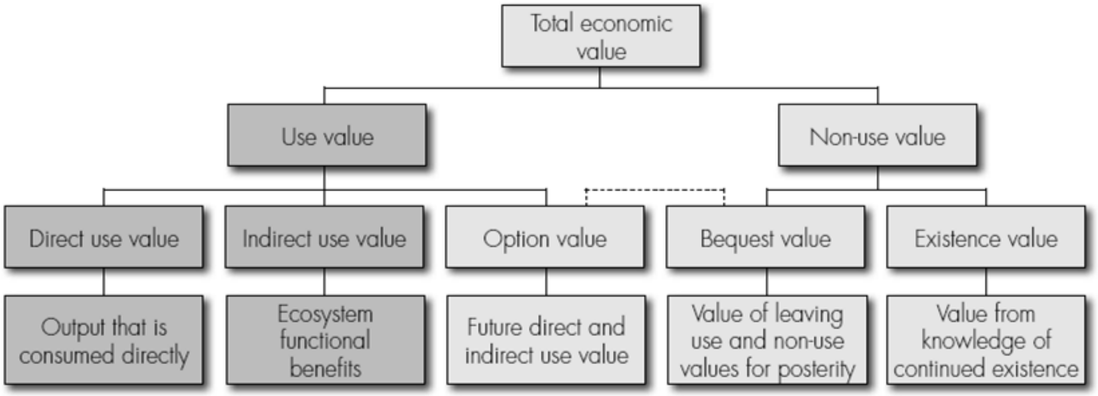


Figure 7. Total economic value (TEV) for use and non-use values of EGS (Forslund et al. 2009).

3.1.8 Freshwater Ecological Goods and Services

Types of freshwater ecosystems include stream and river systems, riparian zones, floodplains, ponds, lakes, wetlands, snowfields/glaciers, and springs/groundwater. Within a catchment, these freshwater ecosystems have unique processes and functions that provide provisioning, regulating, cultural, and supporting EGS (Table 6) (Postel and Carpenter 1997, Postel and Richter 2003, MA 2005a). Freshwater ecosystem provisioning services include both direct consumption uses such as freshwater (drinking and sanitation), food (fish, shellfish, waterfowl), fiber (thatch, pelts), fuel (riparian forests), and plants and animals used in medicines as well as indirect use such as irrigation, manufacturing of products, power generation, and navigation and transportation. Providing freshwater for maintaining aquatic ecosystems is of vital importance in supporting the biological function, sediment, and nutrient supply and habitat (ibid).

Regulating services provided by freshwater ecosystems include the regulation of water (buffering flooding and drought mitigation), filtration and dispersal of pollutants, erosion control, and maintenance of coastal zone salinity (Postel and Carpenter 1997, Postel and Richter 2003, MA 2005a, Brauman 2007, UNEP 2009, IWMI 2011). Lakes and floodplains attenuate flood waters, reducing the magnitude and extent of downstream flooding (ibid). Water infiltrated into the ground during high water events seeps back into the river network during dry periods, creating an instream supply of water throughout the rest of the year. River networks and groundwater systems disperse and degrade point and non-point source pollutants delivered from the landscape (MA 2005a). Lake and wetlands collect sediment migrating down through the river network, absorbing pulses of sediment from increased surface erosions associated with landuse change. Wetlands can provide all regulating services; buffering floods, supply of water during dry periods, filtering pollution, and collecting sediment (Ramsar 2007).

Freshwater ecosystems provide cultural services such as spiritual, educational, recreational, aesthetic, and existence value. Many cultures derive spirituality and education from river networks. For example in India, the Ganges River is worshipped as the Hindu goddess Ganga, and when bathed in, it is believed that it helps the soul attain salvation, cures deadly disease, provides for the remission of sins, and liberates one from the cycle of life and death (MA 2005a). In developed countries, recreation is a significant use of freshwater services through activities such as swimming, boating, fishing, hunting, and wildlife viewing (Postel and Carpenter 1997). As is evident from restoration of river corridors in cities as well as tourism to lakes and rivers, communities value rivers aesthetics and connection with nature.

Table 6. Freshwater ecosystems and the EGS they provide. The EGS categories have been modified from the MA 2003. Ten general references and 36 case studies involving the use of EGS in water management were reviewed and the relevant EGS marked. Relationship strength: ++ = strong relationship, + = moderate relationship, and - = weak relationship.

	EGS	***Riverine System***	***Riparian Zone***	***Floodplain***	***Pond/Tank***	***Lake/Reservoir***	***Wetland***	***Glacier/Snowfield***	***Groundwater***	**References**	**Case Studies**	**Description**
Provisioning	Freshwater: Human/ Ecosystem Consumption	++	++	++	++	++	++	++	++	10	23	Freshwater for direct human consumption: domestic/municipal supply, drinking water, sanitation
	Freshwater: Production	++	++	++	++	++	++	++	++	5	20	Freshwater use by irrigation, commercial, industrial, hydropower, aquaculture, livestock
	Freshwater: Navigation/ Transport	++				++	++	++		4	2	Travel or movement of goods by water
	Food	++	++	++	++	++	++			10	13	Food products derived from plants, animals, and microbes including fish, shellfish, mammals, reptiles, aquatic plants.
	Fiber	++	++	++	++	++	++			10	7	Materials such as wood, jute, hemp, silk, and many other products derived from ecosystems.
	Fuel		++	++			++			8	6	Wood, dung and other biological materials serve as sources of energy
	Genetic-Biochemical Resources	++	++	++	++	++	++			6	2	Medicines, biocides, food additives derived from ecosystems. Genetic information used for animal and plant breeding, and biotechnology.

	EGS	*Riverine System*	*Riparian Zone*	*Floodplain*	*Pond/Tank*	*Lake/Reservoir*	*Wetland*	*Glacier/Snowfield*	*Groundwater*	**References**	**Case Studies**	**Description**
Regulating	Climate Regulation	++				++	++	++		3	4	Influence the local climate
	Water Regulation	++	+	++	+	++	++	++	++	9	11	Timing and magnitude of runoff, flooding and aquifer recharge, water storage potential of the system.
	Erosion Control	++	++	++	++	++	++			4	3	Vegetative cover plays an important role in soil retention and the prevention of landslides
	Water Purification	++		++	++	++	++		++	10	14	Ecosystems can be a source of impurities in fresh water, but also can help to filter out and decompose organic wastes to inland waters ecosystems
	Storm - Flood Protection		++	++		++	++			7	4	Timing and magnitude of runoff associated with flooding
Cultural	Spiritual and religious values	+	+	+	+	+	+	+		9	2	Many religions attach spiritual and religious values to ecosystems or their components
	Knowledge Systems and Educational Values	+	+	+	+	+	+	+		5	3	Ecosystems influence the types of knowledge system and provide a basis for education in many societies
	Inspiration	+	+	+	+	+	+	+		3	3	Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising.
	Aesthetic value	+	+	+	+	+	+	+		4	3	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives” and the selection of housing locations.

	EGS	*Riverine System*	*Riparian Zone*	*Floodplain*	*Pond/Tank*	*Lake/Reservoir*	*Wetland*	*Glacier/Snowfield*	*Groundwater*	References	Case Studies	Description
	Social relations	+	+	+	+	+	+	+	+	2	2	Ecosystems influence the types of social relations that are established in particular cultures. e.g. fishing or herding societies
	Sense of place	+	+	+	+	+	+	+		2	2	Recognized features of people's environment, including aspects of the ecosystem.
	Cultural heritage values	+	+	+	+	+	+	+	+	3	4	Many societies place high value on the maintenance of either historically important landscapes (cultural landscapes) or culturally significant species.
	Recreation and ecotourism	++	++	++	++	++	++	++		10	12	Boating, fishing, swimming, wildlife viewing
	Bequest, Intrinsic, and Existence	+	+	+		+	+	+		0	3	Knowledge that an ecosystem exists for its inherent value.
Supporting	Soil, Nutrient Cycle	++	++	++	++	++	++	++	++	7	7	Healthy river system
	Biodiversity-Habitat	++	++	++	++	++	++	++	+	9	7	Aquatic habitat -biodiversity

Table 7. Links between human well-being to EGS in relation to freshwater. Relationship strength: ++ = strong relationship, + = moderate relationship, and = weak relationship.

		Security			Basic Needs	Health					Good social relations					Freedom
	Ecosystem Services	**A Safe Environment**	**Resilience to Ecological Shock and Stresses**	**Access to EGS**	**Access to Resources for a Viable Livelihood**	**Adequate Food and Nutrition**	**Avoidance of Disease**	**Clean and Safe Drinking Water**	**Clean Air**	**Energy for Temperature Control**	**Realization of Aesthetic and Recreational Values**	**Ability to Express Cultural and Spiritual Values**	**Opportunity to Observe and Learn from Nature**	**Development of Social Capital**	**Avoidance of Tension/Conflict over a Declining Resource Base**	**Influence Decisions Regarding EGS and human well-being**
Provisioning	Freshwater Consumption	++		++	++	-	++	++			+	+	-	-	+	++
	Freshwater Production	++	+	++	+	+				++					+	++
	Freshwater Navigation	-		+	+											-
	Food	++	+	++	++	++					-				-	++
	Fiber				+										-	+
	Fuel				+					++					-	+
	Genetic-Biochemical						++									-
Regulating	Climate Regulation	+	-	+						+						-
	Water Regulation	++		++	++	++	++	++		+	++					++
	Erosion Control	+	+	+		-		+			+					-
	Water Purification	++	++	++	+	+	++	++			++					++
	Storm - Flood Protection	++			+						-					+

	Ecosystem Services	Security			Basic Needs	Health					Good social relations					Freedom
		A Safe Environment	Resilience to Ecological Shock and Stresses	Access to EGS	Access to Resources for a Viable Livelihood	Adequate Food and Nutrition	Avoidance of Disease	Clean and Safe Drinking Water	Clean Air	Energy for Temperature Control	Realization of Aesthetic and Recreational Values	Ability to Express Cultural and Spiritual Values	Opportunity to Observe and Learn from Nature	Development of Social Capital	Avoidance of Tension/Conflict over a Declining Resource Base	Influence Decisions Regarding EGS and human well-being
Cultural	Spiritual and Religious Values			+	-	-	-	-				++			-	+
	Knowledge Systems and Educational Values			+	+	-	-	-						++	+	
	Inspiration							-			+					-
	Aesthetic value							-			++					-
	Social relations											-		++	+	-
	Sense of place										+	+		-		-
	Cultural heritage values					-	-	-			+	++	+	+	-	+
	Recreation and ecotourism			++	+	-		+			++					+
	Bequest, Intrinsic, and Existence											+	+		-	
Supporting	Soil, Nutrient, Water Cycle	+	++	+	+	+	-	+								
	Biodiversity-Habitat	+	++	+	+	+	-	+			+		-			+

Freshwater plays a key role in supporting ecological services including nutrient cycle, soil formation, and habitat/biodiversity. Within floodplains, flood waters deposit nutrient-rich, clay and silt sediment supporting the fertile agricultural land (Postel and Carpenter 1997). Precipitation, percolating through the vadose zone and into groundwater, promotes the chemical weathering and synthesis in the formation of soils. Estuarine and wetland ecosystems act as nurseries for many aquatic species upon which the populations in the greater area rely, thus supporting both biodiversity and valuable habitat (Ramsar 2007).

A review of 36 case studies from six continents shows broad use of EGS in assessing water resources. Typical applications include valuation of EGS in policy review (Acharya 2000, Garrick et al. 2009, Pagiola 2008), inventory of natural capital resources (Batker 2005, Núñez et al. 2006), methods of EGS valuation (Grossman 2012, Milon and Scrogin 2006, Nedkov and Burkhard 2012, Ojeda et al. 2008, Sánchez-Canales et al. 2012, Willaarts et al. 2012, Zander and Straton 2010), PES pricing (Dong et al. 2011, Kosoy et al. 2007, Turpie et al. 2008, Wendland et al. 2010), EGS as an metrics in development indexes (Jenerette et al. 2006a,b), adjustment in EGS value due to climate or landuse change (Bangash et al. 2012, Terrado et al. 2013, Watanabe and Ortega 2014), and CBA analysis of the ecological benefit considering infrastructure, restoration, and mitigation (Hein 2006, Hoehn et al. 2010, Holmes et al. 2004, Prato 2003). Case studies using non-monetary metrics include narratives for use and valuing EGS (Gilvear et al. 2013, Gowan et al. 2006, Leauthaud et al. 2013, Spash et al. 2009), EGS inventories (Jansson et al. 1999, Liquete et al. 2011, Raymond et al. 2009, Thieme et al. 2012), and policy review (Iovanna and Griffith 2006, Kløve et al. 2011, Pittock et al. 2012, Rebelo et al. 2013). Overall, the types EGS used in the case studies included 27 provisioning services 19 regulatory services, 13 cultural, and 14 supporting (Table 6). A review by Trabucchi et al. (2012) of EGS use in basin scale restoration projects found citations referred to supporting service eight times, regulatory three, and cultural and provisioning services each once. As with Trabucchi et al. (ibid), the increase in the use of EGS can be observed in the publication dates over the past decade. Of these studies, only one explicitly linked EGS to human well-being (Liquete et al. 2011).

3.1.9 Freshwater Ecosystems Concepts

For understanding the ecosystem functioning process of river systems, it is helpful to review the riverine literature that explains how ecosystems form and behave in different abiotic and biotic conditions. The River Continuum Theory (Vannote et al. 1980) states there is a continuum in a river system, from the mountains to the ocean, in the streambed gradient and structure, substrate size, magnitude and variability in discharge, water temperature, and nutrient input to which the species have locally adapted. Further influencing species composition, the Intermediate Disturbance Theory (Ward and Stanford 1983) emphasizes that natural disturbances play an important role within riverine ecosystems, strongly influencing the abundance and composition of species communities and shape ecological sustainability. Townsend (1989), in the Path Dynamics Concept, suggested that spatial heterogeneity and temporal variability control the different populations' success of species by different mechanism including resource partitioning, successional mosaic, and competitive lottery. Ward (1989) defined the 4-dimensional Character of Lotic Ecosystems: longitudinal (in-line with the flow), lateral (perpendicular to the flow including riparian and floodplains), vertical (exchange with the porous media), and a temporal component. Depending on the location along the river network, the migration, transport, and exchange of dominating the ecological processes changes within each dimension. Junk et al. (1989) proposed the Flood Pulse Concept that states species and communities in river-floodplain systems are adapted to the predictable rhythm of the seasonal fluctuations of high and low waters. Capturing the temporal and spatial variability, the Shifting Habitat Mosaic (Hauer and Lorang 2004) states that "*hydrogeomorphic processes, driven by river power and cut and till alluviation, produce a dynamic landscape in the floodplain reaches*". In summary, river ecosystems and the species that inhabit them are adjusted in time and space to the hydrogeomorphic processes which shape the river system.

3.1.10 Disturbance of Freshwater Ecosystems, EGS, and Human Well-Being

Whether natural or anthropogenic in origin, disturbances in the hydrologic system affect the freshwater ecological processes and functioning and thus the supply, quality, and delivery of EGS (Postel and Carpenter 1997, Postel and Richter 2003, MA 2005c). So how do disturbances in a river system influence the natural ecosystem and the biodiversity of the species communities within the system? The Serial Discontinuity Concept (Ward and Stanford 1983) states that introduction of structures (e.g. dams) interrupts the continuum of streambed gradient and structure, substrate size, magnitude and variability in discharge, water temperature, and nutrient input, as specified in the River Continuum Theory, as well as sunlight to the bottom and plankton production, thus causing discontinuities in the habitats along river system. The Natural Flow Regime (Poff et al. 1997) identified the "indexes of alterations" of flow for a natural system in dynamic equilibrium and associated these alterations with ecosystem change through shifting the secondary processes. The "indexes of alteration" include magnitude, duration, seasonality and timing, frequency, and rate of change of discharge. The Hierarchical Framework of Stream Habitat Classification (Frissell et al. 1986) states that habitats are arranged at different scales, from watershed to microhabitats, and that changes in larger scale habitats influence all the smaller scale habitats within it. Thus, local disturbances or rehabilitation have little impact on larger habitats. The concepts described in the aforementioned studies were used to identify how riverine ecosystems respond to disturbances and how disturbed ecosystems influence delivery of EGS (Table 8).

Table 8. Examples of disturbances to freshwater ecosystems and associated impacts to EGS. (Postel and Richter 2003).

Human Activity	Impact on Ecosystems	Service at Risk
Dam construction	Alters timing and quantity of river flows. Water temperature, nutrient and sediment transport, delta replenishment, blocks fish migration	Provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economies, productivity of estuarine fisheries
Dike and levee construction	destroys edge habitat and the hydrologic connection between river and floodplain habitat	habitat, sport and commercial fisheries, natural floodplain fertility, natural flood control
Diversions	Depletes stream flows	habitat, sport and commercial fisheries, natural floodplain habitat floodplain fertility, natural flood control
Draining of wetlands	eliminates key component of aquatic ecosystem	natural flood control, habitat for fish and waterfowl, recreation, natural water purification
Deforestation/land use	alters runoff patterns, inhibits natural recharge, fills water bodies with silt	water supply quality and quantity, fish and wildlife habitat, transportation, flood control
Effluent pollutants	diminishes water quality	water supply, habitat, commercial fisheries, recreation
Overharvesting	depletes species populations	sport and commercial fisheries, waterfowl, other biotic populations
Introduction of exotic species	eliminates native species, alters production and nutrient cycling	sport and commercial fisheries, waterfowl, water quality, fish and wildlife habitat, transportation
Metals in air pollution	alters chemistry of rivers and lakes	habitat, fisheries, recreation, water quality
Climate change air pollutants	potential for changes in runoff patterns from increase in temperature and changes in rainfall	water supply, hydropower, transportation, fish and wildlife habitat, pollution dilution, recreation, fisheries, flood control

3.2 The River Basin Assessment Framework

As stated, the important elements of effective frameworks include the ability to frame water resource issues, identify the analyses and indicators to consider, be capable of evaluating a range of decisions, organize input and output analytical data in evaluating alternatives, provide a flexible structure to accommodate growth in understanding and technology, and produce reliable and transparent output from economic, ecological, and social analyses that, when linked to relevant indicators, assists in evaluating policies and decisions affecting water resources in a basin. The following section presents the overview, components, and general application of a framework for enabling these elements.

3.2.1 RBAF Overview

The River Basin Assessment Framework (RBAF) has been developed to evaluate the sustainability of water resources in river basins based on current and future ecologic, economic, and social systems conditions. In this text, the ecological, economic, and social systems are collectively referred to as the sustainability criterion (SC). The framework provides a systematic foundation for conceptually and analytically predicting changes to the SC systems change due to natural and/or anthropogenic disturbances altering the hydrologic system. The basis for the RBAF is the marriage of three conceptual foundations:

1. UN GEO4 DPSIR Framework (UNEP 2007, Pintér et al. 2008) to help users identify the cause-effect relationships;
2. MA Framework (MA 2003, MA 2005a) to improve the linkage between changes in the state of water resources, ecological systems, and human well-being; and
3. Principles of sustainable development (Swanson and Pintér 2007) including inter- and intra-generational assessment of development within a water river basin and the economic, social, and environmental well-being.

The framework is intended to support individual analysis as well as facilitate participatory and adaptive assessment and planning within a basin; bridging the perspectives of the analyst with the needs of the policy-maker and interested stakeholders. Combining the UN GEO4 DPSIR and MA Frameworks provides users a straightforward method for identifying the drivers of change and the associated change in states and impacts to the hydrologic system, freshwater ecosystems, and the EGS which contributes to human well-being.

The drivers acting on the hydrologic system in a river basin are a combination of internal and external pressures and drivers (Figure 8). Internal drivers and pressures, those forces exerted on the hydrologic system within the river basin, include resource demand (e.g. population growth), land use, technology, public concerns, institutions, and invasive species. External drivers and pressures that originate from the outside the basin include water resource and economic demand; regional, national and international government policies; technology; and societal values. Changes in the climate have direct impact on the internal and external drivers and pressures acting on the hydrologic system.

The state of water resources (the hydrologic system) describes the supply, movement, storage, and use of the water in a river basin (or expressed in economic terms, the flows and stocks of water). Typical factors describing the hydrologic system's state include flow magnitude, duration, timing (seasonality), frequency, and rate of change; storage volume; water delivery and consumption; evaporative loss; water level; inundation area; water temperature; water quality; and sediment erosion, transport, and deposition. Alterations in the hydrologic system caused by pressures and drivers vary spatially and temporally throughout the basin that will be reflected in change in the location, magnitude, and timing of these hydrologic factors. For example, introduction of a dam designed for flood control and irrigation water storage mid-basin will have little hydrological effect upstream, but will drastically impact the impoundment zone (flooded area of the dam) and act to modify the natural flow variability in downstream reaches by decreasing peaks and altering base flow conditions.

Changes in the hydrologic system in the river basin have a direct bearing on the freshwater EGS humans benefit (Section 3.1.8). Depending on the freshwater ecosystem impacted, the EGS influenced include provisioning, regulating, cultural, and supporting services (Table 6). The magnitude of the impact to the freshwater EGS is a function of the degree of hydrologic system alteration, the alteration's influence on ecosystems processes/functions, and the capacity of the changed ecosystem to provide EGS.

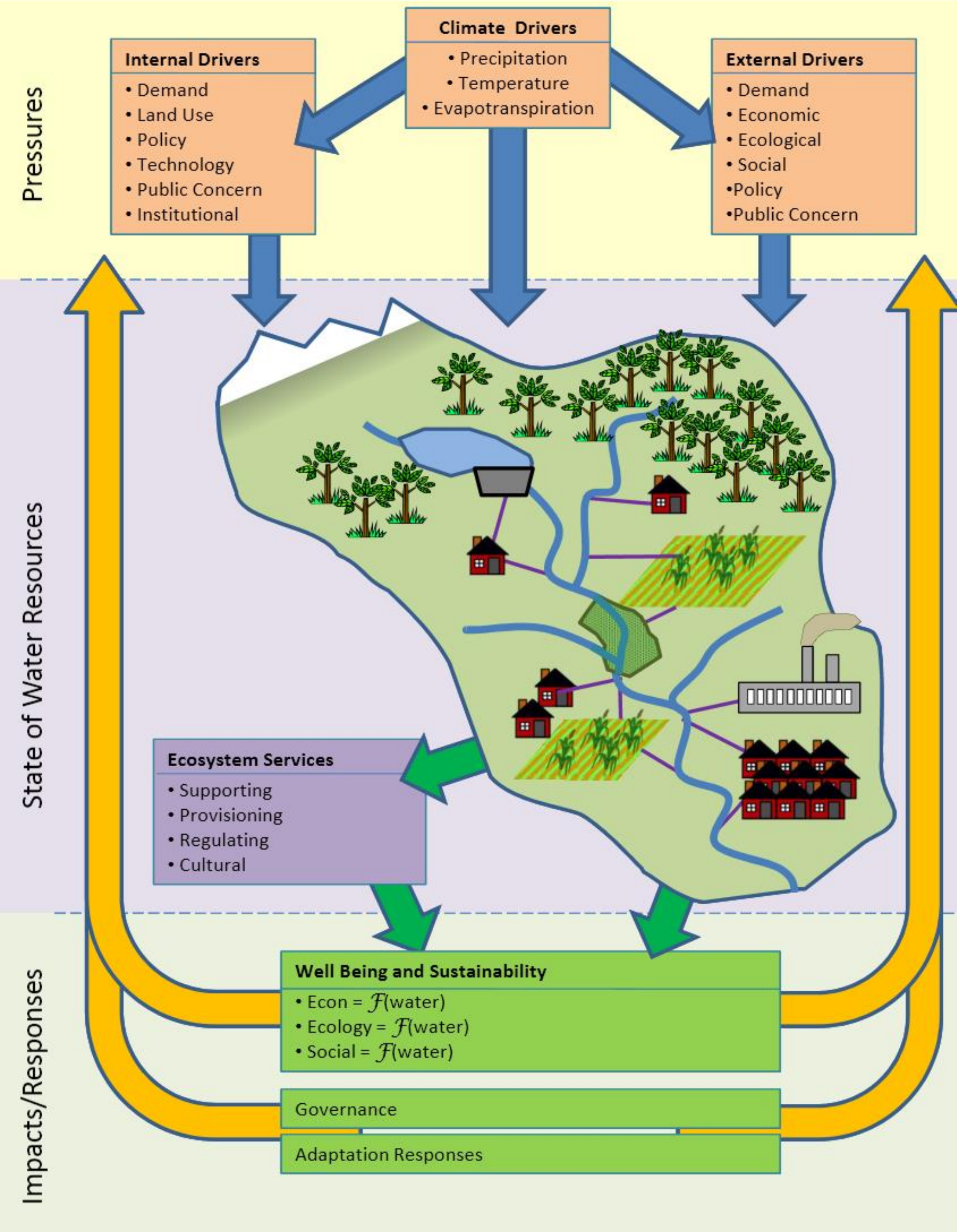


Figure 8. Conceptual diagram of the RBAF showing how internal, external, and climate pressures change the hydrologic system (state of water) and alter ecosystem function and the delivery of EGS, thus impacting ecologic, economic, and social well-being within a basin. Reaction to these impacts influences pressure and drivers directly or indirectly through governance and adaptation responses to the changes.

The spatial and temporal distribution of water in the basin impacts human well-being directly through changing water availability and/or indirectly through changing freshwater ecosystem function and the delivery of EGS (Figure 8). In the RBAF, impacts to human well-being as a result of altering the hydrologic system are assessed with respect to the sustainability criterion. The degree of impact to human well-being is determined through indicators of the SC systems that show change associated to changes in the state of water (a.k.a. hydrologic system). For example, to assess the human well-being aspect of health (a social factor), two indicators that might be assessed are the number of waterborne diseases and the percentage of population having access to safe drinking water. Valuation of these well-being functions includes both monetary and non-monetary indicators. The choice of indicators and the accompanying thresholds are a function of the historical and scientific knowledge, regulatory requirements, and cultural values of the water managers and stakeholders involved in the river basin management. As depicted in Figure 8, attributes of human well-being can be mapped directly to the hydrologic cycle or indirectly through EGS. For example, access to drinking water from a river can be either mapped as the quantity and reliability of delivery of fresh water or the provisioning freshwater EGS.

Impacts to human well-being can directly change the internal, external, and climate pressures and drivers acting on the hydrologic system, thus forming a feedback loop. The impacts may also give rise to new laws, ordinances, and policies and/or, adaptive responses that may also affect the drivers. For example, the external pressure of regionally increasing crop prices creates a local demand for diverting more irrigation water, resulting in a reduction in downstream habitat quality and potentially a decrease in fish population. To address the declining fish population, the government may impose minimum in-stream flow requirements that will limit diversion rates to irrigators during low flow conditions. For assessing new governance policies, adaptive measures, and trade-offs in EGS, the response expressed in changes in external and internal drivers in a following iteration is the proper place to implement the proposed policy in the RBAF analytical cycle.

For most river basins, the relation within and between hydrologic, ecological, economic, and social systems is complex. By structuring the basin analysis as depicted in Figure 8, the RBAF provides a holistic understanding of the natural and anthropogenic drivers and pressures influence on the sustainability of water resources. As the IRBM process involves educating involved parties on water issues and water management alternatives, the RBAF has a conceptual template (RBAF-CT) for qualitatively representing the issues and identifying the pertinent factors and indicators to consider when evaluating the sustainability of water resources issues as well as an analytical interface (RBAF-

AI) for the gathering the analyses results for quantifying the current conditions and analyzing proposed scenarios to address water resources issues.

The RBAF-CT is a screening tool for identifying the relevant hydrologic changes, EGS, constituents of human well-being, and indicators as well as basic connections between SC systems that should be considered in assessing the water resources sustainability in a river basin. Supporting the RBAF-CT is a matrix that guides users on relevant hydrologic factors, EGS, human well-being, and indicators to consider per disturbance and habitat type in the basin. In addition, Driver Templates recommend how to alter the matrix in response to eight disturbance types. Specifically, these templates indicate probable changes in the hydrologic system, potential trend in delivery of EGS, and which constituents of human well-being may be altered. Potential trends in the constituents of human well-being are not provided in the Driver Templates as human well-being is largely context and culturally driven and thus locally defined. Once compiled, users' identify the factors to consider using the template by determining the habitats present in sections of the basin, and for each section, which EGS are used and how the basin community evaluates human well-being. From this compilation, managers and stakeholders comprehend the breadth of relevant ecological, economic, and social factors to consider in their basin as well as potential trends of change due to a driver or pressure (including implementation of management decisions). For scientific, engineering, and technical experts, the RBAF-CT output provides guidance on the required analysis and indicator selection for building the RBAF-AI by spatially mapping the hydrologic system and freshwater habitats; predicting trends of the hydrologic system, EGS, and human well-being in response to a driver; and identifying the indictors to be used to evaluate the sustainability criterion.

The RBAF-AI guides the quantitative evaluation of the current water resources conditions in a river basin (including the magnitude of the problem) and tests potential scenarios with respect to the sustainability criterion. The RBAF-AI provides a toolset for collecting, organizing, and displaying the results from quantitative analyses in a coherent and easily understandable manner. The primary foundation for quantifying water movement is a river basin model. Linked to the river basin model, either separately or dynamically, are analytical tools to compute the changes to the ecological, economic, and social systems. Output from the models and the analytical tools are used as input to indicators that have been identified in the application of RBAF-CT. These indicators are then aggregated in a decision tree to provide single values for the ecological, economic, and social system conditions. Thus to test the impact of a driver or pressure, input data to the river basin model is integrated with a systems analyses to describe alternative future scenarios, presenting managers and stakeholders with a view of how action or inaction in a basin will impact the sustainability of water resources.

To assist the quantitative analysis, the RBAF-AI collects output data from the SC system analyses of a scenario; calculates sustainability indicators; aggregates sustainability indicators in a decision tree; and reports the sustainability indexes for hydrologic, ecologic, economic, and social systems. Within the RBA-AI, three modules support this process: 1) Data Filters to compute the sustainability indicators from the analytical output data, 2) Decision Trees for aggregating disparate and spatially distinct sustainability indicators to indexes, and 3) a Reporting Interface for displaying the resulting Hydrologic, Ecologic, Economic, and Social Index values. The reporting module presents the scenario output as values and trends in ecologic, economic, and social well-being, as well as a star plot for current and future conditions. Output from the RBAF-AI is used to quantitatively evaluate the effects of driver, presenting managers and stakeholders with a view of how action or inaction in a basin will impact the sustainability of water resources in a basin.

The RBAF is intended to address two audiences: 1) non-scientific participants (decision makers, water user associations, concerned stakeholders) and 2) technical participants (scientists and engineers) and to improve communication between these two groups. For non-technical participants, the RBAF is a guide to identify potential pressures and drivers acting within the watershed and the resulting changes to hydrology, EGS, and human well-being. For technical staff supporting the participatory process, the RBAF supports the same understanding as for non-technical staff, but adds the appropriate analyses for computing each indicator and the necessary data exchange between systems and the output data for computing indicators results. Detailed explanation and case studies using the RBAF-CT and RBAF-AI are in Chapters 5 and 6, respectively.

3.2.2 Framework Application

RBAF is applied by using the RBAF-CT to frame the water resource issue and pertinent information to consider followed by the RBAF-AI to quantitatively analyze and report on the sustainability of the basin's water resource management. Mapped on the four steps in knowledge and decision-making for IWRM (Giupponi et al. 2006), the RBAF-CT assists in framing the problem, selecting indicators and measures to evaluate the water resource issue, and provides guidance on element to include as well as a spatial understanding of the active drivers and pressures in the conceptual framework development (Figure 9). The RBAF-AI collects, organizes, and depicts the analytical results from SC systems models to inform interested parties in the sustainability of water resource management alternatives to support decision-making. RBAF may be applied iteratively, providing preliminary screening of key issues, which can then be revisited in the future when the linkages between issues have been quantitatively analyzed. The detailed analyses may show that some parameters are duplicative or insignificant or that new parameters emerge.

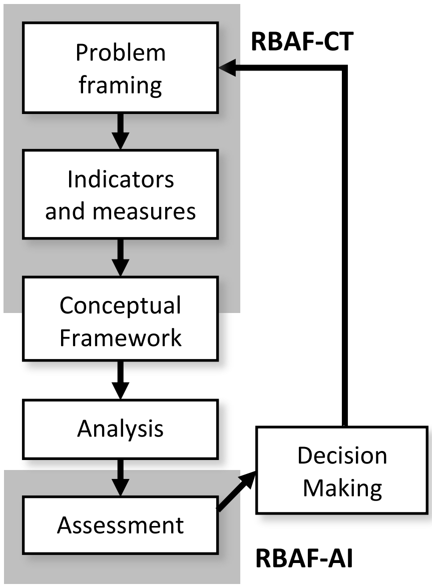


Figure 9. The five steps in knowledge and decision making for IWRM (modified from Giupponi et al. 2005). The grey boxes represent the areas that the RBAF supports the five steps process.

In applying the RBAF-CT, the general procedure involves delineating the basin into sections, developing baseline conditions for each section, creating scenarios that depict impacts from drivers and pressures, and post-processing the analysis to cull irrelevant information and consolidate important factors. In building the RBAF-CT analysis, the basic units are sections that when appended together, provide a spatial representation of the basin. In the RBAF-CT matrix, each section contains 8 freshwater habitats with 24 EGS, which once identified for a section, guides the user to the relevant hydrologic indicators; EGS impact trends, descriptions, and indicators; and constituents of human well-being, human well-being descriptors, and indicators to consider in the analysis. In applying the RBAF-CT, information in each section is adjusted to represent the baseline conditions of the basin, then copied and modified by Driver Templates to form scenarios representing impacts from drivers and pressures in both space and time. Following scenario development in the matrix, a post-processing routine in the RBAF-CT culls irrelevant data and compiles the relevant parameters into an output table that includes the basins representing zones of activity, a list of active and altered sections, freshwater ecosystems, hydrologic alteration, EGS, and human well-being information. In addition, a list of recommended metrics/indicators is generated automatically to guide the development of the quantitative analysis in the RBAF-AI.

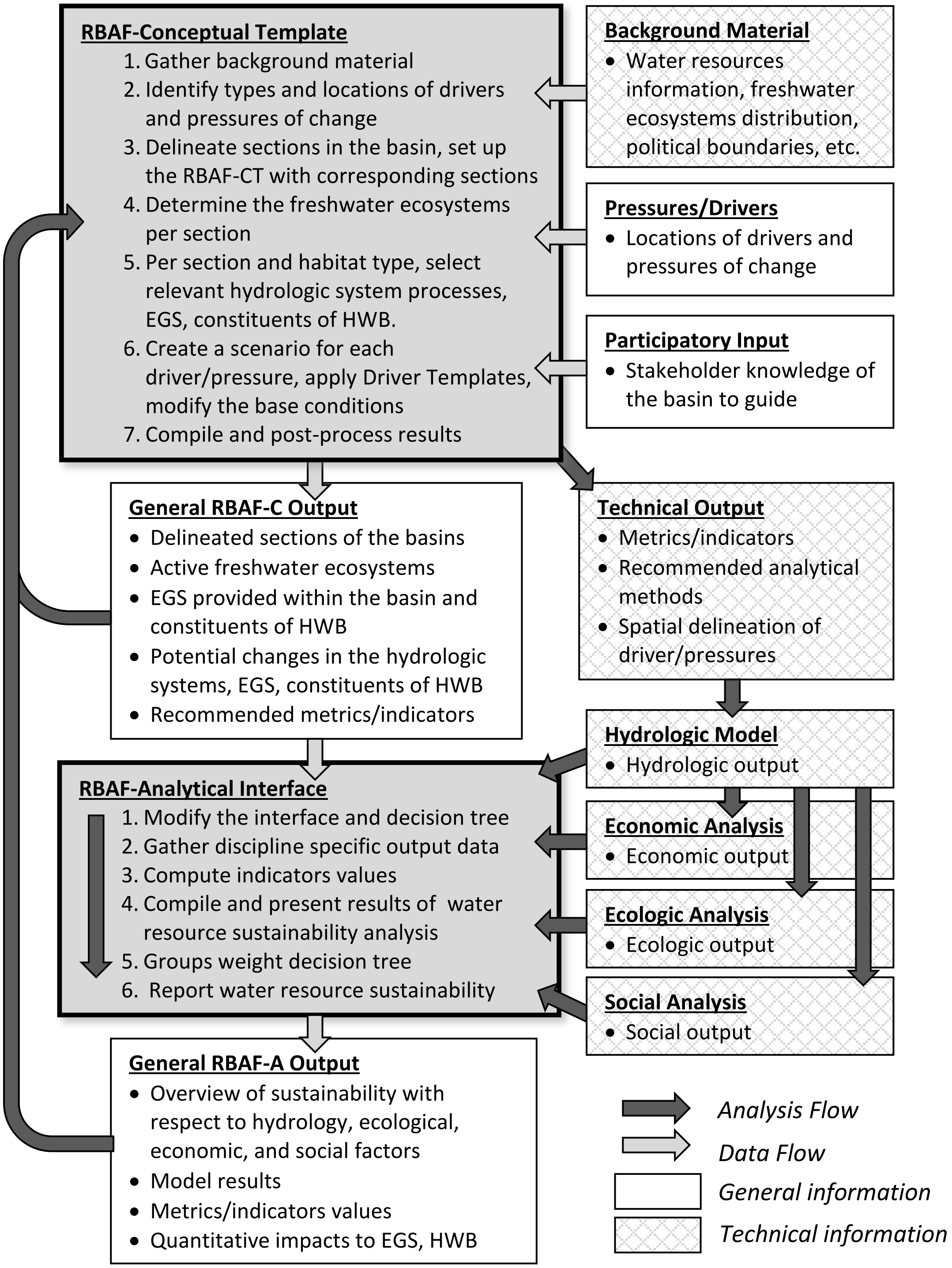


Figure 10. Workflow for implementing RBAF.

Applying the RBAF-CT Template follows the DPSIR Framework (Figure 10). Steps 1-2 determine the Drivers and Pressures acting on the hydrologic system and their location within the basin. These steps provide a foundation for identifying the active zones and contribute to delineating the basin into sections and customizing the RBAF-CT in Step 3. Steps 4-5 define the State of the hydrologic system, freshwater ecosystems, and the EGS through customizing the RBAF-CT to the basin and the water resource issues. Step 6 determines the potential impacts to the hydrologic system, freshwater habitats, EGS, and human well-being for each scenario. Thus when the analysis is completed, the users have identified and located sections of drivers and pressures of change, the current state of the hydrologic systems, freshwater ecosystems, and EGS, and the potential impacts associated with the drivers of change on the freshwater ecosystem and EGS they provide.

The RBAF-AI Interface involves setting up a database to accept model results from the different disciplines, linking to the outputs of the discipline specific models, computing the indicator values from the output, compiling the indicators values into a decision tree, and reporting the water resource sustainability in the basin. The indicators are determined from the list suggested by the RBAF-CT. The output of the RBAF-AI includes an overview of sustainability with respect to hydrologic, ecological, economic, and social factors and values for metrics/indicators.

3.3 Discussion

The combination of the RBAF-CT and RBAF-AI works to support the IWRM process in guiding the formulation of the analysis and providing an interface to collect, analyze, and present multidisciplinary analysis to assessing the sustainability of water resources in a basin. The RBAF promotes multi-stakeholder perspectives to be incorporated in formulating and framing water resource issues and solutions in a participatory setting. Linking the hydrologic system with freshwater habitats, EGS, and constituents of human well-being expands the typical hydrologic analysis to include the inherent connections among the environment, the people living in it, and the basin economy. The selection of relevant indicators that relate the hydrologic conditions to the SC allows stakeholders to identify the thresholds that exist within the interrelated socio-economic and environmental systems. The feedback loop in the workflow indicates that the RBAF can be continually updated allowing for the RBAF to accommodate evolution of decisions, issues, data, scenarios, and models (Figure 10). RBAF’s flexibility to spatially delineate the basin and choose scenarios based on disturbance type and time frame, allow a myriad of water resource issues to be addressed with applications in the “Establish Strategies and Overall Goals”, “Analyzing Gaps”, and “Prepare Strategy and Action Plans” steps in the IWRM cycle (Figure 4). Finally, when coupling the RBAF framework with the policy assessment tools presented in the UNDEP GEO4 DPSIR Framework

(UNEP 2007, Pintér et al. 2008), the results can be used to assess the policies that drive decisions in the basin.

A limitation with RBAF-CT is the reductionist approach it employs to frame and report the water resource issue, as it does not directly illustrate connections and feedback loops that exist within and between systems. Cook and Spray (2012) suggests that a limitation of implementing IWRM has been the use of a reductionism approach, thus missing the complexity in the nonlinear relations in socio-ecological relationships. To address this, it is recommended that the RBAF-CT output be used to identify important components of the hydrologic, ecologic, economic, and social systems in creating a conceptual or systems models of the basin. From this intermediate step, the analysis supporting the connections and feedback loops can be formulated to account for the interconnectivity among system elements and results presented in the RBAF-AI Interface. A further limitation of the RBAF is the ability to produce reliable and transparent output. As the RBAF-AI Interface organizes and processes output from the hydrologic and discipline models, the reliability and transparency of the output is a function of the algorithms employed, input data used, model construction including assumptions, the scenarios run, and uncertainty of the output. While the RBAF-AI Interface allows users to investigate the data used in computing the indicators, it does not allow accessing into the supporting models. However, the RBAF does facilitate dialogue between stakeholders and assists scientists and engineers in prioritizing analyses and monitoring to inform policies and management actions.

3.4 Conclusion

To assist water managers, stakeholders and the technical community in IWRM, the RBAF was developed to guide the assessment of water resource sustainability in a river basin based on the present and future SC system conditions. More specifically, the RBAF provides comprehensive guidance on the important water resources related factors to consider in a basin, emphasizes the importance of the environment through ecosystem services and their impact on human well-being, guides selection of appropriate analyses and relevant indicators to use, and organizes and post-processes the analytical output from discipline models to evaluate water resource issues. The RBAF comprises a conceptualization component (RBAF-CT) and an analytical component (RBAF-AI). The RBAF-CT is primarily for identifying the disturbance mechanism in the hydrologic cycle and how these disturbances change water distribution, ecosystem services, and human well-being as well as recommendations for indicators to measure the impacts. The RBAF-AI assesses how the water distribution, determined by river basin and discipline specific models, affects the sustainability criterion based on alterations of ecosystem services, and human well-being. The RBAF is intended to assist water managers and stakeholders in formulating and analyzing water management decisions in a technical and participatory setting in a wide variety of basins.

Chapter 4. Indicators Selection

To facilitate indicator selection in the RBAF, a candidate list of indicators typically applied to measure hydrologic, ecologic, economic, and social systems was developed. This list compiles 565 indicators from 11 indexes pertaining to water resources management (Table 9). To promote a global perspective, indicators were obtained from every continent, excluding Antarctica. The result is a classified list supports the selection of indicators relevant to the water issue being addressed by the RBAF. This support provides guidance for the selection of applicable indicators in the participatory setting as well as framing the important factors to consider in the analytical assessments of the SC systems.

Table 9. Sustainable development and water vulnerability indexes and indicator data sets used in relating indicators hydrologic alteration, EGS, and constituents of human well-being.

Data Sets	Abbreviation	Source	Categories	Sub-Indexes	Indicators
Arctic Water Resource Vulnerability Index	AVWRI	Alessa et al. (2009)	2	9	24
Canadian Water Sustainability Index	CWSI	Government of Canada (2007)	5	10	15
Environmental Performance Index	EPI	Hsu et al. (2014)	5	4	13
Sustainable Development Indicators	SDI	Mukheibir & Sparks (2003)	5	5	14
SWRR Data Set	SWRR	SWRR (2008)	39	108	371
Vulnerability of Water Systems	WAI	Meigh et al. (1990)	3	3	3
Water Poverty Index (Sullivan 2002)	WPI	Sullivan (2002), Lawrence et al. (2002)	5	11	28
Water Poverty Index (Sullivan 2003)	WPI	Sullivan et al. (2003)	5	11	19
Water, Economy, Investment and Learning Assessment Indicator	WEILAI	Cohen & Sullivan (2000)	8	8	29
Watershed Sustainability Index	WSI	Chaves & Alipaz (2007)	5	6	15
West Java Water Sustainability Index	WJWSI	Juwana et al. (2009)	4	9	12

4.1 Classification Method

Each indicator was mapped to 5 classification categories: DPSIR (Table 3), sustainable development categories (ecologic, economic, and social systems), freshwater EGS (Table 4), constituents of human well-being (Table 5) as well as by continent and spatial scale (Table 10). For the sustainable development categories classification, “hydrology” and “governance” categories were added as these are considered in several indexes including the Arctic Water Resource Vulnerability Index (Alessa et al. 2009) and the Canadian Water Sustainability Index (Government of Canada 2007). For all classifications, indicators were mapped to one or more criteria within the classification based on their strength and relevance. Mapping an indicator to a criterion represents the average characteristics of the indicator, realizing that some indicators are more broadly applicable to criteria than others. There was no attempt to cull similar indicators from multiple sources from the list during this effort. Mapping was conducted in Microsoft EXCEL allowing for analysis and linking to the RBAF-CT matrix.

Table 10. Spatial scale classification criteria based on original scale for which the data set was applied.

Spatial Scale Classification	Arial Extent (km^2)
Local-Project	$10^0 – 10^2$
River Basin	$10^2 – 10^5$
National/Regional	$10^5 – 10^8$
Global	Earth

4.2 Results

The classification resulted in a database of indicators that can be organized and sorted to determine the connections and relevance between categories. For example, organizing the indicators in a matrix of EGS and constituents of human well-being, the number of indicators per paired EGS and constituents of human well-being categories varies between 0 and 107 with an average of approximately 10 indicators (Table 11). Generally, the EGS with the greatest number of indicators is the Freshwater Consumption, Freshwater Production, Water Regulation, Water Purification, and Recreation and Ecotourism. The constituents of human well-being that are associated with the most indicators are Safe Environment, Access to EGS, Basic Needs to Make a Living, Adequate Food and Nutrition, Safe Drinking Water, and Aesthetic and Recreational Values.

The list of indicators related to both EGS and HWB allows users to choose those most applicable to their basin with respect to relevance, feasibility, and cost. For example, for the EGS “Food” and constituents of human well-being “Adequate Food and Nutrition” categories, identifies 55 indicators that have potential to influence these two categories (Table 12). The list provides the available DPSIR and hydrologic, ecologic, economic, and social systems categories to assist in formulation of the analyses. Of these indicators, 27 are listed for driver/pressure, 27 for state, 30 for impact, and 16 for response.

4.3 Application

Classification of the indicators was conducted to help managers and stakeholders identify the appropriate indicators for the SC systems and for technical experts selecting the analytical methods. One of the outcomes of the RBAF-CT is the appropriate indicators that are a product of the template. The output of relevant EGS and constituents of human well-being have been linked to the RBAF-CT to generate a list as presented in Table 12 and in the case studies in Chapter 5. Thus, from the generated list, participants can select the indicators most relevant to the water resource issues in their basin.

To support the analytical assessment, the presentation of the indicators in the DPSIR and sustainable development categories matrix guides the key elements to consider as part of the analysis. Generally, indicators classified as drivers/pressures are those that represent change in analytical input to systems. State indicators represent the elements of the system for which the assessments should account for in the analysis. The impact indicators represent the output factors that need to be addressed, though these may require additional processing beyond the output from the analytical assessment. The impact indicators are those that are input into the RBAF-AI.

For example, a city is undergoing rapid growth in the lower region of a basin. The city relies on available surface runoff but the supply is becoming insufficient during dry periods of the year. In order to provide a buffer in the dry season and increase reliability in drought years, an upstream reservoir is proposed. In this case, the hydrologic pressure indicators generated would include city water demand and indicators that capture the benefits and impacts associated with the reservoir features and operations. The hydrologic state indicators would include reservoir water levels and volumes, river flows, water delivery and shortages to the city, and consumptive use by the city. The hydrologic impact indicators would be the reliability of water delivery, the magnitude and duration of water shortages, and likelihood of filling the reservoir. Thus from these indicators, the hydrologic analytical assessment can be formulated. Similar indicators sets would be developed for the ecologic, economic, and social systems.

Table 11. Number of indicators pertaining to both EGS and constituents of human well-being.

		Security			Basic Needs	Health					Good social relations					Freedom
	Ecosystem Services	**A Safe Environment**	**Resilience to Ecological Shock**	**Access to EGS**	**Access to Resources for a Viable Livelihood**	**Adequate Food and Nutrition**	**Avoidance of Disease**	**Clean and Safe Drinking Water**	**Clean Air**	**Energy for Temperature Control**	**Realization of Aesthetic and Recreational Values**	**Ability to Express Cultural and Spiritual Values**	**Opportunity to Observe and Learn from Nature**	**Development of Social Capital**	**Avoidance of Tension/Conflict over a Declining Resource Base**	**Influence Decisions Regarding EGS and human well-being**
Provisioning	Freshwater Consumption	74	11	64	73	23	15	78		15	28	2		7	8	20
	Freshwater Production	58	8	84	89	27		107		15	29	2		7	11	20
	Freshwater Navigation	2		2	2	2		2			2	2		2	2	2
	Food	10	19	45	71	55	2	45			44	2		7	7	19
	Fiber	9	4	42	62	26		29			29	2		7	7	19
	Fuel	2	2	28	37	9		5			5				6	
	Genetic-Biochemical	6	2	13	13	10	4	8							3	
Regulating	Climate Regulation	7	2	2	2			7								
	Water Regulation	16	5	27	80	29		102		15	28	2		7	5	19
	Erosion Control			13	13	8		6			6					
	Water Purification	65	16	62	40	35	15	107			39	2		7	4	19
	Storm - Flood Protection	2	2	1	1			2			1					

		Security			Basic Needs	Health					Good social relations					Freedom
	Ecosystem Services	**A Safe Environment**	**Resilience to Ecological Shock**	**Access to EGS**	**Access to Resources for a Viable Livelihood**	**Adequate Food and Nutrition**	**Avoidance of Disease**	**Clean and Safe Drinking Water**	**Clean Air**	**Energy for Temperature Control**	**Realization of Aesthetic and Recreational Values**	**Ability to Express Cultural and Spiritual Values**	**Opportunity to Observe and Learn from Nature**	**Development of Social Capital**	**Avoidance of Tension/Conflict over a Declining Resource Base**	**Influence Decisions Regarding EGS and human well-being**
Cultural	Spiritual & Religious Values	15		4		2	15	15								
	Knowledge Systems & Educational Values	12	5	6	24	17		19			23	7		7	2	24
	Inspiration			11	1			4					17	2		5
	Aesthetic value										2					
	Social relations											2				
	Sense of place	2		2	2	2		2			2	2		3	2	2
	Cult. heritage values	6		4	6	4		6			6			4		6
	Recreation and ecotourism	7	5	3	8			3			4	5	1	3	2	7
	Bequest, Intrinsic, & Existence	61	5	62	78	27		53			34	7		7	2	24
Supporting	Soil, Nutrient, Water Cycle	54	29	54	33	15		88			25	5			4	5
	Biodiversity-Habitat	53	27	53	25	15		80			25	5				5

Table 12. Potential indicators for the EGS "Food" and constituents of human well-being "Adequate Food and Nutrition" categories. The "X" and "+"designates a strong and weak relevance to the indicator.

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Fish: Population trends for economically and culturally significant fish species.	Ecological Health	Ecosystem Health	Individuals/Time			X			CWSI
Land Use Changes	Land Use Changes	Water Resources	Acres	X	X		+	+	WJWSI
Aquatic habitat	Subsistence Habitat	Physical index	%			X	X		AWVRI
Terrestrial habitat	Subsistence Habitat	Physical index	%			X	X		AWVRI
Percentage of Basin Area w/ Natural Veg (State)	SD Indicator	Environment	%			X			WSI
People's use of natural resources	Environment Stress	Environment		X	X		+	+	WPI-1
Environmental regulatory stringency	Institutional	Environment	--	X	X			X	WPI-2
Environmental regulatory innovation	Institutional	Environment	--	X	X			X	WPI-2
Number of sectoral EIA guidelines	Institutional	Environment	--	X	X			X	WPI-2
Living in high risk areas – acid mine drainage, radon, fish consumption (subsistence or others with fish-dependent diets)	Recreational exposures	Human Health	Occurrences		+		X		SWRR
Community capacity and opportunity to grow	Domestic water use by	Water use	?	X	X		+	X	SWRR

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Percentage of population using conservation techniques by sector (including individual-municipal-business)	Understanding of water conservation as an ethical value by	Cultural	%	X	X		X	X	SWRR
Municipal regulations that encourage domestic water conservation	Understanding of water conservation as an ethical value by	Cultural	# Policies	X	X			X	SWRR
Incentives for water conservation measures	Ecological Health	Cultural	$	X	X			X	SWRR
Number of volunteer monitors in a watershed	Ecological Health	Cultural	Individuals	X	X		X	X	SWRR
Number of watershed organizations in a state/region promoting water stewardship	Ecological Health	Cultural	# Organizations	X	X		X	X	SWRR
Water rights	Water rights	Legal		X	X			X	SWRR
Number of states going to a permit system	Water markets	Legal		X	X			X	SWRR
Total acreage, by location (Nation, State, County)	Wetlands	Water availability	Acres			X	X		SWRR
Percentage of land surface (in a given area) that is impervious	Land cover: vegetation type	Watershed condition	%	X	X		+	+	SWRR
Percentage of land surface overlying (prime) aquifer-recharge areas covered by development	Land cover: vegetation type	Watershed condition	%	X	X		+	+	SWRR

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Identifying specific pollution sources	Land uses and practices, including water-quality	Watershed condition	# Sites	X	X		+	+	SWRR
Population trends, harvest data	Commercial	Capacity to support non-aquatic species of economic value	Pop. Trends		+	X	X		SWRR
Invertebrates	Measurements of specific organisms inferring water quality	Measurements of water quality	# Individuals/ # species		+	X	X		SWRR
Vertebrates	Measurements of specific organisms inferring water quality	Measurements of water quality	# Individuals/ # species		+	X	X		SWRR
Fecal coliform/pathogens	Measurements of specific organisms inferring water quality	Measurements of water quality	# colonies/ # species		+	X	X		SWRR
Areal extent (natural vs. managed)	Estuaries	Measurements of water that show the amount that is in storage and is available for use	area			X	X		SWRR
Temporal dynamics including volume	Estuaries	Measurements of water that show the amount that is in storage and is available for use	indexes of alteration			X	X		SWRR

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Storage	Wetlands	Measurements of water that show the amount that is in storage and is available for use				X	X		SWRR
Areal extent (natural vs. managed)	Wetlands	Measurements of water that show the amount that is in storage and is available for use				X	X		SWRR
Extent in length and width of riparian vegetation	Land use	Potential human causal factors		X	X		+	+	SWRR
Percentage of impervious surface	Land use	Potential human causal factors		X	X		+	+	SWRR
Composition and configuration of land use	Land use	Potential human causal factors		X	X		+	+	SWRR
NPDES (location, load) number & location of permitted discharges	Land use	Potential human causal factors		X	X			X	SWRR
Non-point sources surface area (animal, mining)	Land use	Potential human causal factors		X	X		+	+	SWRR
Number of stream crossings area of NPS (agriculture, animal feedlots, industry, residential, parks, golf courses)	Land use	Potential human causal factors		X	X		+	+	SWRR
BMPs (#, location, size, conditions)	Structural modifications of hydrologic systems	Potential human causal factors		X	X			X	SWRR

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Percentage of total water	Water conservation measures	Potential human causal factors	BMPs	X	X			X	SWRR
Industrial, agricultural and domestic water use in conservation practice xeriscaping	Water conservation measures	Potential human causal factors		X	X		X	X	SWRR
Disease	Organism Condition	Biotic Integrity	# Occurrences		+	X	X		SWRR
Metabolic state	Organism Condition	Biotic Integrity	Biological Condition		+	X	X		SWRR
Population size	Species/Population Condition	Biotic Integrity	population		+	X	X		SWRR
Population demographics (population structure and dynamics)	Species/Population Condition	Biotic Integrity	# individuals		+	X	X		SWRR
Physical habitat (change) (state + change)	Community	Biotic Integrity	area			X	X		SWRR
Threatened/endangered species	Community	Biotic Integrity	# species		+	X	X		SWRR
Extent of habitat (wetlands, reservoirs, and aquifers)	Extent & Condition of Habitat Types	Landscape Condition	area			X	X		SWRR
Spatial connectivity	Extent & Condition of Habitat Types	Landscape Condition				X	X		SWRR
Diversity of w-d habitats: patch; biological	Extent & Condition of Habitat Types	Landscape Condition	diversity			X	X		SWRR
Extent of terrestrial & aquatic landscapes (connectivity, composition)	Landscape Structure	Landscape Condition	connectivity			X	X		SWRR

Indicator	Sub-Index	Component	Unit	Drivers	Pressures	State	Impacts	Responses	Source
Presence and amount of each part (or patch) within the landscape	Landscape Structure	Landscape Condition				X	X		SWRR
Physical distribution or spatial arrangement of patches within the landscape	Landscape Structure	Landscape Condition				X	X		SWRR
Participation in any type of water management/use program	Water Resource Management Capacity	Water Resource Management Capacity	%	X	X			X	WEILAI
Area of arable land uses/has access	Food Security	Food Security	acres	X	X		+	+	WEILAI
Secondary measure of deteriorating the environment: Insects	Environment	Environment	population		+	X	X		WEILAI
Secondary measure of improved the environment: Wild animal, plants/fungi	Environment	Environment	populations			X	X		WEILAI

Chapter 5. RBAF – Conceptual Template (RBAF-CT)

Freshwater resources are a critical component in human well-being. Humans rely on water not only for direct consumption, but also for production, transportation, sanitation, social relations, recreation, and spiritual rituals. In addition, freshwater supports ecosystems that provide goods and services that further contribute to human well-being (Daily 1997, MA 2003, MA 2005a). As the population and anthropogenic footprint increases on Earth, the balance between water supply reliability with the maintenance and protection of freshwater resources will be a key element in the sustainability of development (WEF 2011). To promote the holistic and sustainable development of water resources, the World Summit on Sustainable Development in Johannesburg 2002 proposed the concept of Integrated Water Resource Management (IWRM) (Hooper 2005). Specifically, the IWRM process was created "to promote the coordinated development and management of water and land resources in an equitable manner in order to maximize socio-economic benefit to mankind and minimize damage to the environment" (GWP 2008). The IWRM concept establishes an environment where cross-sectoral balancing of water for diverse uses is achieved through institutions employing enabling management tools (GWP 2008). The objective of IWRM is to promote wise governance of water management by improving the three e's: economic development, social equality, and environmental sustainability (the sustainability criterion (SC)). For most river basins, the inter-relation between hydrologic, ecologic, economic, and social systems is complex, thus methodologies for holistically conceptualizing, analyzing, and evaluating water management decisions are needed to manage water resources equitably (GWP Toolbox: C1.03 Modeling in IWRM, Stiglitz et al. 2009).

The methodological and guidance literature regarding IWRM implementation has largely focused on the overall process, creating participatory organizations, building institutional capacity, financing programs, developing legal frameworks, developing components of a plan, and implementing management instruments (GWP 2004, Hooper 2005, GWP 2008, UNESCO 2009a,b). Currently, frameworks, decision support software (DSS), and analytical tools exist that address elements of the IWRM analysis including sustainable development assessment frameworks, conceptual models, systems models, hydrologic models, discipline models, ecosystem service valuation programs, and indicator suites. While these frameworks, DSS, and analytical models provide elements of the IWRM analytical processes, there is no one *comprehensive* framework to holistically conceptualize, analyze, and evaluate water resource management in river basins thus requiring water managers, stakeholders, and technical experts are required to cobble together a solution.

The River Basin Assessment Framework (RBAF) has been developed to perform effective IWRM analyses by structuring the formulation and analysis of water resources sustainability in river basins. The RBAF incorporates the principles of sustainable development, the UN GEO4 DPSIR Framework (UNEP 2007, Jager et al. 2008, Pintér et al. 2008), and the Millennium Ecosystems Approach (MA) (Daily 1997, MA 2003, MA 2005a) to develop a holistic understanding of the pressures causing the changes in the hydrologic system, as well as the impacts to the ecological, social, and economic systems. The RBAF contains two components: a Conceptual Template (RBAF-CT) and an Analytical Interface (RBAF-AI). The RBAF-CT guides water managers and stakeholders in realizing and selecting important factors to consider in the sustainability criterion as well as recommendation on the analytical methodologies and indicators to employ in evaluating water management alternatives. The RBAF-AI collects, post-processes, and presents the results of analytical solutions from multiple disciplines to evaluate the water management decisions according to the principles of sustainability and the sustainability criterion. Combining the RBAF-CT and RBAF-AI allows users to conceptualize the water resource issue, determine the appropriate analytical tools and indicators to address a basin's water resource issues, and process the analytical results from disparate disciplines into a single platform for the evaluation of water management decisions.

Conceptual models are an effective method of encapsulating our current understanding of how complex systems are likely to function. The RBAF-CT is a screening framework that assists in conceptualizing the water resource issues, predicting how the spatiotemporal state of the hydrologic systems will change in response to drivers and pressures, identifying the associated potential impacts to EGS and human well-being, and guiding the selection of applicable indicators for evaluating changes in the ecological, social, and economic conditions in a basin. As the RBAF-CT is intended for participatory groups to understand potential outcomes of water management decisions in a wide variety of river basin, the RBAF-CT offers a broad range of hydrologic conditions, freshwater ecosystems, and EGS to initially screen and select the most relevant to the basin characteristics and management strategies. The output of the RBAF-CT is a delineation of the basins to represent zones of activity; a list of unaltered, active, and altered freshwater ecosystems; predicted response in the hydrologic systems associated with the drivers/pressures of change;

impacts to freshwater ecosystem function and the associated change in EGS and human well-being; and the recommended metrics/indicators to use in the quantitative analysis to support the RBAF-AI.

This chapter provides the background, methodology, and case studies of the RBAF-CT. The case study areas are the Lemhi River Basin (LRB), Idaho, United States and the Upper Bhima Basin, Maharashtra, India which have been selected because they both have an existing river basin model, as well as to illustrate the versatility in applying the RBAF-CT to basins of different sizes, population density, water use by sectors, water resource issues, and cultural settings.

5.1 Background

The foundation of the RBAF-CT is the principles of sustainable development (Swanson & Pintér 2007), the UN GEO4 DPSIR Framework (UNEP 2007, Pintér et al. 2008), and the MA Framework (MA 2003, MA 2005a). The principles of sustainable development provide guidance on how the analysis should be evaluated. According to these principles, water resource management should consider intra- and inter-generational linkages, inter-dependence between the sustainability criterion, multi-stakeholder perspectives, multi-scale effect, inherent socio-economic and ecologic capacities, and adaptive learning and management. The DPSIR Framework clearly lays out a methodology for connecting the drivers, pressures, states, impacts, and responses within a system. The DPSIR Framework is straightforward and intuitive for stakeholders to understand the integrated and complex ecological and socio-economic issues within a system. The MA Framework (MA 2003, MA 2005a) provides a systematic link between the ecosystems, the goods and services they provide, and human well-being for a greater awareness of the benefits provided by the environment. While the MA framework also uses the DPSIR concept, it is more narrowly focused on ecosystem services analysis and thus has been criticized as being more difficult to understand the connections between drivers-pressures and the impact and response (UNEP 2005). Thus the RBAF-CT uses the strength of both frameworks to evaluate water resource management according to the principles of sustainability. The clarity of the DPSIR Framework in linking causal effects is combined with the MA Framework's strength in linking impacts to EGS and human well-being,

The logic underlying the RBAF-CT was based on literature review, guidance documents, case studies, and personal experience in hydrologic modeling. Incorporation of the DPSIR methodology was determined from background information (UNEP 2007) and implementation guidance documents (Pintér et al. 2008). Linking freshwater ecosystems with EGS was determined by reviewing guidance documents on freshwater EGS and human well-being (Postel & Carpenter 1997, MA 2003, MA 2005a,b, UNEP 2005, Forslund et al. 2009),as well as 36 studies using EGS in water management, and freshwater ecosystems literature. The links between drivers and pressures of change and hydrologic system alterations, freshwater ecosystem response, and EGS were derived from literature review, case studies, and the author's experience with developing and implementing hydrological models. Indicators appropriate to evaluate the hydrologic system and sustainability criterion were determined from classifying 565 indicators from 11 water management indexes and indicator suites with respect to appropriate hydrologic alterations, EGS, and constituents of human well-being (see Chapter 4). To support its implementation, the RCAF-CT has been developed in Microsoft EXCEL version 2010 to organize the information and post-process the analysis.

5.2 Methodology

The general procedure for applying the RBAF-CT involves delineating the basin into sections, developing baseline conditions for each section, creating scenarios and modifying the baseline conditions in the RBAF-CT for drivers and pressures of change, and post-processing the analysis to cull irrelevant information and consolidate important factors (Figure 11). In applying the RBAF-CT, information in each section is adjusted to represent base conditions, then copied and modified by Driver Templates to form scenarios representing impacts from drivers and pressures in both space and time. Following development of the scenarios, a post-processing routine in the RBAF-CT eliminates duplication or other parameters that are expected to be insignificant in the conceptualization of future conditions. RBAF-CT then compiles the relevant parameters into a single output table that includes the basins representing zones of activity, a list of active and altered sections, freshwater ecosystems, hydrologic alteration, EGS, and human well-being information, as well as the recommended metrics/indicators to use in the quantitative analysis in the RBAF-AI. The process is intended to lead users through understanding the distribution of freshwater habitats, water use, range of EGS, human well-being conditions, locations of disturbances, and the predicted responses to disturbance in space and time. The output is used to support general understanding of the status and threats to water resources as well as guidance in formulating the analysis.

In building the RBAF-CT analysis, the basic unit is a basin section that when appended together, provide a spatial representation of the basin. In the RBAF-CT, each section contains 8 freshwater habitats with up to 24 associated EGS. Freshwater habitats in the RBAF-CT include the riverine system, riparian zone, floodplains, wetlands (including bogs, fens, marshes, swamps), ponds-tanks,

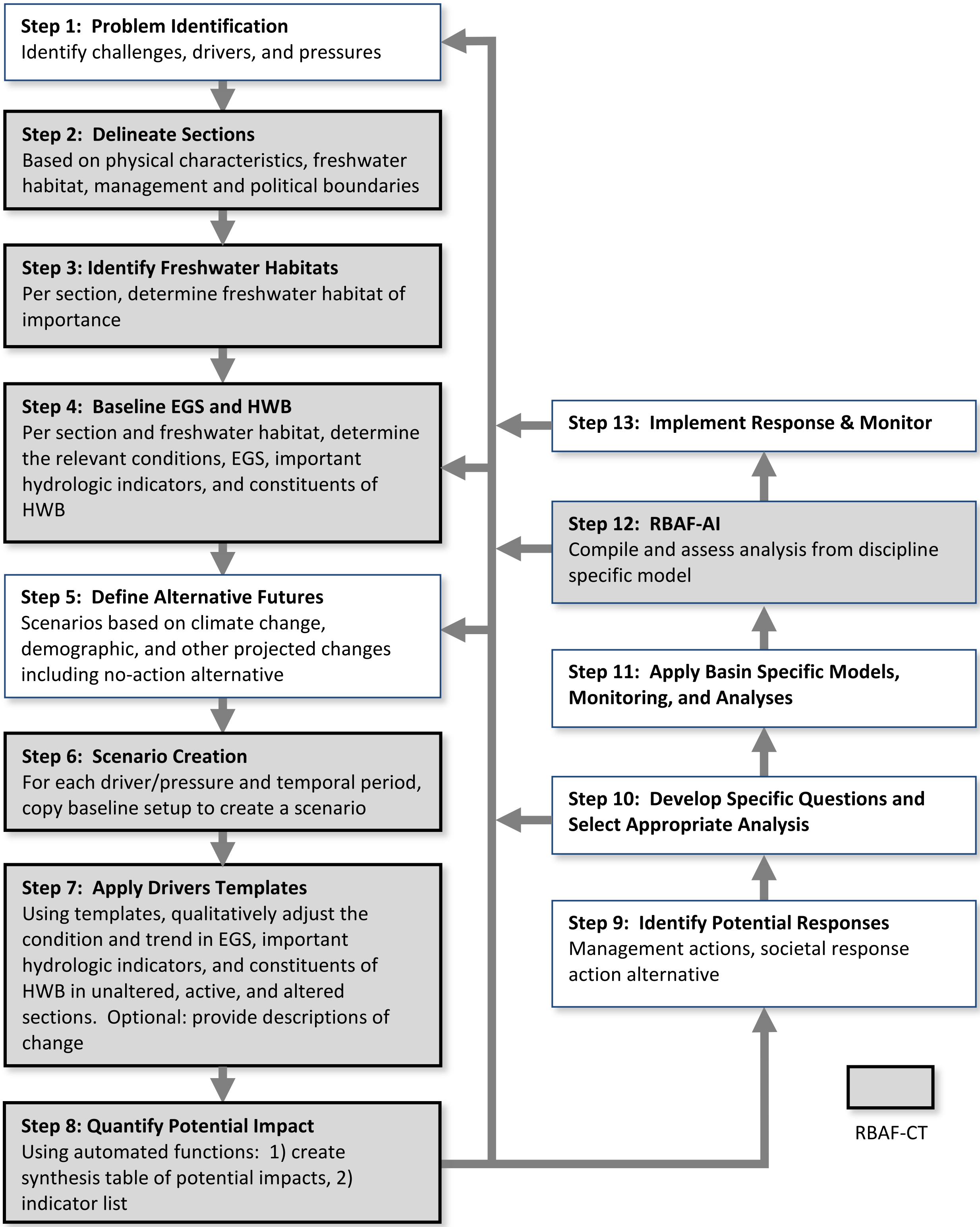
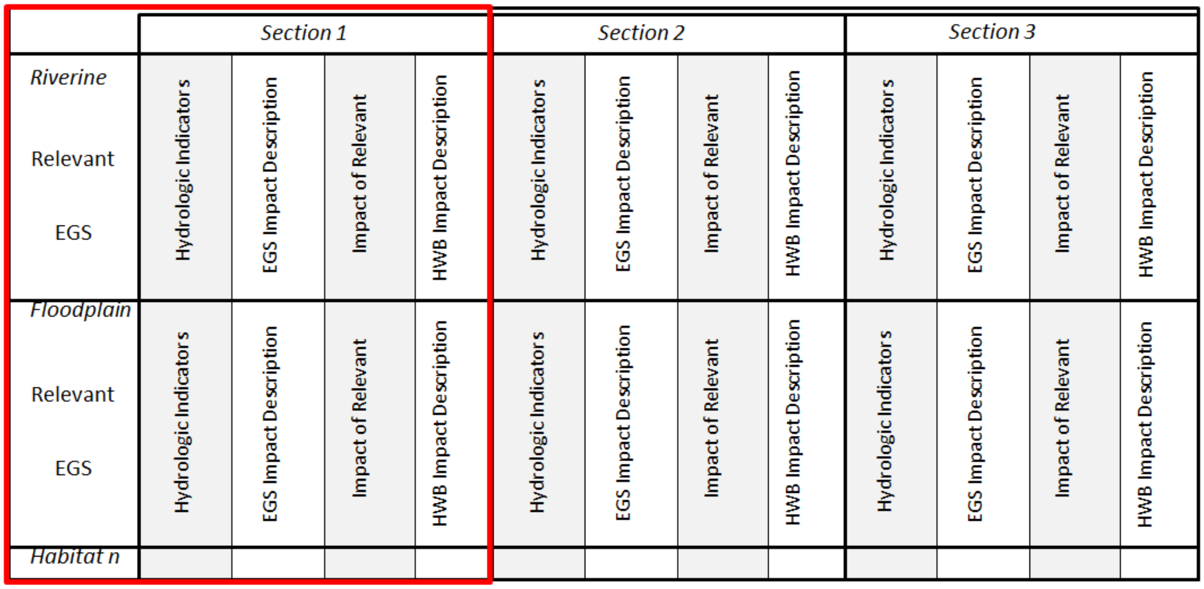


Figure 11. Stepwise progression of the analysis using the RBAF-CT.



	Section 1				*Section 2*				*Section 3*			
Riverine Relevant EGS	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description
Floodplain Relevant EGS	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description	Hydrologic Indicators	EGS Impact Description	Impact of Relevant	HWB Impact Description
Habitat n												

Figure 12. The basic RBAF-CT (an example section is depicted in red showing the riverine and floodplain habitats).

lakes-reservoirs, snowpack-glaciers, and groundwater-springs. The EGS included in the RBAF-CT have been modified from the MA 2003 to those pertinent to freshwater (Table 6). The RBAF-CT is a matrix that connects active EGS in a freshwater habitat with the relevant hydrologic indicators and impact responses; EGS impact trends, descriptions, and indicators; and constituents of human well-being, human well-being descriptions, and indicators to consider in the analysis (Figure 12). The relevant hydrologic indicators include flow magnitude, duration, frequency, timing (seasonality), and rate of change; water storage; water level; inundated area; water quality; water temperature; and sediment erosion and deposition. Table 7 lists the constituents of human well-being included in the RBAF-CT. For this text, the relevant hydrologic indicators and impact responses; EGS impact trends, descriptions, and indicators; and constituents of human well-being, human well-being descriptions, and indicators to consider in the analysis are referred to as the EGSInfo.

Basin sections delineation is based on the spatial relation to drivers influencing the hydrologic system, freshwater habitats, and, optionally, other important economic, governance, ecologic, physical, hydrologic, or social factors. For most cases, the minimum number of sections will be an unaltered section (usually upstream), an active section, and altered section (usually downstream), but it is likely that more sections will be needed to represent different driver activities and spatial zones in the basin. Within each section, one or more freshwater habitats can be experiencing the effects of drivers and pressures. For example, Figure 13 illustrates a hypothetical basin experiencing climate change and population growth as the primary drivers exerting pressures on existing water supply and land use. As a result, the change in the state of the water resources is likely to increase water diversion, alter runoff patterns associated with landuse, and, if an upstream reservoir is built, change the flow patterns in the downstream riverine, floodplain, and wetlands. Likely impacts in the basin are land use conversion of wildlands, rangelands, and wetlands to agriculture and urban expansion as well as greater demands on a limited water resources resulting in reduced water supply reliability. Biological resources will adapt to the change in state of water by altering ecosystem functions. Potential responses by the management agencies may include reservoir development as well as promoting areas of habitat creation, restoration, and conservation.

Figure 13. Basin delineation for application in the RBAF-CT. Red lines and numbers denote section delineations and identification.

In applying the RBAF-CT to this example, the basin is delineated into 4 sections based on physical characteristics and disturbance location. Section 1, the mountainous headwaters, has snowpack, riverine, and floodplain habitats and will experience changes associated with reservoir development and climate change. Section 2, the forested headwaters, has riverine freshwater habitat with climate change the primary pressures acting in this section. The mid-basin, Section 3, represents the portion of the basin where floodplains are being converted to croplands and has riverine, riparian, and wetland freshwater habitat types. Section 4 contains the population centers of the basins with riverine, riparian corridors and floodplain being the freshwater habitats. The primary pressures acting in Section 4 are increasing water demand, significant loss in habitat, fragmentation of habitats and loss of connectivity between habitats within the section.

Following basin delineation, the state of the relevant EGS and EGSInfo are determined for each freshwater habitat in each section. Within a section, users identify the existing freshwater habitat and active EGS, then work from left to right through the template to determine the relevant EGSInfo

(Figure 12). The RBAF-CT is predefined to only identify EGS that are relevant to a particular habitat. For example, the EGS categories of freshwater navigation, climate regulation, and storm protection are not available in the riparian habitat. Similarly, only hydrologic indicators and constituents of human well-being relevant to an EGS are available as potential options to consider. Thus, from the full suite of options, the template guides users as to the relevant EGS and EGSInfo to consider for each section. This allows users to review the full range of factors to consider when evaluating the sustainability of water resources, and then select and condense only pertinent information to consider in a holistic analysis of their basin.

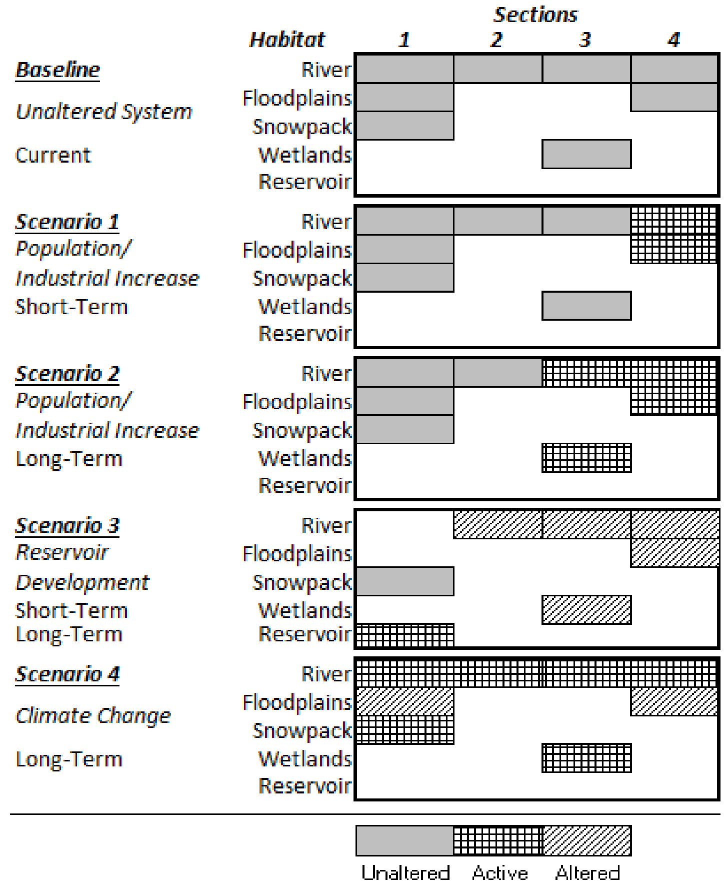


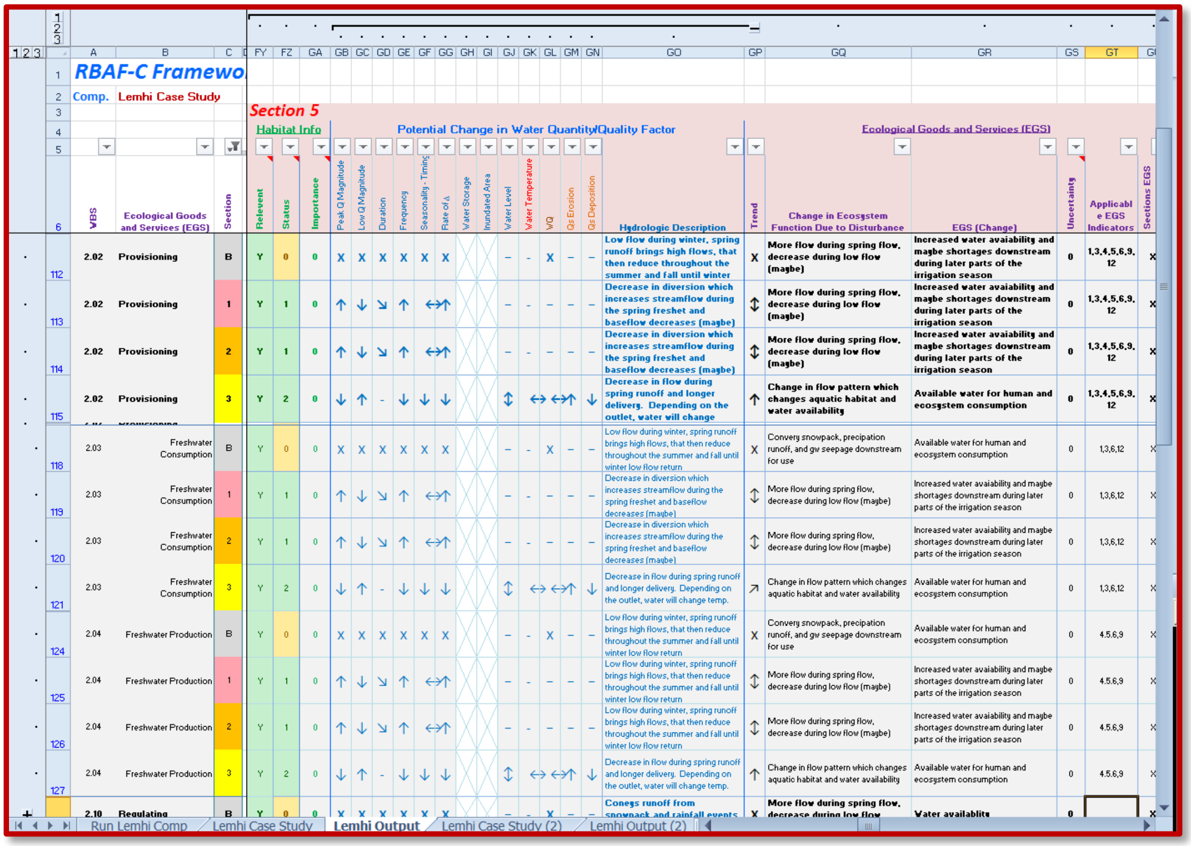
Figure 14. Example of freshwater habitat distribution and alteration status for each scenario in the RBAF-CT analysis of the theoretical basin.

When considering the effects of drivers of pressures or change within the basin, in space and/or time, scenarios are employed. Scenario creation involves modifying the baseline conditions to represent the predicted changes in active habitat types, EGS, and EGSInfo per section. In establishing the scenario analysis, habitats are first classified as unaltered (no affect from pressures), active (directly affected by pressures), or altered (indirectly affected by pressures) per spatial relation and the expected response of the hydrologic system to a driver (Figure 14). The unaltered, active, or altered habitats designation roughly corresponds to upstream, active section, and downstream sections of the basin. In this hypothetical example, drivers may establish the following range of scenarios: Short-term (< 2 decades) 1) Population/Industrial Increase, 2) Reservoir Development and Long-term (5-10 decades), 3) Continued Population/Industrial Increase, and 4) Climate Change. Figure 14 illustrates how the freshwater habitats within each section are classified into unaltered, active, or altered habitats status as a guide for further analysis. Note, freshwater habitats may be lost and created, as in Scenario 2, where inundation from the reservoir creates lake habitat and eliminates the riverine and floodplain habitats. Following completion of this step, a refined analysis is preformed within the sections and habitats for all of the scenarios.

Table 13. Driver Templates description and examples.

Driver Templates	**Type Description**	**Examples**
1. Supply Change	Introduction or removal of structures that regulate flow within the channel or onto the floodplain. New technologies for supplying water are included.	Increase use of groundwater, inter-basin transfer, glacier disappearance, desalinization plants.
2. Demand Change	Change in water requirement for water use including domestic/municipal, agriculture, commercial/industrial, energy sector, recreation, and ecosystems. New technologies for changing demand are included.	Population growth, irrigation practices or crop type, hydropower potential, market price increases for a product.
3. Climate Change	Includes both short- and long-term influences of climate on the watershed hydrology. Includes both short- and long-term climate variability.	Increased precipitation and temperature, flood events, droughts.
4. Landuse Change	Changes to the landscape that will affect the runoff, groundwater recharge, water quality, and erosion/sediment delivery to the river network.	Switching from natural forest to agriculture, desertification associated with climate change, urbanization.
5. Infrastructure Development/Alteration, Removal	Development, alteration, or removal of structures regulating flow within the channel or onto the floodplain. Includes physical structure and operational strategies.	Reservoirs, dams, weirs, diversions, levees, barrages.
6. Policy/Institutional	Changes in policy and institutional regulation alter the distribution of water. Policy-institutional regulation can often be drivers as well.	Drought conservation laws, water banking, water user associations, water distribution laws (prior appropriation doctrine).
7. Society	Change in cultural values or public perception/concern.	Raising awareness of environmental issues, shift from subsidence to industrial livelihood.
8. Ecosystem	Change in ecosystems due to climatic, hydrologic, or anthropogenic changes; change in species diversity and population.	Invasive species, wetlands drying up due to change in flow regime from upstream dam, denuding forest canopy due to fire.
9. Economic	Change in economic drivers due to markets, financial policies, sector expansion/contraction.	Crops grown become more valuable, industry wants to develop in a basin, tax incentives.

To assist users in modifying the baseline conditions in each scenario, Driver Templates are available to illustrate typical changes in EGS and EGSInfo in the unaltered, active, and altered zones. Driver Templates follows the same format as the baseline section, but provides generic guidance on the potential change in the EGSInfo: anticipated trends in hydrologic indicators, quantity or quality of EGS delivered, and impacts to human well-being for the unaltered, active, and altered zones. Driver Templates have been developed for changes in climate, supply, demand, landuse, infrastructure, economic conditions, policy/institutional, societal preferences, and ecosystems (Table 13). For relevant habitats and active EGS identified the baseline conditions, Driver Templates are applied to the active and altered habitats for each section, then modified to reflect local and expert knowledge in the basin.



RBAF-C Framewo

Comp. Lemhi Case Study

Section 5

Habitat Info

Potential Change in Water Quantity/Quality Factor

Ecological Goods and Services (EGS)

	VBS	Ecological Goods and Services (EGS)	Section	Relevent	Status	Importance	Peak Q Magnitude	Low Q Magnitude	Duration	Frequency	Seasonality - Timing	Rate of Δ	Water Storage	Inundated Area	Water Level	Water Temperature	WQ	Qs Erosion	Qs Deposition	Hydrologic Description	Trend	Change in Ecosystem Function Due to Disturbance	EGS (Change)	Uncertainty	Applicable EGS Indicators	Sections EGS
112	2.02	Provisioning	B	Y	0	0	X	X	X	X	X	X			–	-	X	–	–	Low flow during winter, spring runoff brings high flows, that then reduce throughout the summer and fall until winter	X	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	1,3,4,5,6,9, 12	X
113	2.02	Provisioning	1	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Decrease in diversion which increases streamflow during the spring freshet and baseflow decreases (maybe)	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	1,3,4,5,6,9, 12	X
114	2.02	Provisioning	2	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Decrease in diversion which increases streamflow during the spring freshet and baseflow decreases (maybe)	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	1,3,4,5,6,9, 12	X
115	2.02	Provisioning	3	Y	2	0	↓	↑	-	↓	↓	↓			↕	↔	↔↑		↓	Decrease in flow during spring runoff and longer delivery. Depending on the outlet, water will change	↑	Change in flow pattern which changes aquatic habitat and water availability	Available water for human and ecosystem consumption	0	1,3,4,5,6,9, 12	X
118	2.03	Freshwater Consumption	B	Y	0	0	X	X	X	X	X	X			–	-	X	–	–	Low flow during winter, spring runoff brings high flows, that then reduce throughout the summer and fall until winter low flow return	X	Convery snowpack, precipation runoff, and gw seepage downstream for use	Available water for human and ecosystem consumption	0	1,3,6,12	X
119	2.03	Freshwater Consumption	1	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Decrease in diversion which increases streamflow during the spring freshet and baseflow decreases (maybe)	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	1,3,6,12	X
120	2.03	Freshwater Consumption	2	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Decrease in diversion which increases streamflow during the spring freshet and baseflow decreases (maybe)	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	1,3,6,12	X
121	2.03	Freshwater Consumption	3	Y	2	0	↓	↑	-	↓	↓	↓			↕	↔	↔↑		↓	Decrease in flow during spring runoff and longer delivery. Depending on the outlet, water will change temp.	↗	Change in flow pattern which changes aquatic habitat and water availability	Available water for human and ecosystem consumption	0	1,3,6,12	X
124	2.04	Freshwater Production	B	Y	0	0	X	X	X	X	X	X			–	-	X	–	–	Low flow during winter, spring runoff brings high flows, that then reduce throughout the summer and fall until winter low flow return	X	Convery snowpack, precipation runoff, and gw seepage downstream for use	Available water for human and ecosystem consumption	0	4,5,6,9	X
125	2.04	Freshwater Production	1	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Low flow during winter, spring runoff brings high flows, that then reduce throughout the summer and fall until winter low flow return	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	4,5,6,9	X
126	2.04	Freshwater Production	2	Y	1	0	↑	↓	↘	↑		↔↑			–	-	–	–	–	Low flow during winter, spring runoff brings high flows, that then reduce throughout the summer and fall until winter low flow return	↕	More flow during spring flow, decrease during low flow (maybe)	Increased water avaiability and maybe shortages downstream during later parts of the irrigation season	0	4,5,6,9	X
127	2.04	Freshwater Production	3	Y	2	0	↓	↑	-	↓	↓	↓			↕	↔	↔↑		↓	Decrease in flow during spring runoff and longer delivery. Depending on the outlet, water will change temp.	↑	Change in flow pattern which changes aquatic habitat and water availability	Available water for human and ecosystem consumption	0	4,5,6,9	X
	2.10	Regulating	B	Y	0	0	X	X	X	X	X	X			–	-	X	–	–	Coneys runoff from snowpack and rainfall events	X	More flow during spring flow, decrease during low flow	Water availablity	0		X

Figure 15. Example Output Table of RBAF-CT analysis. Displayed are the freshwater consumption and freshwater production EGS in the riverine habitat to in Section 5 for the Baseline Conditions and Scenarios 1-3. Note, only provisioning EGS of relevance this basin are shown.

Once RBAF-CT has been adapted for the baseline conditions and scenarios, a post-processing tool compiles the relevant information to produce the Output Table; a screening level examination of the important freshwater habitats, EGS, constituents of human well-being, and indicators in a spatial and temporal context (Figure 15). In addition, filtering capabilities in Microsoft EXCEL aid in further condensing the output information, allowing the user to pinpoint the information that is of interest. Thus, when sections are integrated to represent flow in the basin, a holistic depiction of the relevant habitats and EGS are revealed to show how they affect human well-being. This holistic depiction of the relevant information with expected trends in response to drivers can be used to help stakeholders better understand the full ramifications of water distribution in the basin, as well as guide technical staff in determining the analyses to apply and the metrics by which the management alternatives can be assessed.

In addition to an Output Table, an Indicator List of potential classes of indicators is generated, organized, and reported into a DPSIR matrix listing the hydrologic, ecologic, economic, and socially relevant indicators. This is an expansion of the DPSIR conceptual framework for water resources presented by Winograd et al. (1999) and Segnestam (2002). Use of the DPSIR Framework allows for the indexes to be recommended as they pertain to the analytical process. In this matrix, the pressures, state, and indicators represent the input–simulation-output of the modeling systems used in the analytical phase of the water resource assessments. Thus, pressure indicators equate to the elements in the systems models that need to be altered to represent the change of pressures. State indexes map to variables in the systems models which are likely to change and need to be extracted to compute the impact indicators. Impact indicators are the processed results that can be used to evaluate the change in the system and can be fed into additional analyses (e.g. calculation of reliability) or inclusion in indexes (e.g. water sustainability index). How drivers change the state of the system and how future conditions can be influenced by management responses (including the no-action alternative) can assist decision makers and stakeholders understand the causes and severity of the challenges and the range of potential responses.

As the RBAF-CT uses the classification of the 565 indicators as the base (see Chapter 4), the output of the Indicator List presents a comprehensive range of choices, allowing the user to select parameters that best resonate with managers and scientists conducting the assessment. For example, a recommended state indicator might be chemical concentration, but whether that chemical is nitrogen, dissolved oxygen, or chlorine has not been specified as it will depend on the system being analyzed. Combined with the Output Table, the Indicator List provides a foundation for selecting analytical methods, establishing thresholds, developing potential solutions, and creating output from the analytical methods that support the participatory water management.

5.3 Case Studies

To demonstrate the RBAF-CT's applicability to establish water resources sustainability assessments, case studies were conducted in the Lemhi River Basin (LRB), Idaho, USA, and the Upper Bhima Basin (UBB), Maharashtra, India. Both basins have dry climates with a large agricultural landuse, but differ in water resource issues, drainage area, population density, and economic, ecological, and societal systems operating in the basin. The following section provides the basin background, major water resource issues, and the application of the RBAF-CT.

5.3.1 Lemhi River Basin (LRB), Idaho

Background: The LRB is a rural basin in North-Eastern Idaho (Figure 16). The basin is 3,149 km^2 and flanked by the Bitterroot Range and Beaverhead Mountains to the east and the Lemhi Range to the west. Elevations range from an average of 1,585 m amsl along the valley floor to heights in excess of 2,745 m amsl along the ridges. The Lemhi River begins at Leadore and flows 97 km to the northwest where it joins the Salmon River at Salmon, Idaho. At the confluence, the minimum, average, and maximum daily average discharge of the Lemhi River is 0.75 ft^3/s (0.02 m^3/s), 251 ft^3/s (7.11 m^3/s), and 2,610 ft^3/s (73.91 m^3/s). Twenty six tributaries join the river in its course from Leadore to Salmon.

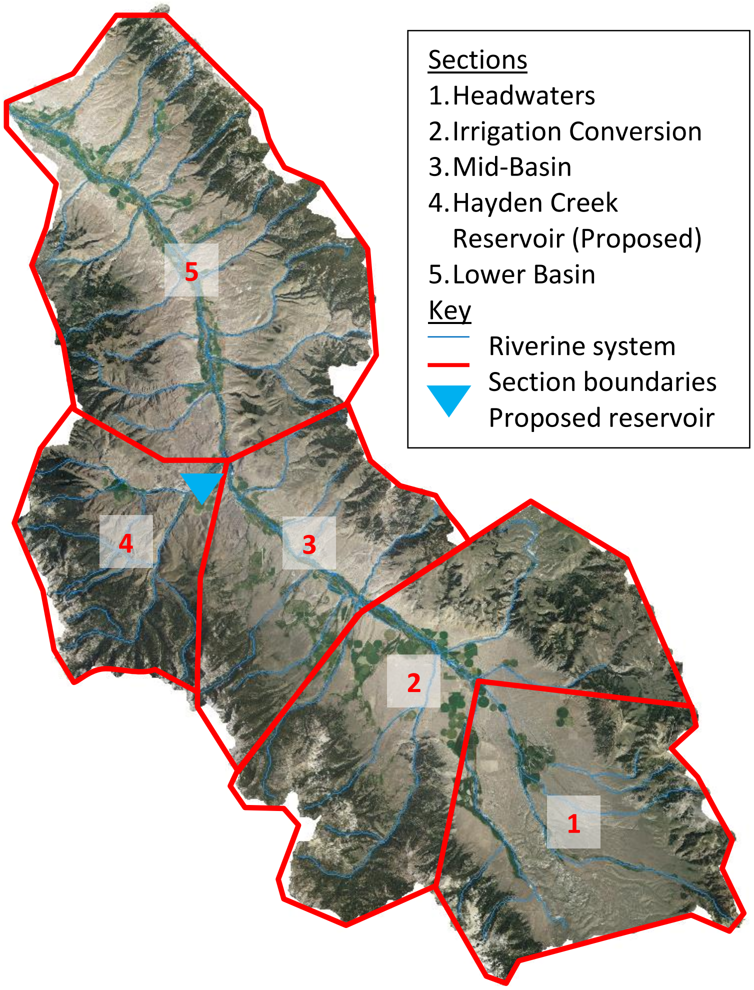


Figure 16. Sectional delineation of the LRB. Flow in the basin is from southeast to northwest.

The LRB has cold, wet winters and warm, dry summers. During the winter months, the LRB experiences maritime weather from the west that produces heavy snowfall. Typically, seasons change gradually with the first snow occurring in October, but can be marked by rapid changes in weather and diverse microclimates throughout the basin. Annual precipitation ranges from 9 inches (~230 mm) on the valley floor to 40 inches (1016 mm) in the mountains, with 70% falling during the winter months between November and April (Idaho Soil Conservation Commission 1995). Snowmelt is usually completed by mid-May. During summer months, warm days and cools nights are the norm (ibid).

The primary economic driver in the LRB is cattle ranching. As the region is arid, ranchers have traditionally flood irrigated the alfalfa hay crops and pastures to support cattle production, requiring large quantities of water to be diverted from the river system to water the crops. Irrigation begins in mid-April to early June, depending on the snow conditions and temperatures, and lasts until October 15 with ranchers harvesting between 1-2 cuttings of alfalfa hay depending on the start of the growing season and location in the basin (Bob Loucks, personal communication 2013). It is typical for a third crop to be grown and cattle left to graze in the latter part of the year. In 2013, the average price of premium hay was $150/ton dry weight (ibid). Irrigation is required to grow feed for cattle, which provides a link between water use and economic output. To a lesser extent, recreational tourism including fishing, hunting, boating, and camping, also supports the local economy. Boating and fishing industries require adequate in-stream flows to maintain desirable floating conditions and aquatic habitats.

Ecologically, freshwater ecosystems are important environs in maintaining resident and migratory fish populations. The river system provides valuable spawning and rearing habitat for anadromous steelhead and Chinook salmon, as well as year round habitat for the resident bull trout. The primary limiting factors for steelhead are migration barriers particularly during low-flow conditions at a major diversion structure (referred to as L-6) before the Spring freshet. Another limiting factor for steelhead and Chinook salmon are warmer water temperature which occur during the late Summer low-flow conditions, degrading rearing habitat in mainstem Lemhi River upstream of McFarland Campground (Sections 2-3 in Figure 16). For bull trout, dewatering of tributaries by irrigation diversions creates migration barriers which effectively disconnect upstream tributary and downstream mainstem Lemhi River habitats. The migration barriers isolate meta-populations of bull trout, thus leaving populations vulnerable to disease, predation and natural drivers such as landslides and mudslides. Steelhead, Chinook salmon, and bull trout are listed as endangered species.

Water Resource Issues: The competing demand between irrigation needs and stream flow to support habitat for endangered species creates a contentious setting for water use in the LRB. To ease the competition for water, conversion from flood irrigation to sprinkler irrigation in the upper portion of the basin is being promoted to leave more flow in the river system. Sprinkler systems require much less water, applying only what is needed for crop consumption. General application rates for flood and sprinkler irrigation in the LRB are 4.00 and 2.70 acre-ft per acre every year. In addition, the Idaho Department of Water Resources has actively been managing water transfers and water banking to lessen the low flow migration restrictions at the L-6 Diversion during the onset of the Spring freshet and the rearing habitat degradation in the mainstem Lemhi River upstream of McFarland Campground during the late Summer months. But questions remain as to the water resource sustainability associated with the conversion to sprinkler in the basin. Will the increase in the sprinkler use benefit or impair the ranching economy? How much external funding should be used to increase or maintain the sprinkler systems? How will this conversion impact the aquatic habitats supporting the steelhead, Chinook salmon, and bull trout populations and what will be the effect on the recovery of the species? Will the reduction in flood irrigation diminish shallow groundwater and reduce seepage from the floodplain to the river later in the season? How will an altered hydrologic regime influence the tourism economy? What are the social impacts of converting to sprinklers?

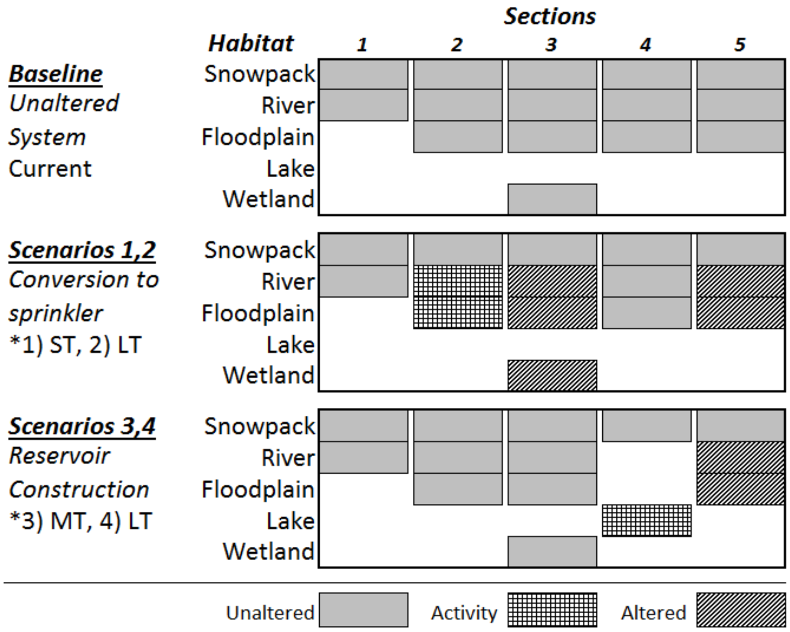
Methodology: To address the water resources sustainability of the conversion to sprinklers in the LRB, the RBAF-CT was used to screen for the relevant freshwater habitats and EGC categories as well as applicability and trends in EGSInfo. In addition, to illustrate the use of the RBAF-CT in screening for multiple drivers that are spatially distinct, the consequences of increasing storage is assessed by considering the development of a fictitious reservoir on Hayden Creek Reservoir. In all, five scenarios were analyzed (Figure 17):

- Baseline Scenario of current conditions,
- Scenario 1 - conversion to sprinkler irrigation (short-term time horizon),
- Scenario 2 - conversion to sprinkler irrigation assuming increased conversions (long-term time horizon),

- Scenario 3 - development of Hayden Creek Reservoir (medium-term time horizon), and
- Scenario 4 - development of Hayden Creek Reservoir (long-term time horizon).

To predict impacts of drivers, the change in demand template was applied for Scenarios 1-2 and the infrastructure template was applied for Scenarios 3-4. As Scenarios 3 and 4 yielded identical results, only Scenario 3 is reported in this text.

Spatially, the LRB has been delineated into 5 sections representing the headwaters (Section 1), the area of primary sprinkler conversion (Section 2), mainstem downstream of the conversion and upstream of the confluence with Hayden Creek (Section 3), proposed Hayden Creek Reservoir location (Section 4), and the lower basin (Section 5) (Figure 16). It is assumed that the headwaters section represents an unaltered zone and remains constant throughout all scenarios. Sections 2 and 4 represent areas expected to experience driver activity due to irrigation conversion and reservoir construction, respectively. Section 3, mid-basin, will likely observe a hydrologic response due conversion to sprinklers in Section 2, but will not be influenced by the proposed reservoir in Section 4. Section 5 will experience changes in the hydrologic system created by all the upstream sections. Baseline results include an inventory of the freshwater habitats, active EGS, and associated EGSInfo per section throughout a basin with scenario results including trends in hydrologic indicators, EGS, and constituent of human well-being per scenario.



	Habitat	**1**	**2**	**3**	**4**	**5**
Baseline *Unaltered* *System* Current	Snowpack	░	░	░	░	░
	River	░	░	░	░	░
	Floodplain		░	░	░	░
	Lake					
	Wetland			░		
Scenarios 1,2 *Conversion to* *sprinkler* *1) ST, 2) LT	Snowpack	░	░	░	░	░
	River	░	▦	▨	░	▨
	Floodplain		▦	▨	░	▨
	Lake					
	Wetland			▨		
Scenarios 3,4 *Reservoir* *Construction* *3) MT, 4) LT	Snowpack	░	░	░	░	░
	River	░	░	░		▨
	Floodplain		░	░		▨
	Lake				▦	
	Wetland			░		

Figure 17. Mapping of freshwater habitats per basin sections for baseline conditions and 4 scenarios in the LRB. The spatial delineation of the five sections is depicted in Figure 16. The abbreviations with "*" are short-term (ST), mid-term (MT), and long-term (LT).

Screening Results: *Baseline Conditions* – The RBAF-CT assessment of the LRB indicated the freshwater habitats to consider include river systems, mountain snowpack, floodplains, wetlands, and, once the proposed reservoir is built, lake and reservoir habitat (Table 14). For all sections, the

EGS provided from the *mountain snowpack* include provisioning supply of freshwater water, regulation in the storage and release of winter snowpack, supporting ecosystems, and cultural benefits of winter recreational activities and the aesthetic beauty of snow-capped mountains. The human well-being constituents that the *mountain snowpack* influences include resilience to stressors such as droughts, access to resources for a viable livelihood, clean and safe drinking water, and realization of aesthetic and recreational values. No change in EGS and constituents of human well-being from the *mountain snowpack* is expected for any scenario.

The *river system* conveys runoff from precipitation and return flow from agriculture, thus providing freshwater supply for irrigation diversion for production, aesthetic and recreational benefits, components of the hydrologic and nutrient cycles, and aquatic habitat supporting biodiversity and healthy ecosystems (Table 14). The constituents of human well-being that the *river system* influences are access to EGS, resilience to ecological shock and stresses, access to resources for a viable livelihood, adequate food and nutrition (indirectly through beef production), and realization of aesthetic and recreational values. Expected impacts from drivers for the *river system* will be seen in all sections barring Section 1. The suggested hydrologic indicators for the *river system* include the indices of alteration (Poff et al. 1997).

Alfalfa production and grazing are primarily conducted on the floodplains and pediment surfaces flanking the valley walls. As stated, crops have traditionally been flood irrigated, requiring large quantities of water to be diverted from the river system to saturate the soils. Excess water not used by the plants for evapotranspiration infiltrates into the shallow groundwater zones returns as base flow to the stream later in the summer when natural stream flows are low. The EGS provided by the *floodplains* includes provisioning services (crop production and cattle grazing), regulating services (water regulation through irrigation return flow), cultural services (recreational opportunities of hunting and wildlife viewing), and supporting services (supporting the hydrologic and nutrient cycles and supporting biodiversity including bird and mammal habitat) (Table 14). The constituents of human well-being that floodplains provide are access to EGS, access to resources for a viable livelihood, adequate food and nutrition, and realization of aesthetic and recreational values. Expected impacts from drivers for the *floodplains* will be seen in all sections barring Section 1. The suggested hydrologic indicators for the floodplains include depth to groundwater (water level), soil moisture, and area irrigated (representing local precipitation).

Table 14. EGS and constituents of human well-being by habitat applicable for the LRB (◊) and the Upper Bhima Basin (+).

		Security			Basic Needs	Health			Good social relations	
	EGS	A Safe Environment	Resilience to Ecological Shock and Stresses	Access to EGS	Access to Resources for a Viable Livelihood	Adequate Food and Nutrition	Avoidance of Disease	Clean and Safe Water	Realization of Aesthetic and Recreational Values	Ability to Express Cultural and Spiritual Values
Mountain Snowpack										
Regulating	Water Regulation		◊		◊			◊		
Cultural	Aesthetic Value								◊	
	Recreation And Ecotourism								◊	
Supporting	Nutrient & Hydrologic Cycle				◊					
River System										
Provisioning	Freshwater Consumption	+						+		
	Freshwater Production			◊+	◊+	◊+				
	Food			+	+	+				
Regulating	Water Purification	+		+		+		+		
Cultural	Aesthetic Value								◊+	
	Recreation And Ecotourism								◊	
	Spiritual & Religious Values									+
Supporting	Nutrient & Hydrologic Cycle	+		◊+	◊					
	Biodiversity-Habitat			◊+	+	+			◊	
Floodplains										
Provisioning	Freshwater Production			◊	◊	◊				
Regulating	Water Regulation			◊	◊					
Cultural	Recreation And Ecotourism								◊	
Supporting	Nutrient & Hydrologic Cycle					◊				
	Biodiversity-Habitat				◊				◊	
Lakes/Reservoirs										
Provisioning	Freshwater Consumption	+		+	+		+	◊+		
	Freshwater Production	◊		◊+	◊+	◊+				
	Navigation			+	+					
	Food		+	+	+	+				

		Security			Basic Needs	Health			Good social relations	
	EGS	A Safe Environment	Resilience to Ecological Shock and Stresses	Access to EGS	Access to Resources for a Viable Livelihood	Adequate Food and Nutrition	Avoidance of Disease	Clean and Safe Water	Realization of Aesthetic and Recreational Values	Ability to Express Cultural and Spiritual Values
Regulating	Water Regulation	+	◊	◊+	◊+	+		+		
	Flood Protection	+								
Cultural	Recreation And Ecotourism				◊+				◊+	
Supporting	Nutrient & Hydrologic Cycle		◊		◊	+				
	Biodiversity-Habitat	+	◊+	+	◊+				◊+	
Ponds/Tanks										
Provisioning	Freshwater Consumption	+		+	+		+	+		
	Freshwater Production			+	+	+				
Regulating	Water Regulation			+	+	+		+		
Cultural	Aesthetic Value								+	
	Recreation And Ecotourism									
	Spiritual & Religious Value									+
Supporting	Nutrient & Hydrologic Cycle			+						
Wetlands										
Provisioning	Food			+	+	+				
Regulating	Water Regulation		◊		◊					
	Water Purification		+							
Cultural	Recreation And Ecotourism				+				+	
Supporting	Nutrient & Hydrologic Cycle		◊+							
	Biodiversity-Habitat		◊+						◊+	
Groundwater										
Provisioning	Freshwater Consumption	+		+			+	+		
	Freshwater Production			+	+	+				
Regulating	Water Regulation	+		+	+	+	+	+		

The *wetlands* habitat, occurring in Section 3, is primarily a function of groundwater upwelling from the upper basin and agricultural return flows from irrigations on the pediment slopes along the valley walls. The EGS provided by the *wetlands* includes water regulation in the storage and release during the late summer months and habitat supporting biodiversity (Table 14). The constituents of human well-being that the *wetlands* influence are resilience to stresses and access to resources for a viable livelihood though metering out water later in the season, and realization of aesthetic and recreational values to support bird watching and hunting. The suggested hydrologic indicators for the *wetlands* include the indexes of alteration and depth to groundwater (water level).

The proposed Hayden Creek Reservoir will create a *lake/reservoir* habitat, inundating the existing river system and floodplains in Section 4. The reservoir is designed to support water supply to irrigators and drinking water for the City of Salmon during dry months in the summer. Irrigation canals will draw water directly from the reservoir, feeding the field currently fed by the L-32 and L-34 diversions. The EGS provided by the *lake/reservoir* habitat includes provisioning services areas for crop production and cattle grazing, water regulation in the storage and release during the late summer months, aesthetic value and recreational opportunities (boating, fishing), and habitat supporting biodiversity for lentic conditions (Table 14). The constituents of human well-being which the river system influences are access to EGS, resilience to stresses, access to resources for a viable livelihood (fishing guiding service), adequate food and nutrition, and realization of aesthetic and recreational values. The suggested hydrologic indicators for the *lake/reservoir* habitat include the inundated area, water storage, and water level.

<u>*Scenarios 1-2:*</u> Hydrologically, as less water is required for sprinkler irrigation, the conversion from flood irrigation will decrease diversion rates thus leaving more water in the Lemhi River and resulting in a less disturbed flow regime. Around the Spring Freshet, a natural flow regime translates higher peak stream flows and a more varied hydrograph that is responsive to snowmelt throughout the river system. However, the conversion may lower the late season stream flows as flood irrigation waters, which are applied during the spring and early summer periods and have excesses that infiltrate into the shallow groundwater system, will not be available to seep back into the stream system later in the summer leaving less water in the system for both fish and ranchers. This hydrologic trend is likely to become more pronounced as conversion to sprinkler irrigation continues from Scenario 1 to 2. How valid this late season low flow assessment is currently unknown, therefore the RBAF-CT results need to be addressed using a technical evaluation such as with hydrologic models and the RBAF-AI. The response to the hydrologic conversion will have impacts not only in Section 2, but also along the mainstem Lemhi River in Sections 3 and 5.

Table 15. EGS and constituents of human well-being (HWB) trends resulting from the RBAF-CT screening of the LRB. “B” is Baseline and “S1”, “S2”, and “S3” are Scenarios 1, 2, and 3, respectively.

		EGS Trend				Impacted Zones	HWB Trend			
Habitat	**EGS**	**B**	**S1**	**S2**	**S3**		**B**	**S1**	**S2**	**S3**
***Section 2:* Riverine**		**–**	**↕**	**↕**	**–**	**3,5,X**	**–**	**↗**	**↑**	**–**
Provisioning	Freshwater Production	–	↗	↑	–	3,5,X	–	↗	↑	–
Cultural	Aesthetic, Recreation	–	↗	↗	–	X	–	↗	↗	–
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	–	3,5,X	–	↔	↔	–
Floodplain		**–**	**↕**	**↕**	**–**	**3,5,X**	**–**	**↗**	**↑**	**–**
Provisioning	Freshwater Production	–	↑	↑	–	3,5,X	–	↗	↑	–
Regulating	Water Regulation	–	↔	↔	–	3,5,X	–	–	–	–
Cultural	Recreation	–	↔	↔	–	X	–	↔	↔	–
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	–	3,5,X	–	↕	↕	–
***Section 3:* Riverine**		**–**	**↕**	**↕**	**–**	**5,X**	**–**	**↗**	**↑**	**–**
Provisioning	Freshwater Production	–	↕	↕	–	5,X	–	↗	↑	–
Cultural	Aesthetic, Recreation	–	↔	↔	–	X	–	↔	↔	–
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	–	5,X	–	↔	↔	–
Floodplain		**–**	**↕**	**↕**	**–**	**5,X**	**–**	**↗**	**↑**	**–**
Provisioning	Freshwater Production	–	↕	↕	–	5,X	–	↗	↑	–
Regulating	Water Regulation	–	↘	↓	–	5,X	–	–	–	–
Cultural	Recreation	–	↔	↔	–	X	–	↔	↔	–
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↓	–	X	–	↕	↕	–
Wetlands		**–**	**↘**	**↓**	**–**	**5,X**	**–**	**↘**	**↓**	**–**
Regulating	Water Regulation, Storm Protection	–	↘	↓	–	5,X	-	↘	↓	-
Cultural	Recreation	–	↘	↓	–	X	-	↘	↓	-
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	–	1,2,5,X	-	↕	↕	-
***Section 4:* Riverine**		**–**	**–**	**–**	**↓**	**5,X**	**–**	**–**	**–**	**↓**
Provisioning	Freshwater Production	–	–	–	↓	5,X	–	–	–	↓
Cultural	Aesthetic, Recreation	–	–	–	↓	X	–	–	–	↓
Supporting	Natural Cycles*, Habitat & Biodiversity	–	–	–	↓	5,X	–	–	–	↓

Habitat	EGS	EGS Trend B	S1	S2	S3	Impacted Zones	HWB Trend B	S1	S2	S3
Floodplain		**–**	**–**	**–**	**↓**	**5,X**	**–**	**–**	**–**	**↓**
Provisioning	Freshwater Production	–	–	–	↓	5,X	–	–	–	↓
Regulating	Water Regulation	–	–	–	↓	5,X	–	–	–	↓
Cultural	Recreation	–	–	–	↓	X	–	–	–	↓
Supporting	Natural Cycles*, Habitat & Biodiversity	–	–	–	↓	X	–	–	–	↓
Lake/Reservoir		**n/a**	**n/a**	**n/a**	**↑**	**5,X**	**n/a**	**n/a**	**n/a**	**↑**
Provisioning	Freshwater Production	n/a	n/a	n/a	↑	5,X	n/a	n/a	n/a	↑
Regulating	Water Regulation, Storm Protection	n/a	n/a	n/a	↑	5,X	n/a	n/a	n/a	↑
Cultural	Aesthetic, Recreation	n/a	n/a	n/a	↑	5,X	n/a	n/a	n/a	↑
Supporting	Natural Cycles*, Habitat & Biodiversity	n/a	n/a	n/a	↕	5,X	n/a	n/a	n/a	↕
Section 5: **Riverine**		**–**	**↕**	**↕**	**↑**	**X**	**–**	**↕**	**↕**	**↑**
Provisioning	Freshwater Production	–	↕	↕	↑	X	–	↕	↕	↑
Cultural	Aesthetic, Recreation	–	↑	↔	↔	X	–	↔	↔	↔
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	↑	1,2,3,4,X	–	↔	↔	↑
Floodplain		**–**	**↕**	**↕**	**↑**	**X**	**–**	**↗**	**↑**	**↑**
Provisioning	Freshwater Production	–	↕	↕	↑	X	–	↗	↑	↑
Regulating	Water Regulation	–	↔	↔	↔	X	–	–	–	↔
Cultural	Recreation	–	↔	↔	↑	X	–	↔	↔	↑
Supporting	Hydrologic Cycle, Habitat & Biodiversity	–	↘	↓	**↑**	X	–	↕	↕	**↑**

In Sections 2, the provisioning services of freshwater production will likely increase throughout most of the irrigation season with the exception of the late summer, when stream flow may drop below current levels. Thus, the water regulation provided by the *floodplains* during late summer is unknown at this time and needs to be addressed analytically (Table 15). Therefore, the provisioning services of freshwater production in Sections 3 and 5 are also unknown for late summer. The increased high water lessens the chance of migration barriers being created in Section 5 and connections of tributaries to the mainstem in Section 2 during the in the early springe before snowmelt has begun in earnest. However, late summer low flow conditions may degrade valuable rearing habitat in the bottom of Section 2 and 3, thus impacting the supporting services associated with habitat and cultural opportunities associated with recreational fishing. Human well-being associated with the increased access to resources for a viable livelihood will go up in Section 2 but may have adverse effect on irrigators in Sections 3 and 5 later in the season.

Scenarios 3-4: Construction of the Hayden Creek Reservoir will inundate the existing *river system* and *floodplain* habitats to create a *lake/reservoir* habitat. Reservoir storage and releases will decrease peak flows and augment lower flows thus reducing flow variability in Section 5. Water temperatures will lower in Section 5 as the reservoir is designed for bottom release. However, if the cold water pool is exhausted in dry years, it is possible that water temperature of the releases could be significantly higher. It is assumed that the reservoir will be oligotrophic with minimal effects on downstream food webs due to events such as lake algal blooms. During this preliminary conceptual stage of the reservoir development, the primary impacts are assumed to be hydrologic alterations. The reservoir will need to be operated such that it does not restrict flows to create migration barriers at the L-6 diversion during the initiation of the Spring Freshet. Hydrologically, the reservoir will have no impact on Sections 1-3.

The EGS lost in Section 4 due to the reservoir include the provisioning services of the *floodplain* and the natural habitat associated with the *riverine* section as the habitat is lost and the dam will act as a migration barrier to aquatic species. Section 5 will likely see an increase in provisioning services associated with freshwater production due to the water regulation associated with the reservoir in Section 4. In terms of human well-being, recreational benefits increase in Section 4 and likelihood of access to resources for a viable livelihood and adequate food and nutrition in Section 5. However, with the loss of the floodplains available for irrigation in Section 4, the local ranchers have lost access to resources for a viable livelihood. If factoring in the cost of reservoir construction, the benefits associated with the increased access to resources for a viable livelihood in Section 5 are likely insignificant and, in fact, cost more when looking at area inundated and EGS lost.

Indicator List: The primary question being assessed is how will methods to increase reliability of water delivery to ranchers benefit the economy and impact endangered species in the basin? Two scenarios are evaluated using the RBAF-CT: 1) conversion from flood to sprinkler irrigation in the upper basin and 2) construction of the Hayden Creek Dam. Thus, the pressures indicators identified are change in water demand for agriculture (hydrologic system) and change in production (economic system) (Table 16). The regulatory requirement to meet endangered species act (ESA) criteria of minimum stream flow is influences flow in the basin, but is considered that is to be considered as a state variable.

The state indicators for the hydrologic system center around water supplied to the irrigators (demand, supply, and deficit) and the ecological functions that are sustained by the flow regime in the river (Table 16). For the proposed dam, state indicators also include water level and storage volume. Economic indicators largely include how much crop is produced, how much revenue crop production generates, and, for the dam, construction, operations, and maintenance costs. Ecological state indicators are the bull trout and salmon aquatic habitat for the spawning, rearing, migration, and adult (bull trout only) life stages. Social state indicators include average annual income for the valley and the recreational use of the reservoir.

Impact indicators include trends, reliability, and average changes in values over the period. Hydrologic indicators included total delivery, demand, deficit, and reliability of delivery for the irrigators. For the river system, the indexes of alteration (Poff et al. 1997) and the reservoir were average annual storage, cold pool storage, and likelihood of filling. For economic, the change in net revenue per acre for each irrigation method and section as well as the change in production were considered. Ecological impacts were measured by the change in habitat for both listed species and the social impact was the trend in household income and recreational access. Responses to the impacts could be reservoir operational rules, Habitat restoration projects, and planning for subsidizing sprinkler irrigation projects.

Table 16. Recommended indicator list for determining the sustainability of water resource management in the LRB.

	Hydrology		Ecologic		Economic		Social	
	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit
Driver	None		None		Agriculture technology change		None	
Pressure	Change in water demand for agriculture	cfs, ac-ft., m^3	None		Change from flood to sprinkler irrigation	acre	None	
	Construction of a reservoir							
State	Water flow in river system	cfs, cms	Aquatic habitat quality for salmon spawning	0-1	Production from irrigation	Tons	Average household income	$
	Irrigation demand	cfs, ac-ft.	Aquatic habitat quality for salmon rearing	0-1	Revenue generated crops	$	Recreational use river system	Daily use
	Water delivery	cfs, ac-ft.	Aquatic habitat quality for salmon migration	0-1	Land under irrigation	acre	Recreational use reservoir	Daily use
	Water deficit	cfs, ac-ft.	Aquatic habitat quality for bull trout spawning	0-1	Crops grown	type		
	Area irrigated	acres	Aquatic habitat quality for bull trout rearing/adult	0-1	Recreational dollars	$		
	Consumptive use, return flow, percolation to groundwater	cfs, ac-ft.	Aquatic habitat quality for bull trout migration	0-1	Reservoir construction cost	$		
	Reservoir storage	ac-ft., ft^3	Minimum stream flow requirements	cfs	Reservoir O & M	$		
	Reservoir water level	ft.						
Impact	Reliability of water supply per sector	0-1	Change in salmon habitat	%	Trend in net revenues	$/time	Trend in household income	$/time
	River systems flow characterization	0-1	Change in bull trout habitat	%	Trend in land under production	acre	Recreational access reservoir	Days of use
Response	Reservoir operation strategies		Habitat restoration projects		Subsidy for irrigation		None	

5.3.2 Upper Bhima Basin (UBB), Maharashtra, India

Background: The UBB background is derived from the Needs Assessment Report for establishing decision support software to manage water resources in the basin (DHI 2009) supplemented by other sources that are referenced.

The UBB originates at Bhimashankar in Ambegaon Taluka in Western Ghats and travels 275 km to Ujjani Dam where it has a drainage area of 14,712 km^2 (Figure 18). The basin has four subbasins: the main Bhima, Mula, Mutha, and Ghod Rivers. Geographically, the basin can be divided into western, central, and eastern zones. The western zone (Sahyadri Hills) is located along the eastern flank of the Western Ghats and ranges in elevation between 700 to 1,300 m amsl. The terrain is extremely rugged with steep slopes, clear cut ridges, and deep ravines. The central zone consists of smaller chains of hills surrounding the plains. In the eastern zone, the table lands become lower and more broken, often little more than rolling uplands and the broader and more level valleys.

The Bhima River and its tributaries take shape in the high rainfall region of the Sahyadri Hills. Across the UBB, the average annual rainfall is 700 mm. The rainfall generally decreases from west to east with three regions of varying rainfall: the extreme western region of heavy annual rainfall (2,300 mm), the foothill region where annual rainfall is moderate (800 to 1,000 mm) and the central and eastern region of lowest annual rainfall (400 to 600 mm). Within the year, 85% of the annual rainfall occurs during Southwest Monsoon from June to September, 11% of the annual rainfall comes during the Northeast Monsoon from September to December, and 4% of the annual rainfall as local storms after December.

In general, water use in the basin is characterized by industrial, municipal, and agricultural in the Western Ghats and moving progressively towards agricultural and domestic eastward in the UBB. In the western portion of the UBB, the primary municipal water use is in the Cities of Pune and Pimpri-Chinchwad with 2011 populations of 5.1m and 1.7m respectively. The city populations are growing rapidly with a 38% increase in the population of Pune between the 2001 and 2011 censuses (http://pibmumbai.gov.in). Industrial uses include the Central Government ammunition factory, pharmaceutical companies, car factories, and other industries. Forests, primarily occurring in the Western Ghats, cover 10.1% of the basin. Agricultural use in the basin makes up 76.3 % or 1,122,000 ha, of which 64.8% are under irrigation. Crops are largely grown during the season of Kharif (June to October) and Rabi (November to March) though limited cultivation occurs during the summer months. Primary crops grown in the basin include jowar, bajra, sugar cane, wheat, bananas, grapes, and vegetable.

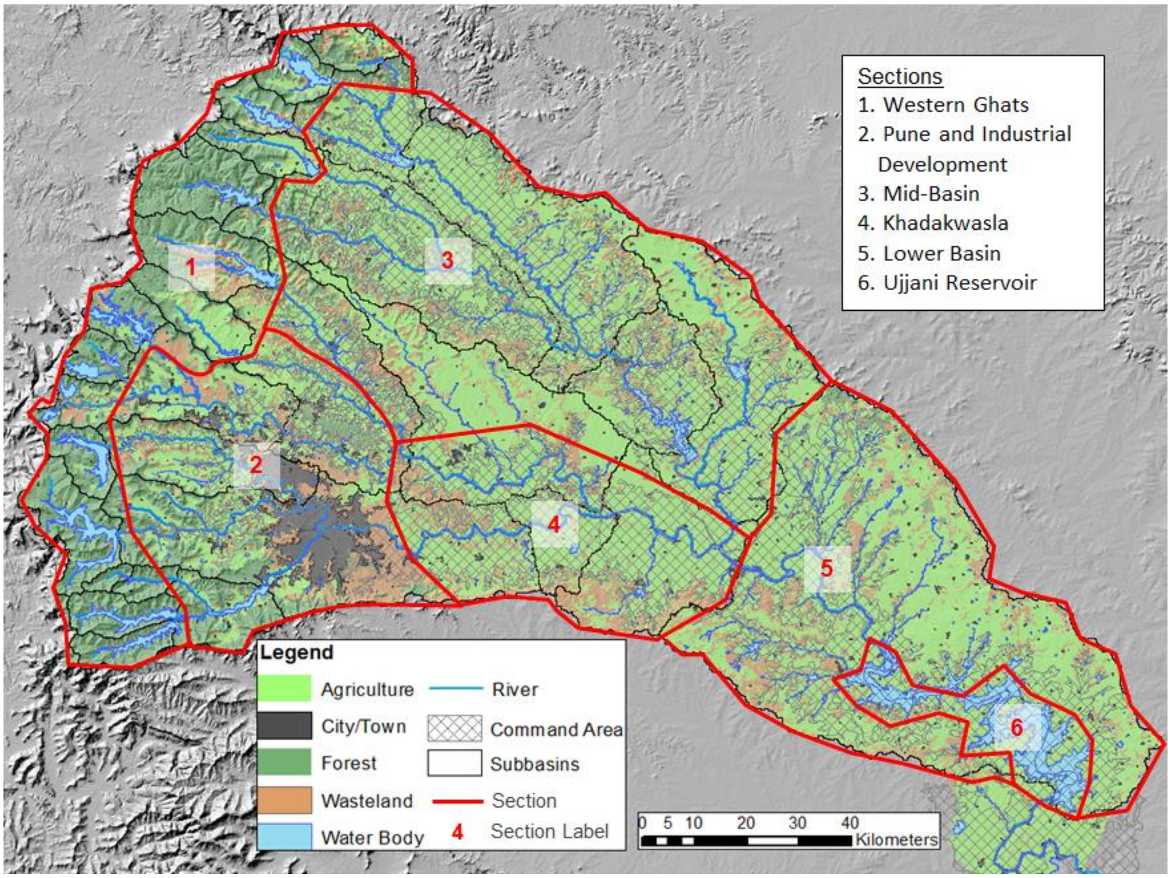


Figure 18. Sectional delineation of the Upper Bhima River Basin used in the RBAF-CT screening. Flow in the basin is from West to East.

Reservoir releases are managed by the Government of Maharashtra Basin Authority. Upstream of the Ujjani Reservoir, 18 projects, originally designed to hold runoff from the Western Ghats for irrigation use in the eastern zone during the non-monsoon period, store greater than 17.4 MCM. Since the development of these projects, municipal and industrial demands have greatly increased and now receive a significant portion of the water supply. In addition, the growth of settlements along the river systems has increased the need for flood protection. Six hydropower projects have a total installed capacity of 318 MW. The Khadakwasla Reservoir supplies water to a large command area with the Chaskaman, Bhama Askhed, Dimbhe, Ghod, Panshet, Warasgaon, Manikdoh, Pawana, Pimpalgaon Joge, Temghar, Wadaj, Yedgaon reservoirs supplying minor command areas. Command areas are regions that receive supplemental irrigation water from a reservoir. In Maharashtra, the state operates the reservoirs and distributes water within the command areas. Ujjani Reservoir, the downstream boundary of the UBB, was constructed in 1980 to supply drinking water and agriculture, as well as provide flood protection to downstream communities, including the pilgrimage city of Pandharpur (Paranjpye & Dandekar 2012).

The UBB is underlain by the Deccan Trap basalts with thin overlying soils. Groundwater is present under shallow unconfined or semi-confined conditions in the mantle of local alluvium, laterite and weathered upper portion of the basalts (Surinaidu et al. 2012). The maximum depth of useful quantities of groundwater is usually limited to about 100 m (Limaye 2010). Across the UBB, recharge rates are highly spatially variable as a function of topography, storm duration, and soil thickness. Water level trends in observation wells indicate that aquifer recharge occurs following prolonged periods of rainfall (Surinaidu et al. 2012).

In command areas, groundwater is used to augment insufficient surface flows during failed monsoons and later in the irrigation season. In the areas outside of command areas (areas receiving water from reservoirs), few options are available for water managers to regulate water use. Tanks (a.k.a. ponds) and check dams are used to store surface water for direct use or infiltration to groundwater. Once these sources have been depleted, groundwater from dug and bore wells is used to supply drinking and irrigation water. For many domestic and village supplies, groundwater is the primary source. The amount of available groundwater is a function of aquifer storage and infiltration rate dictated by the underlying geologic rock type (Surinaidu et al. 2012). Depth to groundwater and recharge rate varies around the basin. In some watersheds, groundwater has limited availability and, where available, has the potential of being over-exploited as there are no enforced restrictions: water is free and power is cheap. Thus to extract groundwater an individual must just have money to dig a borehole deep enough to reach the groundwater. In 2004, of the 65 subcatchments analyzed in Maharashtra's GEC 97 analyses, 13 subcatchments were declared "semi-critical" and 6 "overexploited". These overexploited basins fall within Section 3 and the semi-critical in Sections 3 and 4 in Figure 18.

Freshwater ecosystems in the UBB are primarily riverine and stillwater habitats of lakes and wetlands associated with the reservoirs. These freshwater ecosystems host fish species that support subsistence and local fishing industries. Though beneficial to stillwater species in the backwater, the dams in the UBB have altered the downstream hydrograph and characteristics of the flow regime in the rivers which has been compounded by increasing pollution. The consequences to the stream ecology has been dramatic with a decline from 114 fish species documented in the 1940's, in a recent survey, 48 were not found and 18 are believed locally extinct (Paranjpye & Dandekar 2012). The decrease in number of species and fish populations has had an adverse effect on subsistence fisherman reliant on the river fishing. An ecosystem of particular note is the wetlands created in the 40 km^2 backwaters from Ujjani Reservoir. This large wetland hosts visits from 100–150 species of flamingos and cormorants (ibid) and, along with the reservoir, is home to many species of fish. The large population of birds has created an ecotourism opportunity for wildlife viewing.

Water Resource Issues:

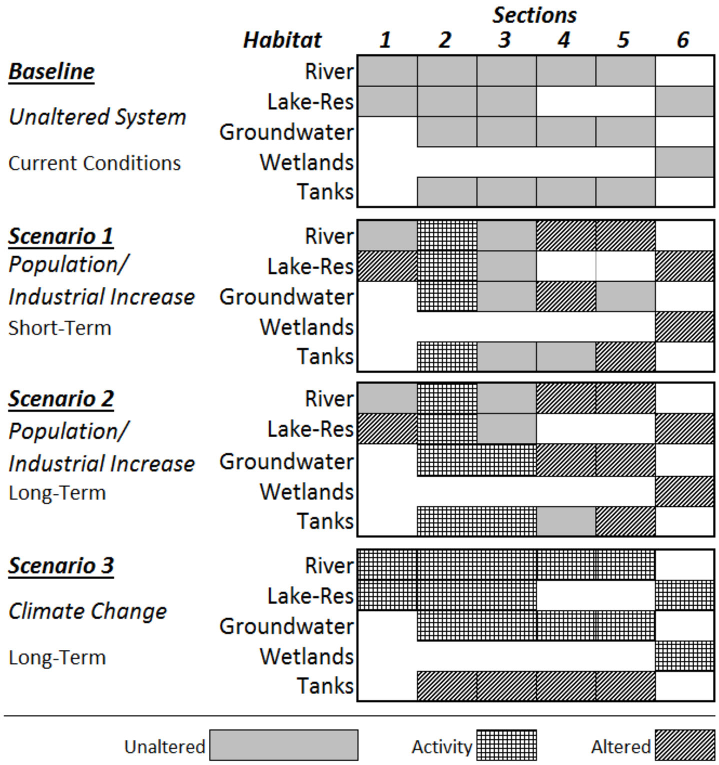
1. Given the uneven distribution of rainfall in the basin, challenges exist for water distribution management. Abundant rainfall in the Western Ghats, falling during the southwest monsoon, is stored in a series of reservoirs for use throughout the duration of the year. Historically, these reservoirs were designed to support irrigation in the central and eastern portions of the basin, but a large quantity of domestic and industrial water is required for the Cities of Pune, Pimpri-Chinchwad, and Solapur. These needs are currently met through surface water from the Temghar and Pawana Reservoirs, shorting the downstream irrigation requirements. River systems without reservoirs exhibit limited storage; therefore supply is limited during non-monsoon periods within the year. Within the western portion of the basin, the issues are reservoir operations, water distribution among different water sectors, and pollution associated with municipal and industrial effluent.
2. Water inflow to Ujjani Reservoir is polluted. In the upstream catchment, 68% of the project area is under surface water irrigation and due to heavy use of chemical fertilizers, groundwater quality is affected. This is further aggravated by the industrial and domestic development upstream within the catchment.
3. Climate change will likely have an impact, but the direction of change in the UBB is uncertain (Surinaidu et al. 2013). Kumar et al. (2006) predict a 20% rise in summer monsoon rainfall across the Indian subcontinent, while Gosain et al. (2006) believe the Krishna Basin (the UBB is in the Krishna Basin) will experience a 20% decrease in precipitation resulting in a 30-50% reduction in runoff. In the drought prone eastern zone, repetitive failure of the southwest monsoon is a serious concern. This will impact reservoir operations and water management in

drought prone areas. For this case study, a 20% decrease in precipitation in the UBB is assumed.

4. Indiscriminate, uncoordinated and unregulated groundwater withdrawal through irrigation bore wells is occurring on a large scale leading to over exploitation of groundwater.
5. Water management has had a severe impact on ecosystems. The forest area in the basin has fallen from approximately 20% in 1950 to approximately 10.1% in 2006 resulting in changes in runoff quantity and timing. The alteration of the hydrological regime in rivers by dams has resulted in a decrease in fish species diversity and population abundance. A recent study conducted in Pune indicated that the diversity of nearly all aquatic and amphibian life forms has reduced drastically (Paranjpye & Dandekar 2012).

Methodology: To assess the influence of increased municipal and industrial water demand and climate change in the UBB, the RBAF-CT was used to screen the relevant freshwater habitats, EGS, and EGS Info to consider for analysis supporting IWRM of the basin. The four scenarios screened include (Figure 19):

- Baseline Scenario: Current status of water resources across the UBB,
- Scenario 1: Population/industrialization increase in Section 2 (short-term, 5-10 year time horizon),
- Scenario 2: Population/industrialization increase in Section 2 (long-term, 30+ year time horizon) where demand in Section 2 is demanding near the total storage capacity of the upstream reservoirs. This scenario also includes expansion of irrigation in Section 3,



	Habitat	***Sections*** ***1***	***2***	***3***	***4***	***5***	***6***
Baseline	River	▒	▒	▒	▒	▒	
Unaltered System	Lake-Res	▒	▒	▒			▒
	Groundwater		▒	▒	▒	▒	
Current Conditions	Wetlands						▒
	Tanks		▒	▒	▒	▒	
Scenario 1	River	▒	▦	▒	▨	▨	
Population/	Lake-Res	▨	▦	▒			▨
Industrial Increase	Groundwater		▦	▒	▨	▒	
Short-Term	Wetlands						▨
	Tanks		▦	▒	▒	▨	
Scenario 2	River	▒	▦	▒	▨	▨	
Population/	Lake-Res	▨	▦	▒			▨
Industrial Increase	Groundwater		▦	▦	▨	▨	
Long-Term	Wetlands						▨
	Tanks		▦	▦	▒	▨	
Scenario 3	River	▦	▦	▦	▦	▦	
Climate Change	Lake-Res	▦	▦	▦			▦
	Groundwater		▦	▦	▦	▦	
Long-Term	Wetlands						▦
	Tanks		▨	▨	▨	▨	

Unaltered ▒ Activity ▦ Altered ▨

Figure 19. For the baseline and 3 scenarios, mapping of habitat types per basin sections in the Upper Bhima Basin. The spatial delineation of the six sections is depicted in Figure 18.

- Scenario 3:

- Scenario 3: Climate change (long-term, 30+ year time horizon) assuming a 20% decrease in precipitation and increase in surface temperatures across the UBB. This represents the more water restrictive scenario of the climate change predictions.

Spatially, the UBB has been divided into six sections based on the landscape physiography, landuse, the “critical” and “over exploited” condition of groundwater according to the GEC 97 assessment (GoM 2004), and locations of drivers and pressures. The delineated sections are the 1) Western Ghats, 2) Pune and Industrial Development, 3) mid-UBB, 4) Khadakwasla Command Area, 5) lower UBB, and 6) Ujjani Reservoir (Figure 18). The Western Ghats section is the source of much of the water supply in the basin, characterized by abundant rain, forest, reservoirs, and steep terrain. The Pune and Industrial Development section, located in the Western Ghats foothills, encompasses the largest city in the UBB and is currently undergoing increased pressure of industrialization and population expansion, creating ever greater demand for water resources. The mid-UBB, Section 3, is located in the Western Ghats foothills north of the Section 2. This area is primarily agricultural, growing crops in both command and non-command areas. For non-command areas, tanks and groundwater are used for irrigation. Section 4 is largely agricultural and experiences lesser rainfall so irrigation is required. Irrigation water in command area is primarily supplied from reservoirs in the Western Ghats, upstream of the municipality and industrial developments in section 2, and groundwater. For non-command areas, tanks and groundwater are used for irrigation. The section hosts the Khadakwasla Command Area. Sections 5 represent the lower basin command and non-command agricultural areas receiving water as in Section 4. The backwater of Ujjani Reservoir is represented in Section 6.

Screening Results: *Baseline conditions* - The significant freshwater habitats in the UBB include *river systems, reservoir, ponds/tanks, groundwater,* and *wetlands* (Figure 19). In the Western Ghats, the abundant rainfall fills the *river systems* conveying the water into the reservoirs and to downstream users. Along its journey, water in *river systems* becomes polluted by municipal and industrial effluent, agricultural return flow, and storm water runoff laden with pollutants and trash. The EGS provided by the *river system* include freshwater supply for human consumption and diversion for production, food, water purification, aesthetic value, components of the hydrologic and nutrient cycles, and aquatic habitat supporting biodiversity and healthy ecosystems (Table 14). The constituents of human well-being the *river system* influences are a safe environment, access to EGS, access to resources for a viable livelihood, adequate food and nutrition, clean and safe drinking water and realization of aesthetic and recreational values.

Reservoir construction in the UBB was intended to store precipitation falling in the Western Ghats to be metered out throughout the Rabi and Summer seasons in support of irrigation. Increasingly, water storage in the *reservoirs* is being used to satisfy growing urban and industrial demands as well as for flood control around the city of Pune. The lentic habitat created in the impoundments has led to fisheries that support both subsistence and commercial fishing. Finally, watercraft use the reservoirs to transport people and goods. Thus, the EGS of the *reservoir/lake* habitats provide provisioning services of freshwater supply for human consumption and production, navigation, and food source; regulating services of water regulation and storm protection; cultural services for recreational use and aesthetic value, and supporting services of aquatic habitat promoting biodiversity and healthy ecosystems. The constituents of human well-being supplies by the *reservoir/lake* habitat are a safe environment, resilience to ecological shock, access to EGS, access to resources for a viable livelihood, adequate food and nutrition, avoidance of disease, clean and safe drinking water, and realization of aesthetic and recreational values (Table 14).

Similar to reservoirs, tanks locally store precipitation for use during the Rabi and summer season for irrigation. In addition, infiltration from the tanks recharges groundwater which provides storage for use as domestic and irrigation water. In addition, tanks associated with local groves of trees are considered holy sites (Paranjpye & Dandekar 2012). The EGS provided by tanks includes freshwater supply for production, water regulation for supply throughout the year, spiritual and religious value, and components of the hydrologic and nutrient cycles. The constituents of human well-being supplies by the *tanks* are a safe environment, access to EGS, access to resources for a viable livelihood, adequate food and nutrition, avoidance of disease, clean and safe drinking water, realization of aesthetic and recreational values, and ability to express cultural and spiritual values (Table 14).

Groundwater from hand dug and bore wells supply drinking water for villages and individual houses as well as supplementing surface water irrigation in both command and non-command areas. The EGS from *groundwater* are primarily provisioning freshwater supply for human consumption and production, water regulation for supply throughout the year, and components of the hydrologic and nutrient cycles. The constituents of human well-being supplies from *groundwater* are a safe environment, access to EGS, access to resources for a viable livelihood, adequate food and nutrition, avoidance of disease, and clean and safe drinking water (Table 14).

The *wetlands* habitat, occurring in Section 6, has been created from the Ujjani Reservoir backwater. The primary EGS provided by the *wetlands* are provisioning food, water purification, cultural ecotourism, and habitat supporting biodiversity for stillwater or lentic conditions. The constituents of human well-being influenced by the *wetlands* are access to resources for a viable livelihood through fishing and ecotourism, cleaner water by water purification, and realization of aesthetic and recreational values. While the *wetlands* provide storage and storm protection, these EGS and the associated constituents of human well-being have not been considered as they have already are accounted for in the Ujjani Reservoir (*lake/reservoir*) habitat.

<u>*Scenarios 1, 2:*</u> Increased demand from growing population and industrialization in both the short- and long-term time frames will alter the water allocation timing, quantity, and quality in all the sections with more pronounced impacts in Scenario 2. Hydrologically, it is predicted that the increased demand in Section 2 will:

- influence the timing and quantity of dam releases in Sections 1 and 2 to meet the increase municipal and industrial demand;
- alter river flows quantity, timing, and quality in Sections 2, 4, 5, and 6 through increased diversion, changes in reservoir releases, modification to runoff patterns from changed landuse, and degraded river water quality due to increased effluent and agricultural runoff; and
- increase groundwater use in command areas in Sections 4, 5, and 6 to account for supply shortages due to the increased municipal and industrial use in Section 2.

For Scenario 2, growing irrigated area in Section 3 will also increase groundwater use in both command and non-command areas. For Sections 2 and 3, tanks storage will likely be used faster as demands increase, but will see no change tank operations in Sections 4 and 5. Due to the changes in Sections 1-5, Ujjani Reservoir (Section 6) will experience a change in the inflow water quality, quantity, and timing as upstream users deplete the amount of inflow, alter return flow quantity and timing and increase pollution from municipal and industrial sources and agricultural lands.

The predicted hydrological changes will impact the freshwater habitats and corresponding EGS throughout the basin (Table 17). Given the initial demand increase in Scenario 1, the provisioning and regulating services supplied by reservoirs will likely change, but how much operations change to account for increased water demand is uncertain. If the pattern and magnitude of reservoir levels changes due to adjusted operational strategies, the reservoir cultural and supporting services may decrease as aesthetic, recreational, and habitat conditions. For Scenario 2, the RBAF-CT screening predicts that reservoir conditions will decrease in provisioning and regulating services supplied by reservoirs as the demand may exceed the capacity of supply. The changes are similar to Scenario 1, but more pronounced in the trend of the EGS. The overall change to constituents of human well-being is negative in terms of security (safe environment, access to EGS), ability to make a living, and health (adequate nutrition, avoidance of disease, clean and safe drinking water).

Population and industrialization increases in Section 2 will change the hydrologic regime and degrade water quality in river systems in Sections 2, 4, and 5 (Table 17). With these changes comes a decrease in the provisioning, regulating, and supporting services. Less water in rivers will decrease the freshwater available for freshwater consumption and production. The decrease in flow will also translate to less ability for water purification as the pollutant transport capacity of the rivers is decreased as the volume of receiving water is less. The overall change to constituents of human well-being is negative in terms of security (safe environment, access to EGS), ability to make a living, and health (adequate nutrition, avoidance of disease, clean and safe drinking water).

As the change in hydrologic regime and decrease in water quality in the river and reservoir system will negatively impact fish populations, the provisions services of food for subsistence fishing and freshwater provisioning for commercial fishing will decrease. The impact is predicted to be slightly negative in Scenario 1 and strongly negative in Scenario 2. The overall change to constituents of human well-being is negative in terms of security (resilience to ecological shock, access to EGS), ability to make a living, and health (adequate nutrition).

The provisions and water regulating services of tanks and groundwater habitats will decrease in response to greater water demands. Thus, in Sections 2 and 3 where the primary development will occur, the EGS of freshwater consumption, freshwater production, and water regulation will decrease (Table 17). Regarding groundwater for freshwater consumption, freshwater production will likely also decrease in the command areas in Sections 4 and 5, as groundwater abstraction has supplanted reservoir releases as the primary irrigation source. The overall change to constituents of

Table 17. EGS and constituents of human well-being (HWB) trends resulting from the RBAF-CT screening of the UBB. “B” is baseline and “S1”, “S2”, and “S3” are Scenarios 1 to 3, respectively.

		EGS Trend				Impacted Zones	HWB Trend			
Habitat	**EGS**	**B**	**S1**	**S2**	**S3**		**B**	**S1**	**S2**	**S3**
Section 1: Riverine		**–**	**–**	**–**	**↘**	2,3,4,5,6,X	**–**	**–**	**–**	**↘**
Provisioning	Freshwater Consumption, Production, Food	–	–	–	↘	2,3,4,5,6,X	–	–	–	↘
Cultural	Aesthetic, Recreation	–	–	–	↘	X	–	–	–	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	–	–	↘	2,3,4,5,6,X	–	–	–	↘
Reservoir		**–**	**↔**	**↘**	**↓**	2,3,4,5,6,X	**–**	**↔**	**↕**	**↕**
Provisioning	Freshwater Consumption, Production, Navigation, Food	–	↔	↘	↓	2,3,4,5,6,X	–	↔	↘	↘
Regulating	Water Regulation, Storm Protection	–	↔	↕	↓	2,3,4,5,6,X	–	↔	↕	↕
Cultural	Aesthetic, Recreation	–	↘	↘	↘	X	–	↔	↘	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↓	↓	2,3,4,5,6,X	–	↕	↕	↘
Section 2: Riverine		**–**	**↓**	**↓**	**↘**	**4,5,6,X**	**–**	**↘**	**↘**	**↓**
Provisioning	Freshwater Consumption, Production, Food	–	↘	↓	↘	4,5,6,X	–	↘	↘	↓
Cultural	Aesthetic, Recreation	–	↘	↓	↘	X	–	↔	↔	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↓	↓	4,5,6,X	–	↕	↕	↘
Reservoir		**–**	**↔**	**↘**	**↓**	**4,5,6,X**	**–**	**↘**	**↓**	**↘**
Provisioning	Freshwater Consumption, Production, Navigation, Food	–	↔	↘	↓	4,5,6,X	–	↔	↘	↘
Regulating	Water Regulation, Storm Protection	–	↔	↘	↓	4,5,6,X	–	↔	↕	↕
Cultural	Aesthetic, Recreation	–	↘	↘	↘	X	–	↘	*?*	*?*
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↓	↓	4,5,6,X	–	↘	↓	↓
Ponds/Tanks		**–**	**↔**	**↓**	**↘**	**4,5,6,X**	**–**	**↘**	**↓**	**↘**
Provisioning	Freshwater Consumption, Production	–	↔	↓	↘	4,5,6,X	–	↘	↓	↘
Regulating	Water Regulation	–	↔	↓	↘	4,5,6,X	–	↘	↓	↘
Supporting	Hydrologic& Nutrient Cycle	–	↕	↕	↘		–	↕	↕	↘

		EGS Trend				Impacted Zones	HWB Trend			
Habitat	**EGS**	**B**	**S1**	**S2**	**S3**		**B**	**S1**	**S2**	**S3**
Groundwater		–	↘	↓	↓		–	↘	↓	↓
Provisioning	Freshwater Consumption, Production	–	↘	↓	↓		-	↘	↓	↓
Regulating	Water Regulation	–	↘	↓	↓		-	↘	↓	↓
Section 3: Riverine		–	–	–	↘	**5,6,X**	–	–	–	↓
Provisioning	Freshwater Consumption, Production, Food	–	–	–	↘	5,6,X	–	–	–	↓
Cultural	Aesthetic, Recreation	–	–	–	↘	X	–	–	–	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↘	↓	5,6,X	–	↓	↓	↘
Reservoir		–	–	↘	↓	**5,6,X**	–	–	↘	↘
Provisioning	Freshwater Consumption, Production, Navigation, Food	–	–	↘	↓	5,6,X	–	–	↘	↘
Regulating	Water Regulation, Storm Protection	–	–	↘	↓	5,6,X	–	–	↘	↕
Supporting	Natural Cycles*, Habitat & Biodiversity	–	–	↓	↓	5,6,X	–	–	↓	↓
Ponds/Tanks		–	–	↘	↘	**5,6,X**	–	–	↘	↘
Provisioning	Freshwater Consumption, Production	–	–	↘	↘	5,6,X	–	–	↘	↘
Regulating	Water Regulation	–	–	↘	↘	5,6,X	–	–	↘	↘
Supporting	Hydrologic& Nutrient Cycle	–	–	↕	↘		–	–	↕	↘
Groundwater		–	–	↓	↓		–	–	↓	↓
Provisioning	Freshwater Consumption, Production	–	–	↓	↓		–	–	↓	↓
Regulating	Water Regulation	–	↘	↓	↓		–	–	↓	↓
Section 4: Riverine		–	↓	↓	↘	**5,6,X**	–	↘	↘	↓
Provisioning	Freshwater Consumption, Production, Food	–	↘	↓	↘	5,6,X	–	↘	↘	↓
Cultural	Aesthetic, Recreation	–	↘	↓	↘	X	–	↔	↔	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↓	↓	5,6,X	–	↕	↕	↘
Ponds/Tanks		–	–	–	↘	**5,6,X**	–	–	–	↘
Provisioning	Freshwater Consumption, Production	–	–	–	↘	5,6,X	–	–	–	↘

Habitat	EGS	EGS Trend				Impacted Zones	HWB Trend			
		B	S1	S2	S3		B	S1	S2	S3
Regulating	Water Regulation	–	–	–	↘	5,6,X	–	–	–	↘
Supporting	Hydrologic& Nutrient Cycle	–	–	–	↘		–	–	–	↘
Groundwater		**–**	**↘**	**↓**	**↓**		**–**	**↘**	**↘**	**↓**
Provisioning	Freshwater Consumption, Production	–	↘	↓	↓		-	↘	↘	↓
Regulating	Water Regulation	–	↘	↓	↓		-	↘	↘	↓
Section 5: Riverine		**–**	**↘**	**↘**	**↓**	**6,X**	**–**	**↘**	**↘**	**↓**
Provisioning	Freshwater Consumption, Production, Food	–	↘	↘	↓	6,X	–	↘	↘	↓
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↘	↘	↓	6,X	–	↕	↕	↘
Ponds/Tanks		**–**	**–**	**–**	**↘**	**6,X**	**–**	**–**	**–**	**↘**
Provisioning	Freshwater Consumption, Production	–	–	–	↘	6,X	–	–	–	↘
Regulating	Water Regulation	–	–	–	↘	6,X	–	–	–	↘
Supporting	Hydrologic& Nutrient Cycle	–	–	–	↘	6,X	–	–	–	↘
Groundwater		**–**	–	–	**↓**		**–**	**↘**	**↘**	**↓**
Provisioning	Freshwater Consumption, Production	–	–	–	↓		-	↘	↘	↓
Regulating	Water Regulation	–	↘	↓	↓		-	↘	↘	↓
Section 6: Reservoir		**–**	**↔**	**↘**	**↓**	**X**	**–**	**↘**	**↓**	**↘**
Provisioning	Freshwater Consumption, Production, Food	–	↔	↘	↓	X	–	↔	↘	↘
Regulating	Water Regulation, Flood Protection	–	↔	↘	↓	X	–	↔	↕	↕
Cultural	Aesthetic, Recreation	–	↘	↘	↘		–	↘	?	?
Supporting	Hydrologic Cycle	–	↘	↓	↓		–	–	↓	↓
Wetlands		**–**	**↘**	**↓**	**↓**		**–**	**↘**	**↓**	**↓**
Provisioning	Food	–	↘	↓	↓		–	↘	↓	↓
Regulating	Water Purification	–	↘	↓	↓			↘	↓	↓
Cultural	Aesthetic, Recreation	–	↔	↘	↘		–	↔	↘	↘
Supporting	Natural Cycles*, Habitat & Biodiversity	–	↕	↕	↓		–	↘	↓	↓

human well-being is negative for security (safe environment, access to EGS), ability to make a living, and health (adequate nutrition, avoidance of disease, clean and safe drinking water).

Ujjani reservoir and wetlands will receive the impacts of all the upstream activities in the form of an altered hydrograph and degraded water quality. The impacts to the lake's wetlands and reservoir habitats will be to reduce provisioning, regulating, cultural, and supporting services. Depending on the operations of the reservoir, the provisioning services of freshwater consumption and production may be reduced in Scenario 1, but will likely decrease with greater inflow depletion in Scenario 2. Regulating services of water regulation will decrease with greater inflow depletion, but downstream flood protection will increase. As the change in operations and decrease in water quality increase, the wetlands and lake habitats will be negatively influenced and thus decrease supporting services of aquatic habitat, biodiversity and the regulating service of the water purification of nutrient uptake by wetlands plants. The negatively impacted wetland habitat will decrease ecotourism associated with viewing of the large bird populations that are resident at the Ujjani Wetland throughout the year. The overall change to constituents of human well-being is negative for security (safe environment, resilience to ecological shock, access to EGS), ability to make a living, health (adequate nutrition, avoidance of disease, clean and safe drinking water), and good social relations (realization of aesthetic and recreational values).

Scenario 3: The predicted 20% reduction in precipitation coupled with rising temperatures associated with climate change is projected to create a shortage of water given the demand in the UBB. Hydrologically, less precipitation will decrease surface runoff to fill rivers, reservoirs, and tanks as well as infiltration to recharge groundwater. Assuming demands remain constant or increase, reservoirs will be drawn down further and more frequently with less likelihood of refilling in drier years. River base flows will decrease during non-monsoon periods. Less available storage in reservoirs and tanks coupled with decreased base flows will lead to greater groundwater abstraction, resulting in deeper groundwater levels. As Ujjani Reservoir's levels decrease, wetlands around the perimeter of the reservoir will decrease in areal expanse and be inundated less frequently.

The result of climate change is that all sections and habitats will experience a decrease in ecosystem function and thus a corresponding drop in provisioning, regulating, cultural, and supporting services and general human well-being (Table 17). Less water in rivers, reservoirs, and tanks equates to a decrease in the available freshwater for consumption and production. Decrease of reservoir and tank inflows will decrease the water regulation services as reservoirs and tanks will have a higher likelihood of not filling during the monsoon. The benefit to increased drawdown during dry periods is greater flood protection as additional space in reservoirs is available to store floodwaters. Decreasing river base flows will also decrease the ability for rivers to carry away pollution, thus water purification services will decrease. The overall change to constituents of human well-being is negative for security (safe environment, access to EGS), ability to make a living, and health (adequate nutrition, avoidance of disease, clean and safe drinking water).

Deeper groundwater levels will decrease available freshwater for consumption and production. The extra price of drilling deeper wells and cost of pumping water from deeper depths will decrease human well-being factors of access to EGS, ability to make a living, and clean and safe drinking water (Table 17). The overall change to constituents of human well-being is negative for security (safe environment, resilience to ecological shock, access to EGS), ability to make a living, health (adequate nutrition, avoidance of disease, clean and safe drinking water), and good social relations (realization of aesthetic and recreational values).

With a change in reservoir operations, the change in hydrologic regime, and decrease in water quantity and quality in the river and reservoir systems, habitat for aquatic and migratory species will be negatively impacted in the river, reservoir, and wetland habitats. Degrading aquatic habitat will decrease fish populations, thus negatively impacting the provisions services of food for subsistence fishing and freshwater provisioning for commercial fishing (Table 17). Reducing the areal expanse of the Ujjani wetlands and degraded water quality will decrease the number of birds using the wetland and decrease the recreational services of ecotourism. The overall change to constituents of human well-being is negative for security (safe environment, resilience to ecological shock, access to EGS), ability to make a living, health (adequate nutrition, avoidance of disease, clean and safe drinking water), and good social relations (realization of aesthetic and recreational values).

Indicator List: The pressure indicators identified are decrease in precipitation, increase in evapotranspiration (ET), increase in water demand and groundwater use (hydrological), industrial expansion (economic), and increase in drinking water supply and sanitation systems (economic and social). Increased contaminants of concern (CoCs) and change in flow regime are listed as pressures to the ecological system, but are the byproducts from the hydrologic, economic, and social systems.

State indicators identified characterize the behavior of the pressures (Table 18). For hydrology, the state indicators are water demand, delivery, and deficit to water sectors and drinking water, flow in the river systems, fate and transport of CoCs, reservoir level and storage, and groundwater characteristics. Ecology focuses on the state of the fish stocks in reservoir and the river systems along with quality of the wetlands. Economic state variables focus on the revenues generated per sector and the cost of supplying drinking water and sanitation to the increased populations. For the social system, the state indicators focus on safe delivery of water for consumption and sanitation, water available to support religious sites, ability for commercial fishermen to make a living, and ecotourism.

Impact indicators include trends, reliability, and average changes in values over the period. Hydrological impact indicators focus on the amount of water and reliability of delivery per sector, change in reservoir storage and groundwater supply reliability, and trends in water quality. Ecological impact indicators focus on trends in the wetlands function and fish stocks in rivers and reservoirs. The revenues generated per sector, the cost of delivery of drinking water, and the employee’s incomes per sector are recommended for characterizing the economic impacts. For the social system, the impact indicators focus on the percentage of the population with safe delivery of water for consumption and sanitation, reliability of water to support religious sites, and the ability for commercial fishermen to make a living.

5.4 Discussions and Limitations

Important elements of effective frameworks and DSS supporting IWRM analysis include the ability to frame water resource issues in the participatory setting; be capable of evaluating a range of decisions, from simple to complex; identify analyses and indicators to employ given water resource issues; support the organization of input and output data in evaluating alternatives; produce reliable and transparent output that is linked to relevant indicators used in the evaluating policies and decisions directly or indirectly affecting water resources in a basin; and provide a flexible structure to accommodate evolution of decisions, issues, data, scenarios, and models (Millington et al. 2011). Towards these elements, the RBAF-CT assists in conceptualizing a range of water resource issues by predicting how the spatiotemporal state of the water will change the EGSInfo in response to drivers and pressures as well as selecting the applicable indicators for evaluating changes in the hydrological, ecological, social, and economic conditions in a basin. The RBAF-CT’s versatility in framing water resource issues and addressing a wide range of decisions lies in the flexibility of delineating the basin into sections; standardization of sections linking a comprehensive list of freshwater ecosystems, EGS, and EGSInfo; guidance in potential changes of the EGSInfo from 8 Driver Templates characterizing typical water resource issues; presentation of a large suite of indicators for evaluating the water resource issues; and post-processing tools in Microsoft Excel (a widely available and low-cost platform) for culling extraneous EGSInfo and focusing on indicators relevant to the basin. These elements are illustrated in the case studies of the LRB and UBB: basins of different physical, hydrological, ecological, economic, and cultural characteristics.

Delineating the basin into sections allows flexibility in building the RBAF-CT analysis to determine how the drivers and pressures of change will spatially have impact. In the LRB example, the basin is delineated into 5 sections with two sections representing active sections (Section 2 for the sprinkler conversion and Section 4 for the proposed reservoir development (Figure 16)). This configuration permits the RBAF-CT to not only target activities along the mainstem Lemhi River, but also highlight activities in tributaries such as the proposed Hayden Creek Reservoir in Scenarios 3-4. Similarly in the UBB, Section 2 will experience increasing water demand through population and industrial growth (Figure 18). Isolating the activity to basin delineation allows for the influence of this activity to be determined for Sections 2 and 4, but isolated from the impacts to the Western Ghat foothills to the north. Furthermore, when sections are labeled as unaltered, active, and altered, the impact extent associated with the driver and pressures of change outside the active sections are shown (Figure 17, Figure 19). Some alterations outside the active section are apparent, such as the changing of the hydrologic regime in the river system downstream of a reservoir in both the LRB Section 5 and UBB Sections 2, 3, 4, 5, and 6. However, not all the altered sections identified by the RBAF-CT labeling of sections exercise are apparent. In the UBB, Section 2 (population growth) may have an impact on upstream reservoir conditions in Section 1 as the quantity and timing of releases may be altered to meet the new downstream demands. Thus, following the delineation and categorization of sections in the basin, users have a spatial overview of where pressures and drivers are active and how their impacts influence other basin sections.

Within each section is a comprehensive list of freshwater habitats and the EGS that have been developed by the MA (2003) and modified in Chapter 3. Connecting the relevant EGSInfo to EGS provides users a full spectrum of options to consider when evaluating a water resources problem and increases the prominence that the environment plays in human well-being (Daily 1997, MA

2003). Having a comprehensive list on EGS that is based on an internationally developed framework increases the applicability to address water resource problems in a variety of basins. In the LRB and UBB, the RBAF-CT identified the important EGS provided by each freshwater habitat in each section (Table 14). Furthermore, the RBAF-CT was able to identify the important hydrologic indicators, EGS, and constituents of human well-being that was used for each section, freshwater habitat, and EGS. For example, the river system in the LRB is primarily a conveying that supplies water to irrigations, provides habitat for fish, and supports recreational activities. In the UBB, the river system conveys water to irrigations and provides habitat for fish, but also supplies water to municipal and industrial demands, transports pollutions, provides food and a source of income to subsistence and commercial fisherman, and has spiritual value. When all the sections are compiled during post-processing, the relevant freshwater habitats, EGS, and EGSInfo are consolidated to provide an overview of who is using water and for what purpose: greatly aiding in framing the water resource issues. Included in the EGSInfo are the applicable indicators to address the sustainable development of water resources in the basins.

Scenarios provide a further means of framing the water resources issues from a range of decisions. Specifically, scenarios illustrate the impact drivers and pressures have on the hydrologic system, freshwater habitats, EGS, and human well-being in space and time. The use of driver templates guides the user in predicting the change in the hydrologic system, EGS, and human well-being, thus simplifying the development of scenarios. In the LRB, the demand template was applied for irrigation conversion and the infrastructure template was applied for the proposed Hayden Creek Reservoir to illustrate the changes in the active and altered zones within the basin. Sections 2 and 4 had disturbances, but the results show alterations to EGS is Sections 3 and 5 as well. Similarly, the UBB had disturbances in Section 2, but Sections 1, 4, 5, and 6 have alterations to EGS. The climate change scenario predicts changes in all sections. Thus, the RBAF-CT predicts changes it different disturbance type, freshwater habitats, and EGS in basins of different size and regions of the world.

Combining the Output Templates (Table 15, Table 17) with the Indicator Lists (Table 16, Table 18) helps frame and formulate specific analyses of the change in the state of the system. The Output Template provides prediction of the trending direction for EGS to help decision makers and stakeholders understand the breadth of the water resource issues. The Indicator List provides technical members guidance on what to monitor for conveying information to the non-technical members and establish analysis methods for quantitative analysis.

Table 18. Recommended indicators for determining the sustainability of water resource management in the UBB. IoA* is the indices of alteration (Poff et al. 1997).

	Hydrology		Ecologic		Economic		Social	
	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit
Driver	Climate Change		None		Increased industrialization		Increased urban expansion	
Pressure	Decrease precipitation, increase ET	mm	Increase in constituents of concern	mg/l	Industrial expansion: sector		Increased drinking water supply	
	Increase in water demand, municipal and agriculture	Mcm, m^3	Change in flow regime	cms			Increased sanitation requirements	
	Landuse change	Hectares						
	Groundwater use	Mcm, m^3						
State	Surface water runoff	mm/ hectares	Fish populations river system	# fish	Production from irrigation per crops	Tons	Increased flood protection for land change	$
	Groundwater recharge	mm/ hectares	Fish harvested river system	# fish	Land under irrigation	Hectares	% of households served by private wells	%
	Water flow in river system	cms	Fish populations reservoirs	# fish	Groundwater well development cost	₹	Household per capita use per day	%
	Inundation area during peak flow events	Hectares	Fish harvested reservoir	# fish	Pumping power cost	₹	Exposure to water not meeting water quality standards	# people
	Sector users: water delivery-deficiency per time	Mcm/ time	Biodiversity wetlands	# Types species	Cost in water treatment	₹	Population with access to sanitation	# people
	Consumptive use, return flow/sector	Mcm, m^3/s	Wetland inundation area	Hectares	Agriculture revenues/costs	₹	Child mortality under 5	# deaths
	Domestic/municipal water delivery-deficit-source per time	Hectares			Hydropower generation	kW-h	Water borne diseases	# cases
	Fate and transport of constituents of concern	mg/l			Hydropower revenues	₹	Population living on floodplains	# people
	Waste water treatment	Mcm, m^3/s			Commercial fishing revenues	₹	Religious sites access to sufficient water	# days

	Hydrology		Ecologic		Economic		Social	
	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit
	Depth to groundwater	m			Ecotourism revenues	₹	Religious sites access to sufficient water	# days
	Groundwater availability	Mcm, m^3					Ecotourism access	# days
							Access to commercial fishing stocks	# days
							Population relying on commercial fishing	# people
							Government water planning	# plans
Impact	Trend in surface water runoff	mm/ hectares/ time	Trend in wetland size	Hectares/ time	Change in land under production		Access to potable water (%)	# people
	Trend in groundwater recharge	mm/ hectares/ time	Trend in fish populations rivers	#/time	Industrial employment (number of employees)	# people	Access to Sanitation (%)	# people
	Average water supply per sector	Mcm, m^3	Trend in fish populations reservoir	#/time	Agricultural employment (number of employees)	# people	Trend in water quality related health criteria	# cased, # deaths
	Reliability of water supply per sector	%	Change in wetland function		Number of wastewater-treatment facilities needing major investments or recently having undergone such improvement	# plants	Population at risk of inundation	%
	Average drinking water supply	Mcm, m^3					Religious sites access to sufficient water	%
	Reliability of drinking water supply	%					Commercial fishing stocks reliability	%
	River systems flow characterization	IoA*					Access to ecotourism sites	%

	Hydrology		Ecologic		Economic		Social	
	Indicator	Unit	Indicator	Unit	Indicator	Unit	Indicator	Unit
	Trend in constituents of concern	mg/l/time					Equity of water distribution	%
	Average depth to groundwater	m					Adequacy of time horizon of governmental planning efforts	
	Trend in depth to groundwater	m/time						
	Average groundwater availability	Mcm, m^3						
	Trend in groundwater availability	Mcm/ time						
	Reservoirs likely to fill	%						
	Reliability of water supply to religious locations	%						
Response	Water conservation policies		Environmental releases from reservoirs				Landuse planning	
			Habitat restoration projects				WUA associations	
			Wetlands protection areas					

The RBAF-CT flexible structure accommodates evolution of decisions, issues, and scenarios. The modular use of sections to spatially define the active drivers and pressures associate with decision or new issues can be refined and the section information updated to reflect the freshwater habitats and EGS of the new section. Driver templates coupled with scenarios can be used to predict changes. The implementation of the RBAF-CT in Microsoft EXCEL allows for quick post-processing and filtering in order to determine the potential impacts, analyses to perform, and indicators to select to analyze.

Several lessons were learned from applying the RBAF-CT to make future uses more effective. These observations are:

1. To apply the RBAF-CT effectively, a rudimentary understanding of EGS and human well-being should be understood by the participants. It is suggested that introductory information on these topics be supplied to stakeholders and managers before applying the template within a basin. Background information is provided in Chapters 2, 3.
2. Delineating the sections and recognizing the alteration status of the sections (unaltered, active, altered sections) were deemed the most important steps in applying the RBAF-CT for both basins. Once these steps were accomplished, filling in the relevant EGSInfo was relatively straightforward.
3. Prior to delineation, a basic knowledge of the freshwater habitat locations need be known and, ideally, the locations of driver and pressures of change (a.k.a. active sections). Landuse data presented in a GIS platform is very useful in understanding the distribution of freshwater habitat and active sections within a basin.
4. The RBAF-CT includes potential for a full range of freshwater habitats and associated EGS; including expected EGS and habitat types for both developed and developing countries. The size and magnitude of the information included in the RBAF-CT matrix may be overwhelming to users; therefore, it may be beneficial to eliminate irrelevant parameters prior to applying the template. For example, when applying the RBAF-CT in the Upper Bhima Basin where it never snows, the Mountain Snowpack-Glacier Habitat is unnecessary.
5. Classifying freshwater habitat can be difficult due to seasonality. For example, the snowy peaks of the LRB are dry during the summer and fall and therefore the snowpack only exists for 6 months. Additionally, in Africa seasonal wetlands fill during rainy seasons providing wetland habitat, but dry pasture during the rest of the year. Questions that arise include

whether to classify these sections as freshwater habitat (snowpack, wetlands) or uplands and how the EGS provided by these sections are considered during the wet and dry periods.

6. Some disturbances may be a combination of disturbance types. For example, changing from flood to sprinkler irrigation in the LRB could be represented by one of three disturbance types: demand change, technology change, or landuse change. While all consider similar factors, application of the different Driver Templates may lead to slightly different factors to consider and indicators to use.
7. Applying the Driver Templates eased the modification potential changes in direction of EGSInfo. The Driver Templates were very effective at assessing trends in section, but when assessing how these factors may increase or decrease through time, it was more difficult to assign the magnitude of change in EGSInfo as the determination proved full of conditional considerations. For example, the LRB Scenarios 3 and 4 had exactly the same results.
8. As the RBAF-CT examines each driver and pressure in isolation, for long–term projections, water resource management will likely adjust to address the changes to the long-term scenarios becomes less accurate. That said, in progressing through the RBAF-CT analysis, potential solutions came to light as the extent evolution of the issue illuminated.
9. The RBAF-CT has been developed to support the IWRM process. However, it is envisioned that the tool could be modified to address other studies such as water- energy-food security, planned and autonomous adaptability, and build resilience.

While the RBAF-CT shows a basic connection between each component, the reductionist approach it uses does not directly illustrate complexity such spatiotemporal scale and feedback loops of hydrologic, ecologic, and socio-economic process in the basin as well as tradeoffs between EGS and human well-being between scenarios. Cook & Spray (2012) suggests that a limitation of implementing IWRM has been the use of a reductionism approach, thus missing the complexity in the nonlinear relations in socio-ecological relationships. As the RBAF-CT is a screening tool, it is assumed that these connections will be illuminated in subsequent conceptual models, systems dynamic models, or quantitative analyses.

5.5 Conclusion

The RBAF-CT has been developed to address a wide range of basin types; hydrologic, economic, ecologic, and social conditions; and water resource issues. The RBAF-CT is a screening tool for identifying the relevant hydrologic changes, EGS, constituents of human well-being, and indicators, as well as basic connections between hydrologic, economic, ecological, and social systems that need be considered in assessing the sustainability of water resources in a river basin. Implementing the RBAF-CT involves delineating the basin into sections, developing baseline conditions for each section, creating scenarios that depict impacts from drivers and pressures of change, and post-processing the analysis to cull irrelevant information and consolidate important factors and indicators. Driver Templates help modify users baseline conditions for changes in climate, supply, demand, landuse, infrastructure, economic conditions, policy/institutional, societal preferences, and ecosystems. Following scenario development, a post-processing routine in the RBAF-CT culls irrelevant data and compiles the relevant data into a single output table that includes the basins representing zones of activity, a list of active and altered sections, freshwater ecosystems, hydrologic alteration, EGS, and human well-being information, as well as the recommended metrics/indicators to use in the quantitative analysis in the RBAF-AI. RBAF-CT provides an easy user-interface for individuals and groups to structure their collective thinking, and to update as more information becomes known about the river basin.

To demonstrate the applicability of the RBAF-CT, case studies were conducted on the Lemhi River Basin, Idaho, US and Upper Bhima Basin, Maharashtra, India. Irrigated agriculture is a large component of landuse within each basin, but differed in physical, hydrological, ecological, economic, and cultural characteristics. The RBAF-CT was used to evaluate the impacts from increased demands, reservoir construction, and climate change. The flexible use of delineated standardized sections to spatially depict the locations of drivers and pressures of change allowed the analysis to be configures to each basin. Comprehensive lists of EGS with the connections to the EGSInfo provided insight to how and where water was being used to improve human well-being within the basin. Driver templates applied in scenarios provided the potential trends in the EGSInfo associated with each driver and pressure of change. Linking the impacts to indicator suites, the RBAF-CT provided guidance on the indicators to use during the analytical portion of the IWRM analysis.

Thus, the RBAF-CT provides a solid platform for guiding users through the conceptual analysis, continually narrowing the focus until the important factors have been identified, trends predicted, and relevant indicators selected. This holistic depiction of the relevant information with expected trends in response to drivers can be used to help stakeholders better understand the full ramification of water distribution in the basin, as well as to guide technical staff in determining the analyses to apply and the metrics by which the management alternatives can be addressed.

Chapter 6. RBAF-Analytical Interface

The RBAF-AI supports the analytical assessment component of IWRM by organizing and processing the output from the hydrologic model and ecological and socio-economic models/analyses. This chapter provides the background, methodology, and a case study of the RBAF-AI. The case study examines the effects of changing irrigation practices on the water management and environmental resources and human well-being in the Lemhi River Basin (LRB).

6.1 RBAF- Analytical Interface

6.1.1 Background

The foundation of the RBAF-AI is the principles of sustainable development (Swanson & Pintér 2007), the UN GEO4 DPSIR Framework (UNEP 2007, Pintér et al. 2008), and the Millennium Ecosystem Assessment Framework (MA 2003, MA 2005a). The principles of sustainable development assessment state that assessments should consider intra- and inter-generational linkages, inter-dependence between the sustainability criterion, multi-stakeholder perspectives, multi-scale effect, inherent socio-economic and ecologic capacities, and adaptive learning and management. The UN GEO4 DPSIR Framework is a straightforward and intuitive framework for stakeholders to understand the integrated and complex ecological and socio-economic issues within a system. The DPSIR Framework clearly lays out the methodology for connecting the drivers, pressures, states, impacts, and responses within systems in order to identify cause and effect relationships of a change to the system. The MA Framework (MA 2003, MA 2005a) provides a systematic link between the ecosystems, the goods and services they provide, and human well-being for a greater awareness of the benefits provided by the environment. While the MA Framework also uses the DPSIR concept, it is more narrowly focused on the analysis of ecosystem services and thus has been criticized as being more difficult to understand the connections between drivers-pressures and the impact and response (UNEP 2005). Thus the RBAF-AI uses the clarity of the UN GEO4 DPSIR Framework in linking causal effects and the MA Framework’s strength in linking impacts to EGS and human well-being to evaluate water resource management according to the principles of sustainability.

6.1.2 Analytical Interface Description

The RBAF-AI supports the IWRM process by organizing and processing the output from the hydrologic, ecological, economic, and social systems analyses (SC systems analyses) into a cohesive and comprehensible summary presentation on the sustainability of water resources (Figure 20). Output data produced from each SC systems analysis are used to compute impact indicators that represent change in the individual systems as guided by the RBAF-CT output. The SC systems analytical output is collected, the sustainability of water resource conditions computed via data filters and decision trees for each discipline, and conditions presented by a reporting interface per water management scenario. Note, analytical methods and discipline-specific models are purposely not included in the RBAF-AI to allow for flexibility in its application as these methods will change depending on the question being addressed, the data and computational tools available, and the technical expertise of individuals supporting the IWRM process. RBAF-AI is a synthesis tool that can gather quantitative information from multiple sources and structure results in a manner that is consistent with the conceptual model created by the RBAF-CT.

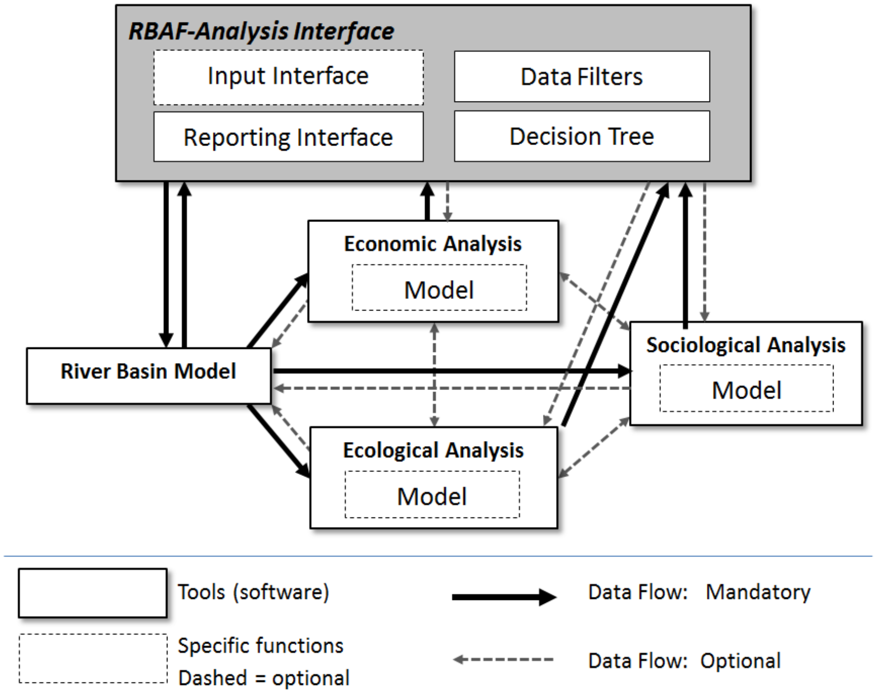


Figure 20. Conceptual diagram of the data flow between RBAF- AI and the SC systems analyses. Dashed box labeled “Model” indicates that modeling is an option, but not mandatory for the discipline specific analysis. Data exchange may occur between SC systems analyses, though how tools are connected depends on the analytical methods chosen.

The specific operations of the RBAF-AI include collecting output data from SC system analyses of a scenario; calculating sustainability indicators; aggregating sustainability indicators in decision trees; and reporting the sustainability indexes for each SC system analyses (Figure 21). Within the RBAF-AI, three modules support this process: 1) Data Filters to compute the sustainability indicators from the analytical output data, 2) Decision Trees for aggregating disparate and spatially distinct sustainability indicators to indexes, and 3) a Reporting Interface for displaying the resulting Index values. For development, the RBAF-AI has been formulated in Microsoft EXCEL and the intent is to develop an open and transparent tool that is widely accessible to stake-holders and agency staff without cost becoming a barrier. The ease and flexibility to automate data retrieval using macros, organize data, make computations, and graph results in Microsoft EXCEL was extremely useful in developing and testing the RBAF-AI modules and interface.

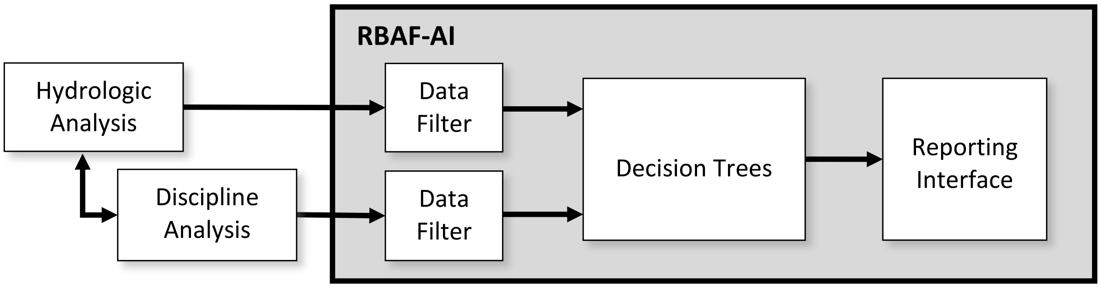


Figure 21. Data flow in the RBAF-AI.

6.1.2.1 Data Filters

Sustainability indicator (SI) values are a quality assessment of the discipline specific analytical output with respect to sustainability. SI values range from 0.0 to 1.0 with 1.0 being desirable. The SI values are computed from the RBAF-AI Data Filters that include trend (Equation 1), reliability (Equation 2), resilience (Equation 3), vulnerability (Equation 4), and equanimity (Equation 5). As stated in Chapter 2, when calculating these sustainability terms upper and lower thresholds and duration periods need to be specified for each data stream being processed. These terms can be valued individually or combined to a sustainability index such as in Equation 7 (see Section 6.1.2.2), which combines reliability, resilience, and vulnerability for computing SI values as was used in the LRB case study.

Show stoppers (SS) flags are unacceptable conditions predicted by the analyses that would render the system unviable regardless of other conditions in the system. For example, stream temperatures reaching 30^{o}C are uninhabitable by salmonids and thus habitat conditions such as substrate conditions and water velocity and depth are inconsequential. Thresholds are specified and a Data Filter applied to determine if a SS Flags of “Pass” or “Fail” is assigned for the evaluation period. Once the analytical data fails during an evaluation period, the entire period is marked with a “Fail” rating. In the example above, when water temperature reached 30°C on July 16th, then the SS Flag for entire year was tagged “Fail”. In the current version, SS Flags are only reported for the evaluation period and do not consider future conditions. For example, SS Flags would not reflect that the salmon smolt killed in a current year would not be returning from the ocean as adults 4 years later.

6.1.2.2 The Decision Tree

RBAF-AI Decision Trees employ four layers to combine disparate and spatially distinct SI values to the Hydrologic, Ecologic, Economic, and Social Indexes presented in the Reporting Interface (Figure 22). The four layers include an Indicator Level, Component Level, Theme Level, and Index Level. Table 19 describes the characteristics of the each level in Decision Trees. Though depicted as having a distinct structure in the example figure, there is no set structure as Decision Trees must be modified to suit the analyses employed, available data and questions being addressed. General guidelines for the construction and operation of Decision Tree have been developed. The formulation of a Decision Tree starts at the Index Level and proceeds downwards through the Theme and Component Levels until it links with the data in the SI Indicators which are reported at the Indicator Level in RBAF-AI (Figure 22). The reverse happens when analyzing a scenario: analytical output is processed through SI filters and then aggregated upwards through the Indicator, Component, and Theme Levels to ultimately produce Indexes.

Combining SI values from a lower level up to the next level in and Decision Tree uses the equation:

$$SI_{level+1} = \Sigma SI_i * wt_i \quad \text{given} \quad \Sigma wt_i = 1 \tag{7}$$

where SI_i is the SI value for the ith term and wt_i is the weight for the ith term.

Weights range from 0.0 to 1.0 with all associated SI values weights totalling 1.0. The weighting of associated SI values indicates their relative importance. For example, if evaluating a river reach habitat for steelhead at the Component Level, then the rearing, spawning, and migration habitat conditions at the Indicator Level may be weighted at 0.5, 0.3, and 0.2, respectively. This weighting reflects that, for this reach, rearing is most important habitat conditions followed by spawning and migration. Weights are subjective to the individuals evaluating the conditions and changing the weights can result in different outcomes. The scientific basis for weight selection generally

Table 19. Levels characteristics of SI values in RBAF-AI Decisions Trees.

Level	Level Characteristics	Ecological Example
Index	This level comprises the Hydrologic, Ecologic, Economic, and Social SI Indexes aggregated from Theme Level SI values. These SI values are presented in the RBAF-AI Reporting Interface.	Ecological score based on the weighting of the importance of salmon, steelhead, bull trout.
Theme	Aggregates spatially distinct Component SI values for zones, sites, or reaches into a single SI value for the basin.	Salmon, steelhead, bull trout habitat conditions in the basin.
Component	Combines Indicator SI Values into a single SI value for zones, sites, or reaches.	Salmon, steelhead, bull trout habitat conditions per reach.
Indicator	The indicator can be defined from a single or several impact indicators from output data.	Per species, spawning, rearing, and migration habitat conditions of reach are defined from the SI Values of stream velocity, depth, and substrate.

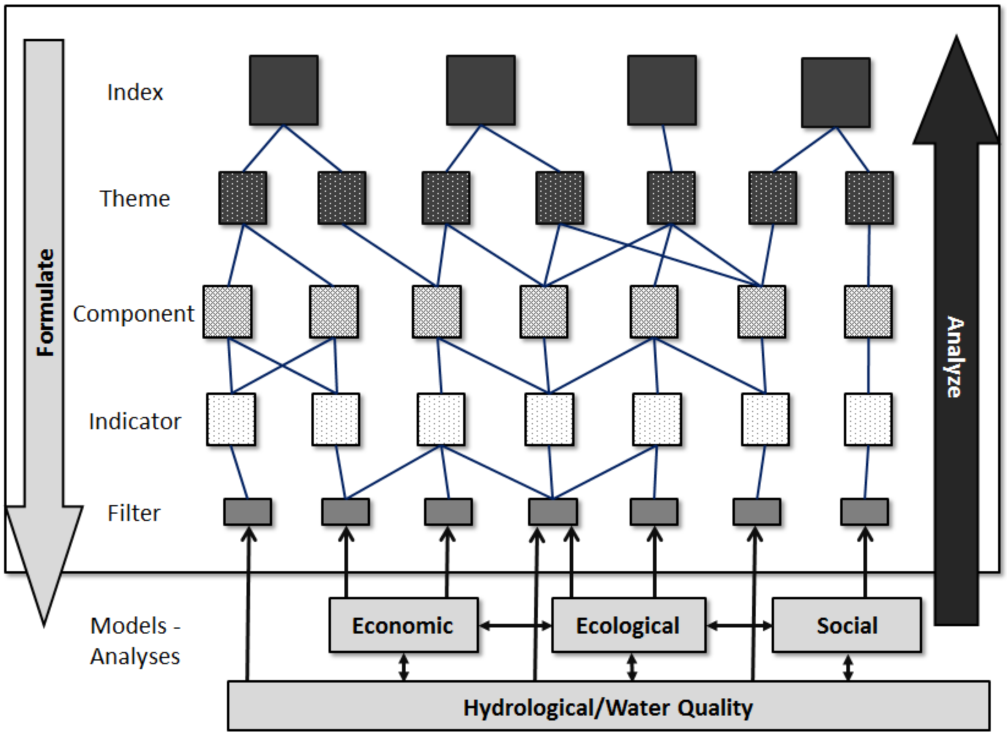


Figure 22. Generic decision tree format used in the RBAF-AI.

decreases in upper layers of the Decision Tree as these layers more reflect societal judgment rather than scientific facts or predictions. As the RBAF-AI is intended to support participatory water management, it is envisioned that selection of the weighting for SI values will be a source of debate amongst water managers and stakeholders as alternatives are evaluated.   RBAF-AI is also structured to allow different groups to add their own weights which helps focus where there is divergence of opinions and idea.

Unlike SI values, SS Flags are determined from the output data and the status carried through Indicator and Component Levels to signify that the system is critically limited by a parameter or condition. At the Theme Level, where spatially disparate sites or zones are aggregated, the number of sites or zones that having a “Fail” status are compared against an “acceptable” criteria to determine if the system as a whole is impaired.   For example, if 80% of the sites in a basin have a SS Flag assessment of “Pass” and it is deemed that having 70% “Pass” is sufficient for the system to be deemed unimpaired, and the SS Flag assessment for that system would be “Pass”. The SS Flag designation in the Theme Layer is carried through to the Index Level with “Fail” given if any component is critically limited. This allows diverse conditions across large spatial scales to be accounted for within RBAF-AI.

6.1.2.3 Reporting Interface

The RBAF-AI Reporting Interface displays a star plot and annual time series of the SI Indexes for different scenarios (Figure 23). The star plot axes include Hydrology, Ecology, Economics, and Social Index SI Scores, providing an overview of scenario results over the entire analysis period and basin. The time series plots displays the scenario results per time step relevant to the basin for the simulation period (e.g. annual results). SS Flags below each plot show which years are within viable range. Basic information of the scenarios being modeled and versions of Decision Tree applied for each discipline are also included for tracking simulations being analyzed.   The default RBAF-AI Reporting Interface generated in this first proof-of-concept model version has been developed to demonstrate how the sustainability of water resource management could be displayed. Given that each participatory group has different means of displaying and reviewing results, it is envisioned that the interface will be customized to meet cultural norms and stakeholder interests within a basin.

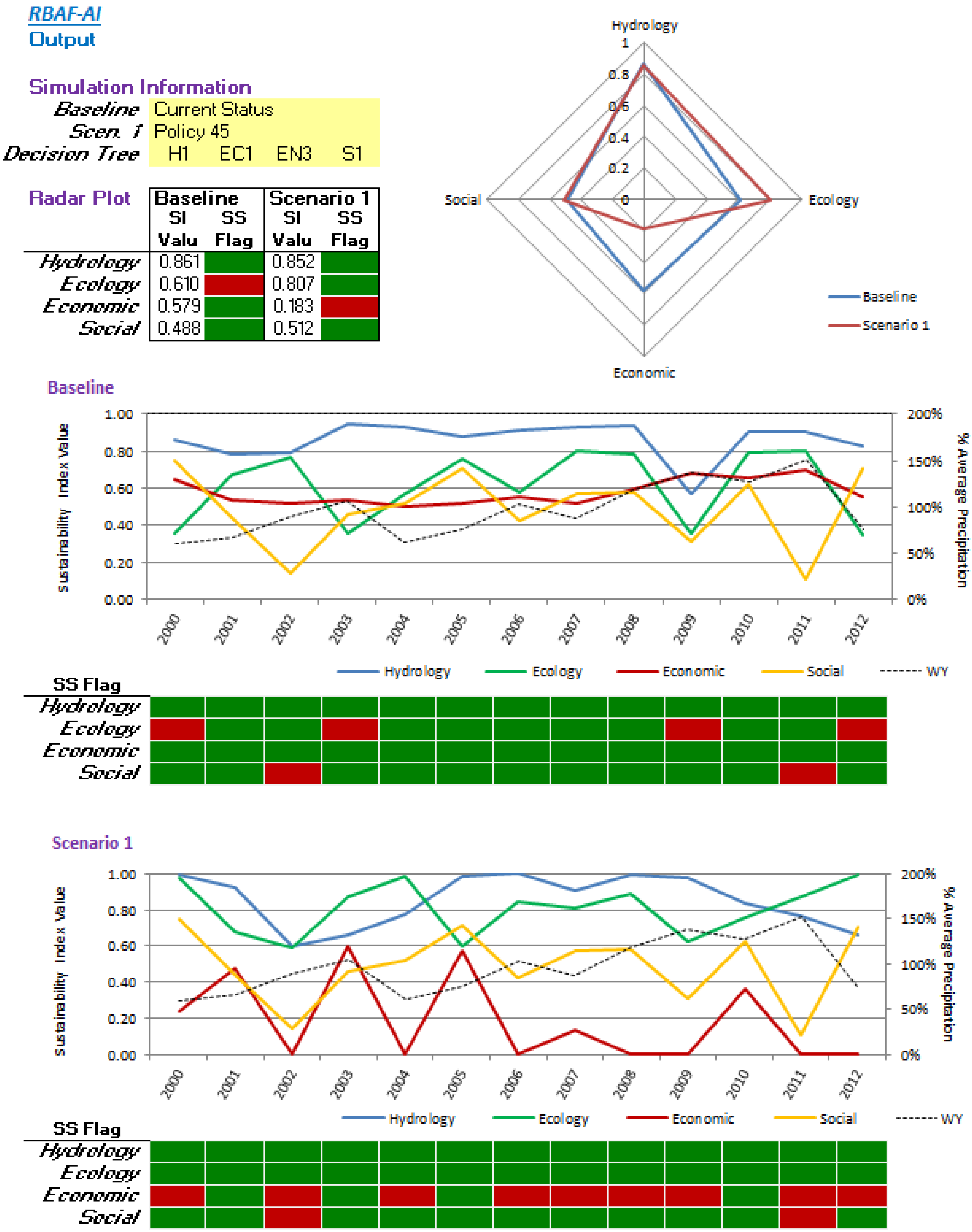
6.1.3 Assessment Process

In implementing the RBAF-AI, steps are required to set up the Data Filters, Decisions Trees, and Reporting Interface to interface with different analytical methods and users' preference towards output. Steps for implementation are:

1. Selection of Impact Indicators - From the RBAF-CT output, select the relevant impact indicators for each of the DSA to address the scenarios. Impact indicators provide the foundations for the post-processing in the RBAF-AI.
2. Data Filters – For the selected Impact indicators, select the data filters that will be used to convert the data output to SI values for the Indicator Level. In addition, for the SI value filters determine the upper and lower threshold values, vulnerability duration period (if appropriate), and analysis period and for the SS Flag the critical limits.
3. Formulate of Decision Trees – For each discipline, determine the Decision Tree structure by determining how SI values will be organized into the Indicator, Component, Theme, and Index Levels.
4. Customize the Reporting Tool - A default star plot and time series plot are available in the reporting tool, but other criteria may need to be reported to assist water managers and stakeholders in evaluating the scenarios. The final interface will likely be developed through an iterative process between water managers and stakeholders and technical staff implementing the RBAF-AI.
5. Connect the analytical output of SC system analyses to indicators, filtering data as required. Filtering and spatiotemporal aggregation may or may not be required on developing indicator values. If possible, directly connect the SC systems analyses output with the RBAF-AI to ease processing of scenarios.
6. Weighting Associated SI Values – For associated SI values in a level defined in Decision Tree, weight the SI values to determine their relative importance.
7. Conduct the discipline specific analyses, load data, and evaluate scenarios.

6.2 Case Study – Lemhi River Basin Flood to Sprinkler Conversion

The RBAF-AI was applied to the LRB, Idaho, to demonstrate how the tool can be applied to evaluate the effect of management actions on the overall sustainability of water resources in a river basin. As presented in Chapter 5, the Lemhi Basin is mountainous arid basin where irrigation is required to grow hay and alfalfa which supports the cattle industry (Bob Loucks, personal communication 2013).



RBAF-AI
Output

Simulation Information

Baseline	Current Status			
Scen. 1	Policy 45			
Decision Tree	H1	EC1	EN3	S1

Radar Plot

	Baseline		Scenario 1	
	SI Valu	SS Flag	SI Valu	SS Flag
Hydrology	0.861	🟩	0.852	🟩
Ecology	0.610	🟥	0.807	🟩
Economic	0.579	🟩	0.183	🟥
Social	0.488	🟩	0.512	🟩

SS Flag (Baseline)

SS Flag													
Hydrology	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ecology	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟥
Economic	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Social	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩

SS Flag													
Hydrology	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ecology	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Economic	🟥	🟩	🟥	🟩	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥
Social	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩

Figure 23. RBAF-AI Reporting Interface displaying the star plot, annual time series, and SS Flags for the Hydrologic, Ecologic, Economic, and Social SI Indexes.

Traditionally, flood irrigation was the preferred method, but sprinkler irrigation is growing in use due to the decrease in labor requirements and increase in production. Sprinkler irrigation requires less diverted water per acre; diverting the water from the Lemhi River system (groundwater is not used for irrigation) in such quantity as to apply only what is needed to account for crop consumption as well as evaporative and conveyance losses. However, the application efficiency of sprinklers renders little contribution to the shallow groundwater system and thus provides negligible return flow later in the summer season, further decreasing base flows during the hot, dry summer months. The endangered species of steelhead, Chinook salmon, and bull trout need a requisite amount of stream flow for adequate spawning, rearing, and migratory habitat. The case study scenario evaluated the impacts associated with the conversion from flood to sprinkler irrigation on the ecologic, economic, and social systems in the basin. The questions formulating the case study conditions include:

- Will the increase in sprinkler use benefit or impair the ranching economy?
- What is the optimum allocation of sprinkler and flood irrigation systems in the basin for agricultural producers?
- If the optimum sprinkler flood conversion is realized, what is the impact to the ecologic, economic, and social systems in the basin?

To address these questions as well as assess the sustainability of the water resource conditions associated with a change in irrigation method, a preliminary hydrologic and economic modeling study was conducted for the LRB. The preliminary analysis determined the optimal distribution of flood and sprinkler irrigation in the LRB to produce the maximum economic benefit. Once the optimal irrigation distribution was determined, SC systems analyses were conducted on the current (Baseline Scenario) and optimal distribution (Optimized Irrigation Scenario) conditions. The SC systems analytical results were processed in the RBAF-AI according to the procedure outlined above and using the RBAF-CT indicator list developed for the irrigation conversion scenario for the LRB case study (Table 16).

The LRB case study provides an example of how water resource management scenarios may be addressed using the RBAF-AI. The following text provides an overview of analytical methods per discipline, the case study scenario results, and the RBAF-AI implementation, results, and discussion. It should be noted that while the analytical methods are sound, the models and analyses have not been fully calibrated. The level of analyses was deemed sufficient to demonstrate the RBAF-AI, but results should be considered preliminary. Overviews of the SC systems analyses are provided in the main text with specific details presented in Appendix A (Economic Analysis) and B (Ecological Analysis).

6.2.1 Discipline Specific Analyses

6.2.1.1 Hydrological Model

The Lemhi River Basin Model (LRBM), the hydrologic model used in this case study, was developed by the Idaho Department of Water Resources (IDWR) for evaluating diversion operations and tributary reconnections in the LRB (DHI 2003, DHI 2006). The LRBM included rainfall-runoff model, to predict inflow to the system, and a river basin model to route water in the stream network and account for off-stream water use. The software that provides the basis for LRBM is DHI Water and Environment's (DHI) MIKE BASIN Software. This geographic information systems (GIS)-based software uses polygons to represent catchment inflow and groundwater storage, branches to route water, and nodes to account for water as well as represent different uses of water. The software simulates the system's performance by calculating water mass balance at every node and routing water between nodes via branches. Results from the model can be viewed as a time series of any computational component (e.g. river flows, groundwater storage volumes, deficits for water users), a water distribution map of the model network with graduated color result presentations for many combinations of results, or statistical analysis that can also be plotted on the map. Though conceptually simple, river basin models allow water managers to investigate different management alternatives associated with different diversion operations, crop irrigation/rotation methods, and an understanding of how return flows influence stream flows in response to irrigation practices. Full description of the construction and calibration of the LRBM can be found in DHI (2003), DHI (2006), and Dixon (2012).

In the LRBM, branches represent rivers and canals and water user nodes represent domestic and irrigation water use. Construction of the LRBM involved gathering GIS coverages of the stream network from the NHD hydrography layer, points of diversion (PODs), places of use (POUs), and aerial photography and then consulting local water authorities and stakeholders to construct the model network (Figure 24). The stream network, developed from the NHD hydrography layer, represents the Lemhi River and 26 tributaries. Sixty-five catchments representing inflows from precipitation were delineated from the USGS 30m NED digital elevation model (DEM) (DHI 2006).

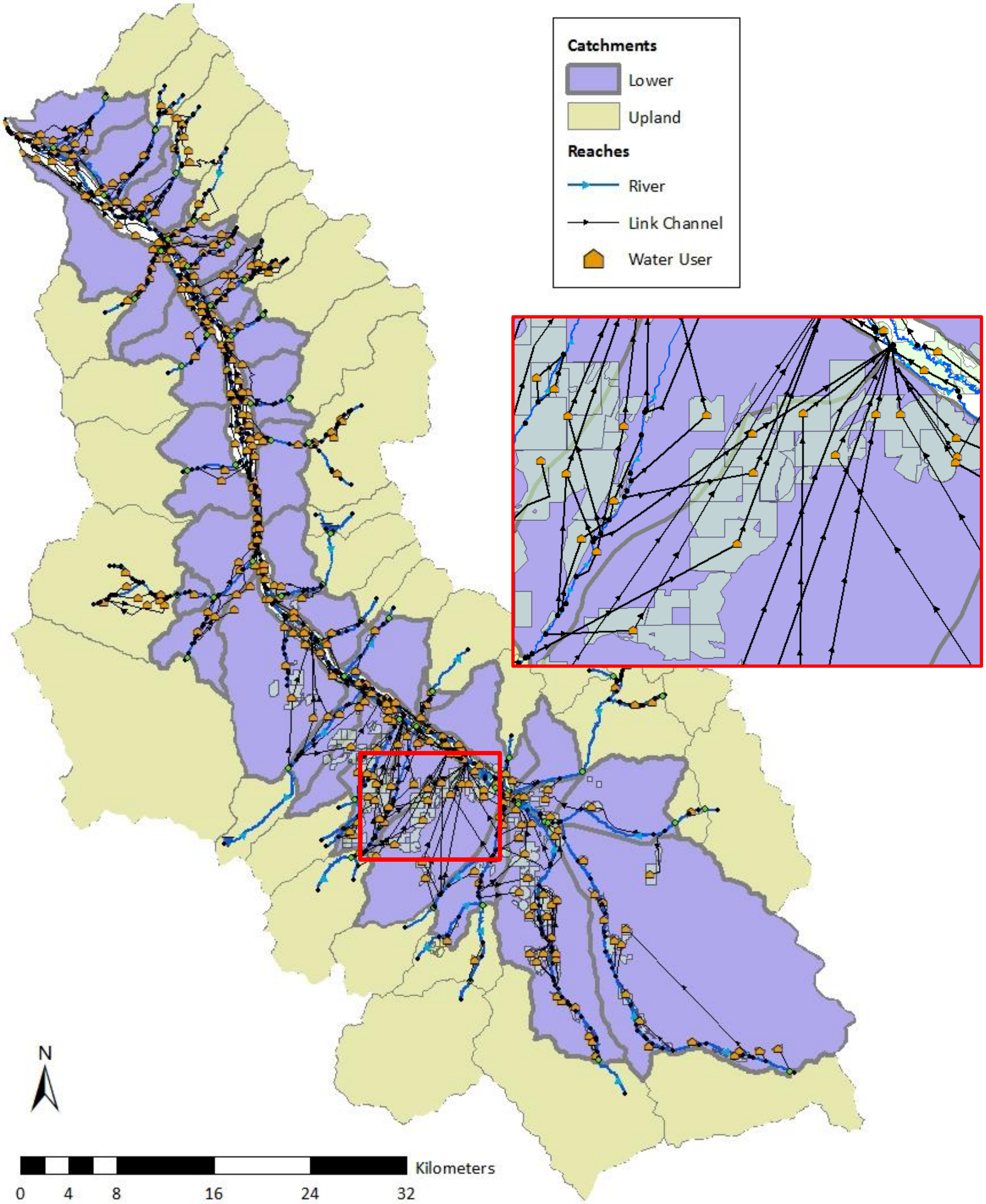


Figure 24. Lemhi River Basin Model (LRBM) used for the case study. Green polygons in the inset represent the POUs where the symbolic in the water allocation.

Delineations are based on a catchment pour point, typically located at the upstream boundary of the tributaries developed in LRBM (upper catchments) and at the confluence of the Lemhi River and the tributary (lower catchments).

Inflows to the LRBM were determined using the DHI's Nedbør-Afstrømnings-Model (NAM) rainfall-runoff model. NAM is a lumped conceptual model that uses precipitation, evaporation, and temperature time series to predict outflow from a catchment. NAM operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow, and baseflow. A fourth storage unit can be used if snow is prevalent in the catchment. For catchments with snowfall over a wide elevation range, such as in the LRB, the snow storage unit can be divided in up to ten subunits to represent different elevation zones. The result is a continuous time series of the runoff from the catchment as well as groundwater infiltration throughout the modeling period.

Basic data requirements for the NAM model include catchment area, initial conditions, and concurrent time series of precipitation, potential evapotranspiration, and, for calibration, stream discharge. When snowmelt is included in the model, temperature is required and radiation is optional. If the catchment is divided into elevation zones for the snowmelt calculation, also required are elevation of the precipitation and temperature gages, wet and dry adiabatic lapse rates (the rate of decrease of temperature with increasing altitude in the atmosphere), precipitation accumulation per zone, and maximum accumulation per zone. Though required, default values are available for all but the elevation of the precipitation and temperature gages. Calibration of the NAM model involves adjusting the coefficients for the exchange of water between storage units and the storage unit depth so that simulated and observed discharges match as best as possible (Figure 25). For the LRBM, 8 catchments were calibrated with the calibration parameters being transferred to remaining ungauged basins.

Using water right information and consultation from local water authorities, PODs were connected via a link channel to POUs to simulate irrigation use in the basin. From this effort, the model uses 322 water user nodes to representing POUs throughout the basin. Irrigation nodes require time series data for water demand, fraction of the demand satisfied by ground water, fraction of the demand returning to the system (a.k.a. consumptive component of diverted water), and lag time for the return fraction to re-enter the stream. Associated with each water user node is irrigated acreage, irrigation method, and crops grown as well as the historic diversion rate (if known) or the legal diversion amount as stated in the water rights for the POUs. Consumptive rates were determined by the method outline by DHI in 2003, which uses crop coefficients and reference evapotranspiration records (ETo) reported by ETidaho (www.kimberly.uidaho.edu/ETIdaho/). To predict the surface and shallow groundwater return flow fraction return flow of the unconsumed diverted water, local water authorities provided insight in the location and timing of returns. The return flow fraction and lag time for each water user were used to calibrate the LRBM at 12 gage locations throughout the basin.

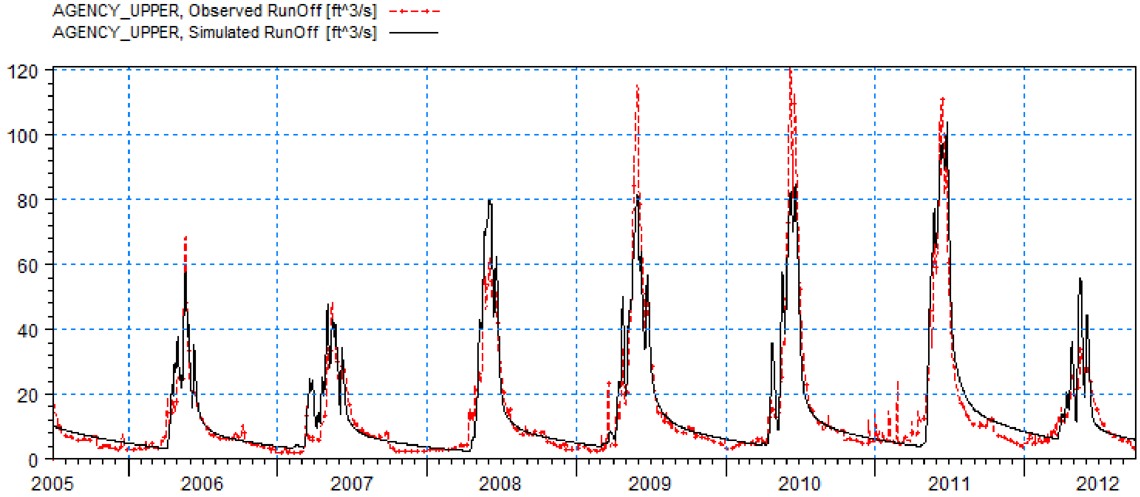


Figure 25. Final calibration plot for the Agency Creek upper catchment.

For each gage downstream of diversions within the network, reach gains were calculated. Reach gains have been computed for baseline conditions and are the difference is simulated and observed flows that account for processes not directly represented in the model: direct rainfall, contribution from un-modeled minor tributaries, and groundwater loss and recharge to and from the deeper groundwater system. Calibration of the model involved determining the return flow fraction and lag time from irrigation nodes, then developing reach gain time series at gage locations. Reach gains were determined after calibrating the model to baseline conditions, the subtracting the difference with the observed flow. Reach gains were held constant for all scenario simulations.

The LRBM simulates the performance of the overall system by accounting for catchment inflows; routing of water in the stream network; and diversion operation, consumption, and return flows for irrigation. Simulations take into account the irrigation water use by individual extraction points throughout the system on a daily time step. Results from the LRBM are viewed as a time series of any computational component (e.g. river flows, groundwater storage volumes, deficits for water users) and a water distribution map of the model network with graduated color result presentations of results. Supporting the LRBM are several Microsoft EXCEL workbooks that aid in inputting data for catchments and irrigation nodes as well as extracting output results for display and computing ecological, economic, and social system analytical results from a water distribution scenario.

For the case study, the Baseline and Optimized Irrigation Scenarios used the calibrated LRBM with hydrology from historic water years 2000 to 2012. Output from the LRBM used for the case study included:

- Daily flows in branches in the ecological analysis, and
- Daily water delivery and deficit to each water user node (Figure 26).

The hydrological analysis used water deficit output, aggregating the results in the 5 zones defined in the economic analysis (see Economic Analysis Section). To reflect water year type, the yearly annual precipitation was normalized to the average annual precipitation as computed by summing the annual precipitation of the 65 catchments. To support other disciplines, the daily flows in branches for the ecological analysis where directly used as input to the ecological study. Water delivery and deficit outputs to water users were used to generate production in the economic analysis.

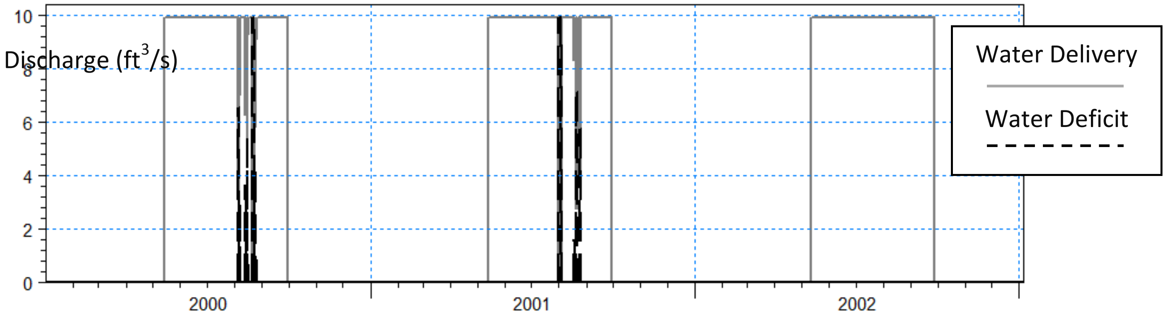


Figure 26. Water delivery and deficit time series results for the L-22 water user from the LRBM during the Baseline Scenario.

6.2.1.2 Economic Analyses

The economic analysis was used preliminarily to develop the case study scenario as well as for taking the LRBM results for scenarios and computing Economic SI Indexes. The economic analysis, as linked to irrigation practices, was determined by the benefit-cost analysis of grass hay and alfalfa production as well as pasture rental rates in the LRB. Benefits (revenues) were determined by the production of grass hay and alfalfa and the rental rates of pasture for grazing cattle. Water delivery was provided by LRBM output and production rates determined by FAO 33 (Allen et al. 2002). Costs were computed based on the crop type and irrigation method scaled to the area under irrigation. Production costs were derived from the crop enterprise databases generated by the University of Idaho, Department of Agricultural Economics and Rural Sociology (http://web.cals.uidaho.edu/idahoagbiz/). The benefit-cost analysis was conducted annually for the full simulation period with annual cost-benefits being adjusted for time using a real discount rate of 5% to compute the net present value of each scenario. A detailed explanation of the economic analysis is presented in Appendix A.

As there are 322 water user nodes representing irrigated fields in the LRBM, reporting each would be difficult and confusing. To simplify the economic analysis and support the economic optimization analysis of flood and sprinkler irrigation for the case study, water users were organized into 5 economic zones (Figure 27, Table 20). Each economic zone had paired demand nodes to represent the total irrigation: one demand node representing the contribution from flood irrigation and other demand node sprinkler irrigation. Representing irrigation by two demand nodes per zone allowed for evaluation of tradeoffs between irrigation methods. For example, if water users are switching to sprinkler irrigation, then the demand node representing sprinkler irrigation would increase and the node representing flood irrigation decrease for that zone. As the production revenue and costs are different between flood and sprinkler irrigation, the benefit and cost for each node was calculated independently but with respect to the area that is being irrigated by irrigation method.

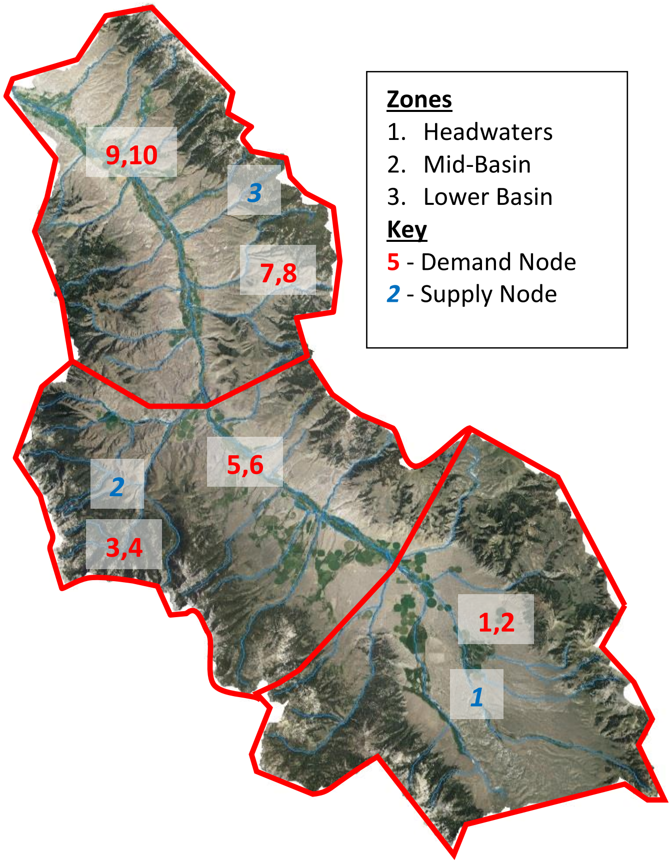


Figure 27. Schematic of LRB delineation for the economic analysis.

The total production per zone is sum of the net revenue from the water nodes representing flood and sprinkler irrigation in that zone. Note that only the irrigation method changes while the total irrigated area and crops produced remains fixed for all scenarios (Table 21). As the crop type grown (pasture and alfalfa hay) are assumed to be fixed, no additional nodes are defined to account for the different crops grown.

For the irrigation optimization analysis, the water supply sources were organized in the upper (S1), middle (S2), and lower (S3) supply sources (Figure 27, Table 20). As irrigation water is supplied by surface water flow, the three supply sources represent surface water runoff. Each economic zone has a different array of sources from which to receive water. Economic zone 1 receives water from S1. Economic zones 2T and 3T represent irrigated POUs located on tributaries and thus also get only local supply of S2, and S3 respectively. Irrigated POUs in the LRB, economic zones 2 and 3, supply sources are available from local runoff as well as mainstem Lemhi water from upstream sources. For the scenario analysis, supply to the water users was dictated by the catchment runoff and stream flows in the LRBM.

Table 20. Descriptions of the economic zones and supply and demand nodes used in the economic analysis.

Economic Zone	Demand Node	Demand Description	Supply Source	Supply Description
Z1	D1	Z1: Mainstem – Flood	S1	Runoff from Supply Zone 1
	D2	Z1: Mainstem – Sprinkler	S1	
Z2T	D3	Z2T: Tributary – Flood	S2	Runoff from Supply Zone 2
	D4	Z2T: Tributary – Sprinkler	S2	
Z2	D5	Z2: Mainstem – Flood	S1, S2	Runoff from Supply Zone 2, Discharge from Supply Zone 1
	D6	Z2: Mainstem – Sprinkler	S1, S2	
Z3T	D7	Z3T: Tributary – Flood	S3	Runoff from Supply Zone 3
	D8	Z3T: Tributary – Sprinkler	S3	
Z3	D9	Z3: Mainstem – Flood	S1, S2, S3	Runoff from Supply Zone 3, Discharge from Supply Zones 1, 2
	D10	Z3: Mainstem – Sprinkler	S1, S2, S3	

Economic analysis results generated for the preliminary analysis and the sustainability analysis generated net revenues from production. The preliminary analysis provided the net revenues for the 10 demand nodes that were translated into the acres of production of flood and sprinkler irrigation (Table 21). The distribution of the flood and sprinkler irrigation was used to simulate the scenarios in the LRBM. The scenario output of the economic analysis was the annual revenues per economic zone from 2000 – 2012 (Table 22).

Table 21. Zonal statistics concerning water users attributes in the economic analysis.

Zone	Water User Nodes	Irrigated Area (ac)	Alfalfa	Grass Hay
Z1	40	5864	30%	70%
Z2	71	8709	11%	89%
Z2T	58	9530	27%	73%
Z3	47	14658	9%	91%
Z3T	104	11523	12%	88%

Table 22. Revenues per economic zone for the Optimized Irrigation Scenarios. All values are in x1000.

Year	1	2	2t	3	3t	Total
2000	$ 19	$ 61	$ 45	$ 251	$ 6	$ 383
2001	$ 25	$ 79	$ 59	$ 325	$ 8	$ 496
2002	$ 34	$ 107	$ 80	$ 443	$ 11	$ 676
2003	$ 40	$ 126	$ 94	$ 522	$ 13	$ 796
2004	$ 24	$ 74	$ 55	$ 305	$ 7	$ 466
2005	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563
2006	$ 39	$ 123	$ 92	$ 507	$ 12	$ 773
2007	$ 33	$ 105	$ 78	$ 433	$ 11	$ 661
2008	$ 45	$ 142	$ 106	$ 586	$ 14	$ 894
2009	$ 53	$ 164	$ 123	$ 680	$ 17	$ 1,036
2010	$ 48	$ 151	$ 113	$ 626	$ 15	$ 954
2011	$ 58	$ 181	$ 135	$ 749	$ 18	$ 1,141
2012	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563

6.2.1.3 Ecological Analyses

The ecological analysis examined how change in river flows, associated with the conversion from flood to sprinkler irrigation, effects aquatic habitat for endangered species for steelhead, Chinook salmon, and bull trout. As identified from the RBAF-CT, the ecological analysis should consider change in flow conditions as state indicators and habitat quality as impact indicators. The ecological score in the LRB was determined by evaluating the aquatic habitat for steelhead, Chinook salmon,

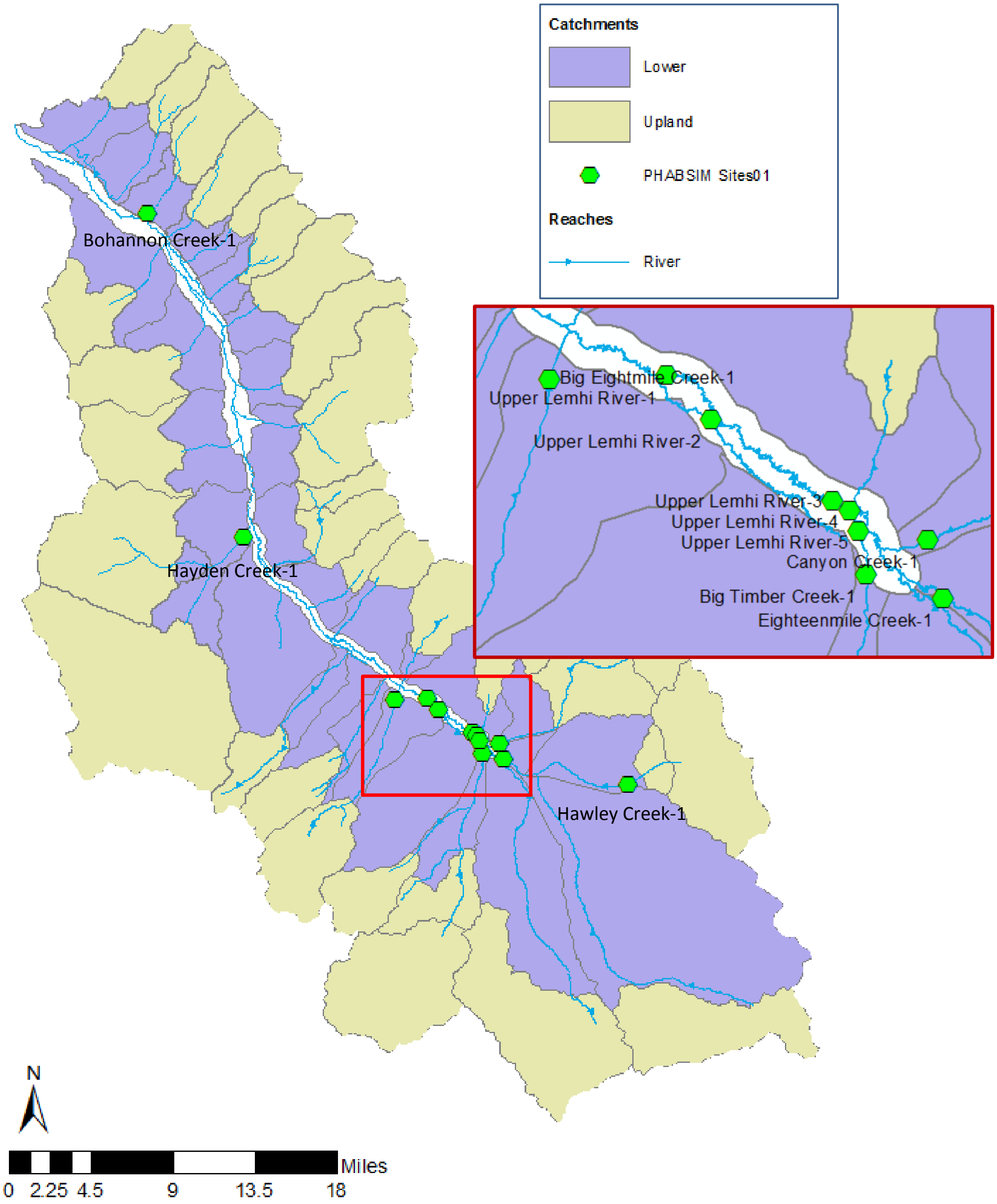


Figure 28. PHABSIM sites incorporated in the ecological analysis of the LRB.

and bull trout adult and spawning life stages at 12 sites (Table 23, Figure 28). The ecological analysis combined the flow time series from the LRBM with the discharge-normalized weighted usable area relationships (Figure 29) from the USBR in-stream flow assessment studies (Sutton & Morris 2004, Sutton & Morris 2005, Sutton & Morris 2006, Morris & Sutton 2007) to generate a daily percentage of maximum habitat available for steelhead, Chinook Salmon, and bull trout spawning and rearing life stages (Figure 30). It is from the daily percentage of maximum habitat time series that the SI values for the ecological score were determined.

Table 23. Sites incorporated in the ecological analysis of Lemhi River sustainability analysis. Life stages notations are *"Sp"* denotes spawning, *"A"* denotes adult, and *"J"* denotes juvenile.

Stream	USGS Site	LRBM Arc	Life Stages Steelhead	 Chinook	 Bull Trout	Source
Big Timber Creek	1	E2296	Sp, A, J	Sp, A, J	Sp, A, J	Sutton & Morris 2004
Big Eightmile Creek	1	E2683	Sp, A	Sp, A	Sp, A	Sutton & Morris 2005
Bohannon Creek	1	E4131	Sp, A	Sp, A	Sp, A	Sutton & Morris 2005
Hayden Creek	1	E5008	Sp, A	Sp, A	Sp, A	Sutton & Morris 2005
U. Lemhi River	1	E2287	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
U. Lemhi River	2	E1861	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
U. Lemhi River	3	E3129	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
U. Lemhi River	4	E3129	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
U. Lemhi River	5	E3053	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
Canyon Creek	1	E2687	Sp, A	Sp, A	Sp, A	Sutton & Morris 2006
Hawley Creek	1	E2187	Sp, A	Sp, A	Sp, A	Morris & Sutton 2007
Eighteenmile Creek	1	E3056	Sp, A	Sp, A	Sp, A	Morris & Sutton 2007

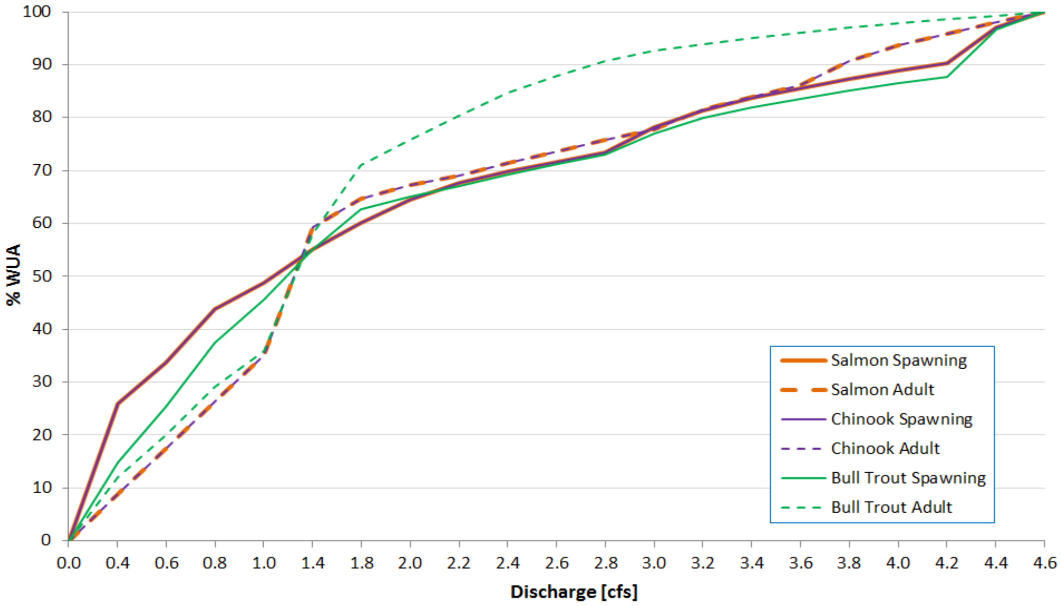


Figure 29. Discharge-normalized weighted usable area relationships for Big Eightmile Creek Site Number 1 (Sutton & Morris 2005).

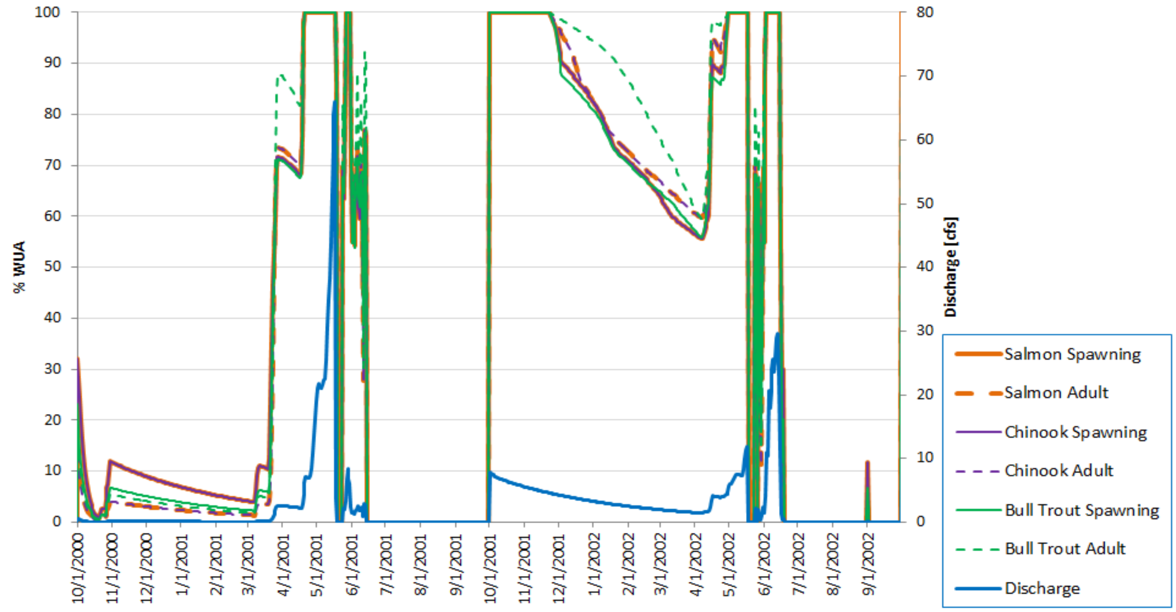


Figure 30. Normalized weighted usable area and discharge time series for the Baseline Scenario at Big Eightmile Creek Site Number 1 for water years 2001 and 2002.

6.2.1.4 Social Analyses

The social analysis examined how changes in flow conditions associated with a conversion from flood to sprinkler irrigation effects residential income. Linking water distribution to residential income proved difficult as the relationship was poor as such, no social analysis results are reported in this case study.

6.2.2 Case Study Scenario Development

Conversion from flood to sprinkler irrigation has been increasing over the past 10 years in the LRB. With the irrigation conversion come questions as to the sustainability of the SC systems within the LRB. For example, will the increase in the sprinkler use benefit or impair the agricultural economy? Will the reduction in flood irrigation diminish shallow groundwater and reduce seepage from the floodplain to the river later in the season? How will this conversion impact the aquatic habitats supporting the steelhead, Chinook salmon, and bull trout populations? What are the social impacts of converting to sprinklers? These are the types of questions that the RBAF-AI is intended to answer and the ones addressed in this case study.

For demonstration of the RBAF-AI, the scenario evaluated focused on the ramifications to the SC disciplines of flood to sprinkler irrigation conversion to optimize economic output. The scenario involved a preliminary analysis to determine the optimal distribution of flood and sprinkler irrigation, then applying the SC system analyses to determine the sustainability of the SC disciplines. The results of the case study analysis was processed and presented in the RBAF-AI.

To determine the optimal allocation of flood and sprinkler irrigation in the LRB, a benefit-cost analysis of crop production was conducted using a partial equilibrium solution. The allocation of water within the LRB that results in the maximum consumer and producer surpluses was determined by solving a constrained set of non-linear equations. The solution algorithm used in this study was a Gradient Descent Methodology (Avriel 2003, Snyman 2005), with constraints on maximum and minimum water usage incorporated into the iterative solution. This technique uses the marginal rate of substitution as defined by supply and demand curves to calculate the net benefit per different conversion rates from flood to sprinkler irrigation. As presented in the economic analysis section above, water users in the Lemhi River were divided into 5 paired demand nodes receiving water from 3 supply nodes (Figure 27, Table 20). The demand nodes represented 5 areas, each with a pair of nodes representing flood and sprinkler irrigation. This analysis assumes the supply and demand curves are fixed as are the crops produced and irrigated area. Factored into the demand curves are the production rate and costs, including sprinkler installation and operation, for each irrigation and crop type. Curve development is detailed in Appendix A.

The output from the optimal allocation of flood and sprinkler irrigation is the net revenue per demand node (Table 24). The results indicate that economically, it is advantageous to increase the use of sprinklers within the basin. Zones 1 and 2 convert fully to sprinkler with Zones 2T, 3, and 3T increasing by 38%, 68%, and 42%, respectively. As indicated in Appendix A, built into this analysis are a series of assumptions on crop production, pricing, and costs and therefore the results should be considered preliminary in terms of magnitude of change. However, they do indicate the trend in irrigation pattern if solely economics were considered and were used as the foundation for the scenario evaluated in the RBAF-AI.

To determine the impact of this irrigation conversion on the SC disciplines, a Baseline Scenario, representing current conditions, and an Optimized Irrigation Scenario, representing the distribution of flood and sprinkler irrigation for maximum economic production, were analyzed. For analysis, water user nodes in the LRBM were altered to represent the irrigation distribution and simulated for water years 2000 to 2012. Alterations of the irrigation conversion involved changing water demand

and consumptive time series to represent typical sprinkler irrigation. Results of stream flow and water delivery to water user nodes from the LRBM simulations were used as inputs to the economic, ecologic, and social analyses as described in Section 6.2.1.

Table 24. Distribution of flood and sprinkler irrigation per economic zone for the Baseline and Optimized Irrigation Scenarios.

Economic Zone	Demand Nodes	Baseline Scenario		Optimized Irrigation Scenario	
		Flood	Sprinkler	Flood	Sprinkler
Z1	1,2	80%	20%	0%	100%
Z2	5,6	89%	11%	0%	100%
Z2T	3,4	68%	32%	30%	70%
Z3	9,10	81%	19%	13%	87%
Z3T	7,8	51%	49%	9%	91%

6.2.3 RBAF-AI Application

This assessment evaluates the impacts of optimizing the economic output from the agricultural sector in the LRB given the conversion from flood to sprinkler irrigation. For each case, the LRBM simulated water distribution using inflow hydrology from historic water years 2000 to 2012. Cropping patterns and irrigated area also remained constant. The difference in the two scenarios involved changing the irrigation methods and thus the quantity of diverted water and the accompanying return flow later in the season. Results of the LRBM were processed for the Hydrologic Index as well as providing input to the other disciplines' analysis. The results from the analyses were aggregated, filters applied to compute SI Indicators and SS Flags, SI Indicators and SS Flags processed in the Decision Trees, and SI Index values plotted in the Results Interface. The following summarizes the methods of applying the RBAF-AI for the LRB case study.

6.2.3.1 Filters and Decision Trees

From the discipline specific analyses, output data was processed through filters into the SI Indicators that fed into the Decision Trees. The equations used to compute the SI Indicators are:

$$SI_i\,(D) = [Rel_i\,(D)*Res_i\,(D)(1-Vul_i\,(D))]^{1/3} \qquad (7)$$

Where

$$Rel_i(D) = \Delta D/\Delta t \qquad (2)$$

$$Res_i\,(D) = \Sigma\#D_A/\Sigma\#D \qquad \text{where } D_A = T_L < D < T_U \qquad (3)$$

$$Vul_i\,(D) = \Sigma\#C/\Sigma\#D_U \qquad \text{where } C = 1 \text{ when } D_{U\,t},\, D_{A\,t+1} \qquad (4)$$

Given:

- D – data,
- #D - number of occurrences
- D_T – target value
- D_A, D_U - acceptable, unacceptable data
- C – criteria value
- T_L ,T_U - lower, upper threshold

Acceptable range thresholds, vulnerability duration period, and SS Flag critical limits were defined for each data type per discipline. These criteria for each discipline were developed based on literature or professional judgment.

From the impact indicators determined by the RBAF-CT, Decision Trees were customized for each discipline linking SI Indicators to SI Indexes. The Decision Trees followed the four layer format and weighting was held equal in all categories. For each discipline specific analysis, output data was entered into the Microsoft EXCEL interface, data filters applied, and SI Indexes calculated via the Decision Trees. The following outlines the filter criteria and decision trees for the hydrologic, economic, and economic disciplines. RBAF-AI also has the capacity to include social indices, but this category is not included in this example.

Hydrological SI Index – The SI Indicators were calculated for the water demand and deficit output from water users nodes to compute the relative water deficit (RWD). Water demand and deficit output were aggregated for all the nodes in each economic zone to compute the RWD for the analysis. Water deficit output was aggregated into the economic demand zones to determine the RWD per zone. SI Indicators were calculated using the filter sustainability criteria presented in Table 25. No upper SI threshold and duration or SS critical limit were specified for the filters as excess water in major flood events is not a problem for irrigators in the LRB.

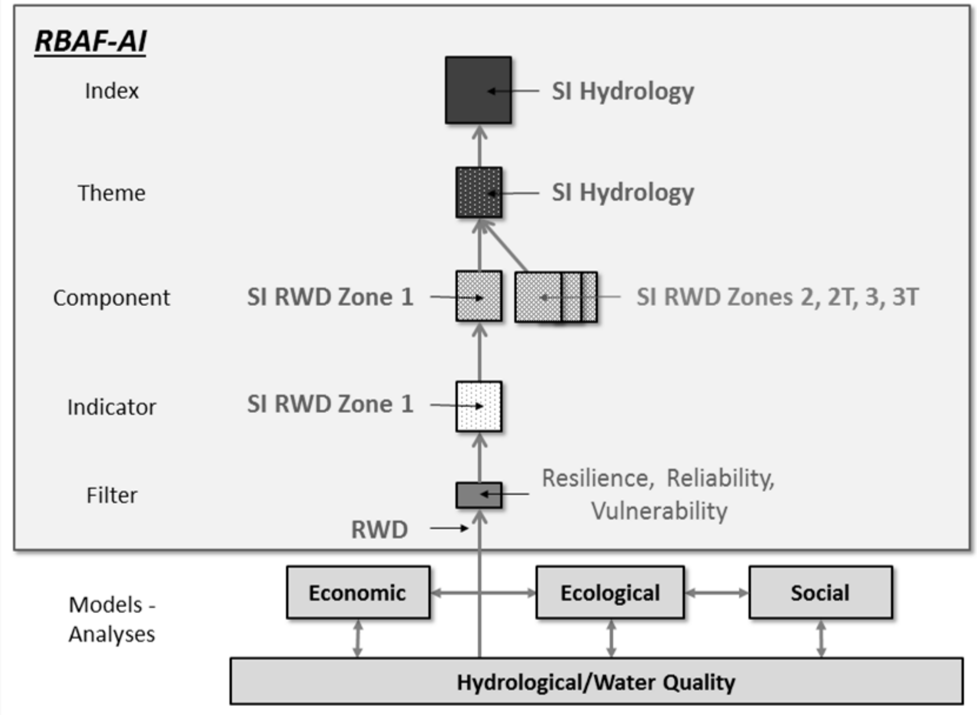


Figure 31. The Decision Tree used to compute the Hydrologic Index score from the relative water deficit (RWD) time series from a zone. The figure shows the path followed from data output to the Hydrologic Index score. The grey labels in the Component Level are the SI scores from the other zones.

Table 25. Sustainability criteria used to compute the RWD SI Indicator values and SS Flags for the hydrologic and economic analyses.

Sustainability Criteria	**Unit**	**Demand Zone 1**	**Demand Zone 2**	**Demand Zone 2T**	**Demand Zone 3**	**Demand Zone 3T**
Lower SI Threshold	% Deficit	n/a	n/a	n/a	n/a	n/a
Lower SI Duration	Days	n/a	n/a	n/a	n/a	n/a
Lower SS Critical Limit	% Deficit	n/a	n/a	n/a	n/a	n/a
Upper SI Threshold	% Deficit	0.25	0.25	0.25	0.25	0.25
Upper SI Duration	Days	7.0	7.0	7.0	7.0	7.0
Upper SS Critical Limit	% Deficit	0.50	0.50	0.50	0.50	0.50
Evaluation Period Start	Day-Mon.	15-Apr	15-Apr	15-Apr	15-Apr	15-Apr
Evaluation Period End	Day-Mon.	30-Sep	30-Sep	30-Sep	30-Sep	30-Sep

To determine the Hydrologic SI Index score, the SI Indicators for relative water deficit were aggregated according to the Hydrologic Decision Tree (Figure 31). The Indicator Level represents the SI values of the relative water deficit per economic zone. The Indicator and Component Layers and the Theme and Index Layers have the same scores. The Component Level combines the SI value of the relative water deficit per economic zone to provide an overall score for the basin in the

Theme Layer. Within the Component level, weighting between economic zones was 0.20. For the remaining levels, the weighting was 1.0. The SI values at the Indicator Level could be combined in the Component, but are combined in the Theme Level as that is where SI values are spatially aggregated.

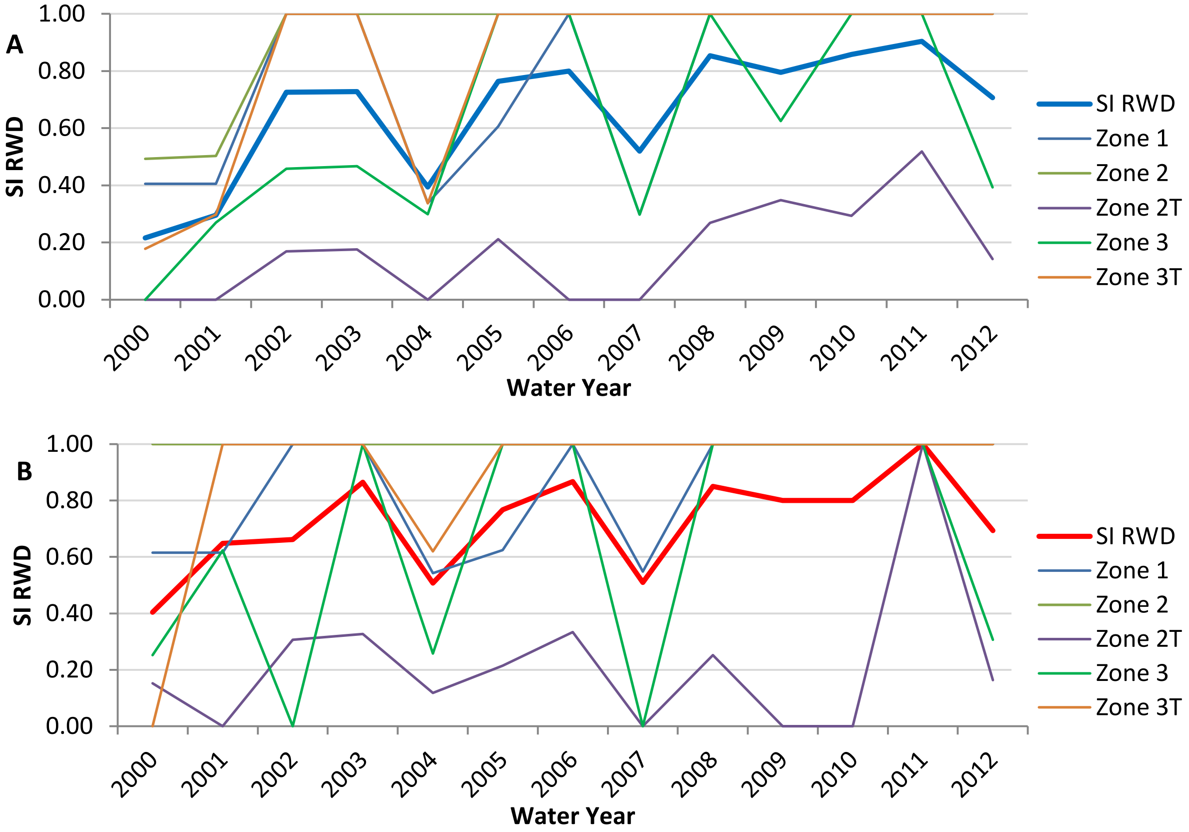


Figure 32. SI Hydrology scores for the Baseline (A) and Optimized Irrigation (B) Scenarios in the LRB overall and as applied to the economic analysis zones.

The SI Hydrology scores derived from the relative water deficit indicate that the Optimized Irrigation Scenario improves water delivery (Figure 32, Table 26). Baseline Scenario SI Hydrology scores range from 0.34 to 0.78 and average 0.56 while the Optimized Irrigation Scenario SI Hydrology scores range from 0.43 to 0.91 and average 0.67. In addition, the overall reliability of the delivery increased with the increase in sprinkler use in the basin with a decrease from 11 to 4 occurrences of SS Flags. In both scenarios, the SI Hydrology scores are sensitive to water year type illustrating the significant hydrologic inter-annual variability in the basin that the management actions must function within (Table 26).

Increased sprinkler use improves the delivery of water in Zones 1 and Zones 3T, relatively no change in Zones 2 and 2T, and decreases delivery in Zone 3 (Figure 32). As many of the users in Zones 1 and Zones 3T are in headwaters where the stream flow greatly decreases during the late summer, the ability to deliver water to the crops efficiently with less supply improves delivery. The result is in an increase in RWD. The trade-off in the basin is the decrease in water available to the downstream users in Zones 3 who traditionally rely on return flows from upstream users. When the system is switched to sprinkler, it appears that the return flows decrease and less is available during late season irrigation. Zone 2T experiences a slight decrease in delivery reliability, decreasing from an overall SI RWD score from 0.31 to 0.29 and Zone 2 appears to be insensitive to the changes uses in irrigation method.

Table 26. Tabular results of the Hydrology SI Scores and SS Flags for the Baseline and Optimized Irrigation Scenarios.

	Water Year	Baseline		Scenario	
Year	**[% normal]**	**SI Score**	**SS Flag**	**SI Score**	**SS Flag**
Overall	100%	0.61	False	0.72	False
2000	51%	0.20	True	0.40	True
2001	66%	0.30	False	0.65	False
2002	90%	0.52	False	0.66	False
2003	106%	0.72	False	0.87	False
2004	62%	0.31	True	0.51	False
2005	75%	0.73	False	0.77	False
2006	103%	0.72	False	0.87	False
2007	88%	0.44	True	0.51	True
2008	119%	0.85	False	0.85	False
2009	138%	0.75	False	0.80	False
2010	127%	0.80	False	0.80	False
2011	152%	0.90	False	1.00	False
2012	75%	0.71	False	0.69	False

Economic SI Index – Two SI Indicators were used to evaluate the economic system: net revenues and RWD (Figure 33). The former was used to demonstrate the economic efficiency of the flood and sprinkler irrigation system distribution and the RWD to illustrate the reliability of the water supply to irrigators. As the net revenue is reported on an annual basis, which also corresponds to the reporting interval for the economic analysis, the reliability, resilience, and vulnerability Si scores could not be assessed for the indicator level. Instead, the revenue indicator is taken as the net balance (net loss or gain for the year) for each zone based on if the zone had a net annual loss or gain throughout the simulation period. Reliability, resilience, and vulnerability Si scores were assessed for the entire period for the star plot. The RWD calculations were the same as those used in the Hydrologic SI Index.

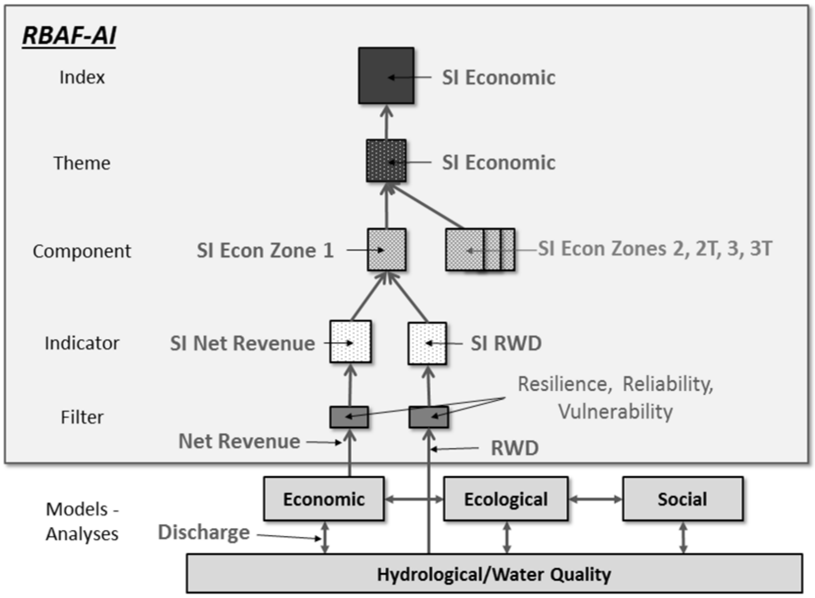


Figure 33. The Decision Tree used to compute the Economic SI Index score from relative water deficiency (RWD) and net revenues per economic zone. The figure shows the path followed from data output from the economic analysis and LRBM in Zone 1 to the Economic SI Index score. The grey labels in the Component Level are the SI scores from the other economic zones.

Table 27. Sustainability criteria used to compute net revenue SI Indicator values and SS Flags for the economic analysis.

Criteria	**Unit**	**Demand Zone 1**	**Demand Zone 2**	**Demand Zone 2T**	**Demand Zone 3**	**Demand Zone 3T**
Lower SI Threshold	% Revenues	0	0	0	0	0
Lower SI Duration	Year	2	2	2	2	2
Lower SS Critical Limit	% Revenues	-20	-20	-20	-20	-20
Upper SI Threshold	% Revenues	n/a	n/a	n/a	n/a	n/a
Upper SI Duration	Years	n/a	n/a	n/a	n/a	n/a
Upper SS Critical Limit	% Revenues	n/a	n/a	n/a	n/a	n/a
Evaluation Period Start	Day-Mon.	Oct-1	Oct-1	Oct-1	Oct-1	Oct-1
Evaluation Period End	Day-Mon.	Sept-30	Sept-30	Sept-30	Sept-30	Sept-30

Table 28. Revenues, economic SI Index scores, and SS Flags for the Baseline and Optimized Irrigation Scenarios.

	Baseline Scenario			**Optimal Irrigation Scenario**		
Year	**Revenues**	**SI Value**	**SS Flag**	**Revenues**	**SI Value**	**SS Flag**
2000	$ 348	0.65	No	$ 383	0.75	No
2001	$ 439	0.54	No	$ 496	0.64	No
2002	$ 595	0.52	No	$ 676	0.62	No
2003	$ 694	0.54	No	$ 796	0.65	No
2004	$ 401	0.5	Yes	$ 466	0.61	No
2005	$ 488	0.52	No	$ 563	0.63	No
2006	$ 677	0.55	No	$ 773	0.66	No
2007	$ 591	0.52	No	$ 661	0.61	No
2008	$ 793	0.6	No	$ 894	0.71	No
2009	$ 937	0.68	No	$ 1,036	0.79	No
2010	$ 847	0.66	No	$ 954	0.78	No
2011	$ 1,049	0.7	No	$ 1,141	0.8	No
2012	$ 477	0.55	No	$ 563	0.65	No

Based on RWD and revenue from economic model, the SI Indicator scores for net revenue and water deficiency per economic zone are aggregated to the Economic Index according to the Decision Tree in Figure 33. The Indicator Level represents the SI Indicator scores for net revenue and RWD per economic zone. The Component Level combines the SI Indicator scores to determine the SI Economic score per economic zone. In this analysis, SI Indicator scores for net revenue and RWD were weighted 0.7 and 0.3 for all zones. The Component Level scores from the 5 economic zones were weighted evenly and combined to form Theme Level scores. The Theme Level score is equal to the Economic Index score.

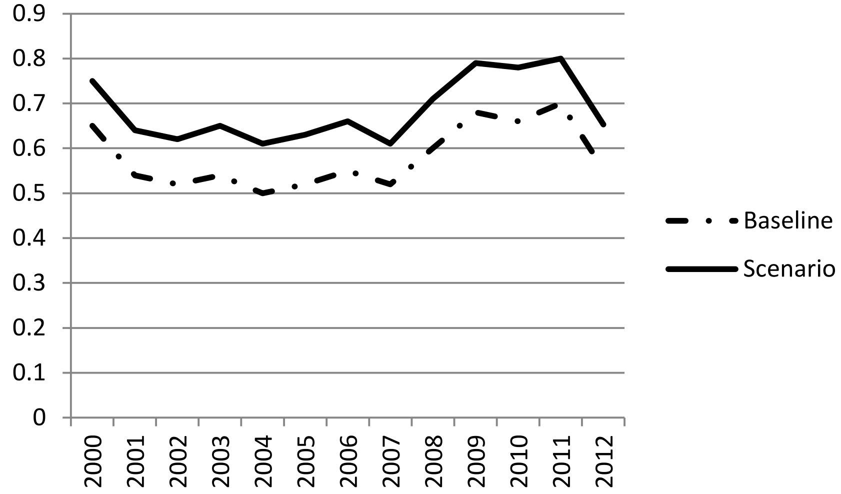


Figure 34. Economic SI Index scores for the Baseline and Optimized Irrigation Scenarios.

Limitation and future recommendations for the agricultural economic analysis and computation of the Economic SI Index of the LRB include:

- Economic analysis only evaluates hay and alfalfa production as well as pasture rental rates. As cattle production is the primary source of income, the economic analysis should be extended to include revenues raised through cattle sales.
- It is assumed that all the production rates across all zones are equal. In reality, the tons per acre vary depending on the location in the basin due to soils and the lower elevations have a the longer growing season, for example: pastures near Salmon can yield a third crop.
- The analysis only uses a single discount rate to develop the supply and demand curves. A sensitivity analysis should be conducted as to the impact of this parameter.
- Future analyses should be expanded to include the impacts of subsidies for installation of sprinkler systems.
- Other economic sectors could be included in the economic analysis, for example: the tourism industry representing hunting, fishing, and boating .

Ecology - For computing the resilience, reliability, and vulnerability, the lower acceptable range threshold of daily percentage of maximum habitat for selected species' life stages that were assumed to be key limiting factors for the aquatic conditions in the river. These ecological parameters were assumed to be 50% daily percentage of maximum habitat with duration for spawning and adult being 3 and 7 days (Table 29). The seasonal period for each species life stage was determined from the USGS report (Sutton & Morris 2005) (Table 30). In addition, SS daily limit whereupon the conditions are no longer acceptable regardless of the resilience, reliability, and vulnerability score was assumed to be 20% daily percentage of maximum habitat. The SI Life Stage scores for each life stage per species at a site were computed using Equation 6 and the result input to the decision tree for aggregation to the SI Ecological score (Figure 35).

Table 29. Sustainability criteria used to compute the SI Indicator values and SS Flags for the ecological analysis.

Sustainability Criteria	**Unit**	**Steelhead Spawning**	**Steelhead Adult**	**Chinook Spawning**	**Chinook Adult**	**Bull Trout Spawning**	**Bull Trout Adult**
Lower Threshold	%WUA	50.0	50.0	50.0	50.0	50.0	50.0
Lower Duration	Days	5.0	7.0	5.0	7.0	5.0	14.0
Lower SS Threshold	%WUA	20.0	20.0	20.0	20.0	20.0	20.0
Upper Threshold	%WUA	n/a	n/a	n/a	n/a	n/a	n/a
Upper Duration	Days	n/a	n/a	n/a	n/a	n/a	n/a
Upper SS Threshold	%WUA	n/a	n/a	n/a	n/a	n/a	n/a
Evaluation Period Start	Day-Mon.	1-Apr	1-Mar	1-Jul	1-May	1-Sep	1-Mar
Evaluation Period End	Day-Mon.	30-Jun	30-Jun	31-Oct	31-Oct	31-Oct	31-Oct

Based on flow and the ecological model, the SI Life Stage scores per species are aggregated to the final ecological score according to the Decision Tree in Figure 35. The Indicator Level represents the SI Life Stage scores per species at each site. The Component Level combines the SI Life Stage scores to determine the SI Species score per site. The Theme Level is the combination of the SI Species scores for the 12 sites to form a single SI Summary Species Score per species and the Index Level compares the SI Summary Species Scores to derive the SI Ecological Score.

Table 30. Periodicity chart for steelhead in Lemhi River Drainage (EA Engineering 1991, Sutton & Morris 2005). The term *S* denotes steelhead, *C* denotes Chinook salmon, and *B* denotes bull trout.

Life Stage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Adult			S,B	S,B	S,C,B	S,C,B	C,B	C,B	C,B	C,B		
Spawning				S	S	S	C	C	C,B	C,B		
Incubation	C,B	C,B	C,B	S,C,B	S,C,B	S	S,C	S,C	C,B	C,B	C,B	C,B
Fry			C,B	C,B	S,C,B	S,C,B	S,C,B	S,B	S,B	S,B		
Juvenile	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B	S,C,B
Outmigration		S	S,C	S,C	S,C	S,C						

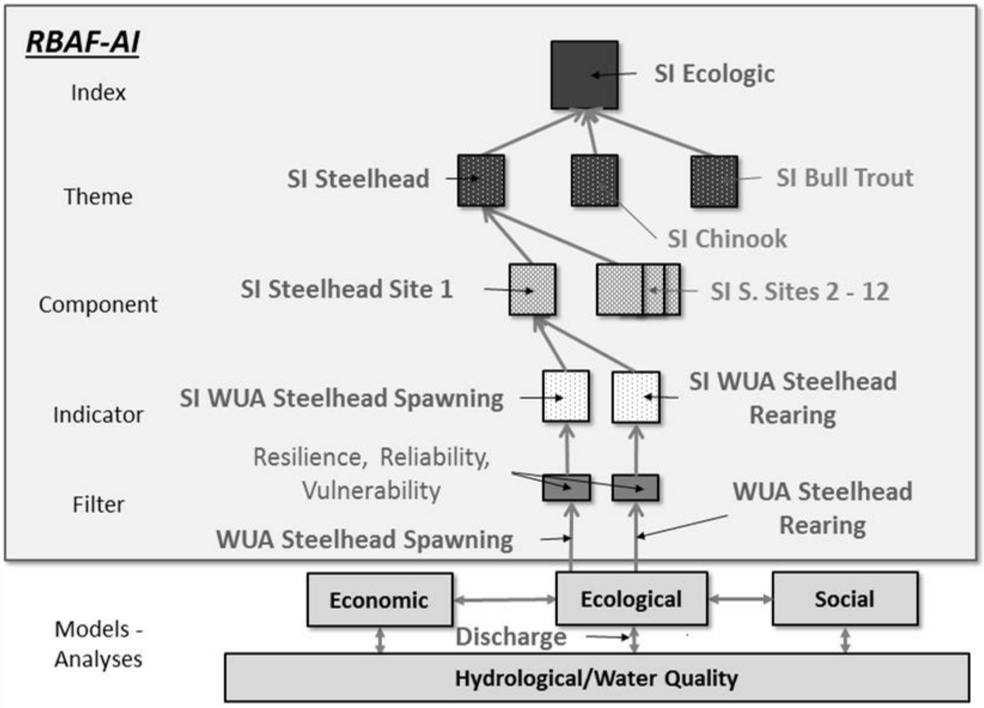


Figure 35. Decision tree used to compute the Ecological SI Index from the habitat assessment of weighted usable area (WUA) from a site. The figure shows the path followed from ecological data output at Site 1 to the Ecological Index score. The grey labels in the Component Lever are SI scores from different sites and the Theme Level are the SI scores from the other species.

Ecological SI Index scores increased from 0.67 to 0.72 in the Baseline and Optimized Irrigation Scenarios (Table 31). Results from both scenarios followed the water year type, increasing with more abundant water availability (Figure 36), but were more sensitive to changes when water availability was below 100% average. Individual Species SI Scores also followed the Ecological SI Index scores fairly closely. Thus according to the results, there is a slight improvement to the habitat conditions when the optimal sprinkler distribution is implemented as more water is delivered to the PHABSIM study sites. It should be noted that the Ecological SI Index scores primarily represent habitat conditions in the upper basin where the PHABSIM studies were conducted. Given the decrease in flows later in the season, it is anticipated that the Ecological SI Index score for the SPOS could decrease when the entire basin is taken into consideration.

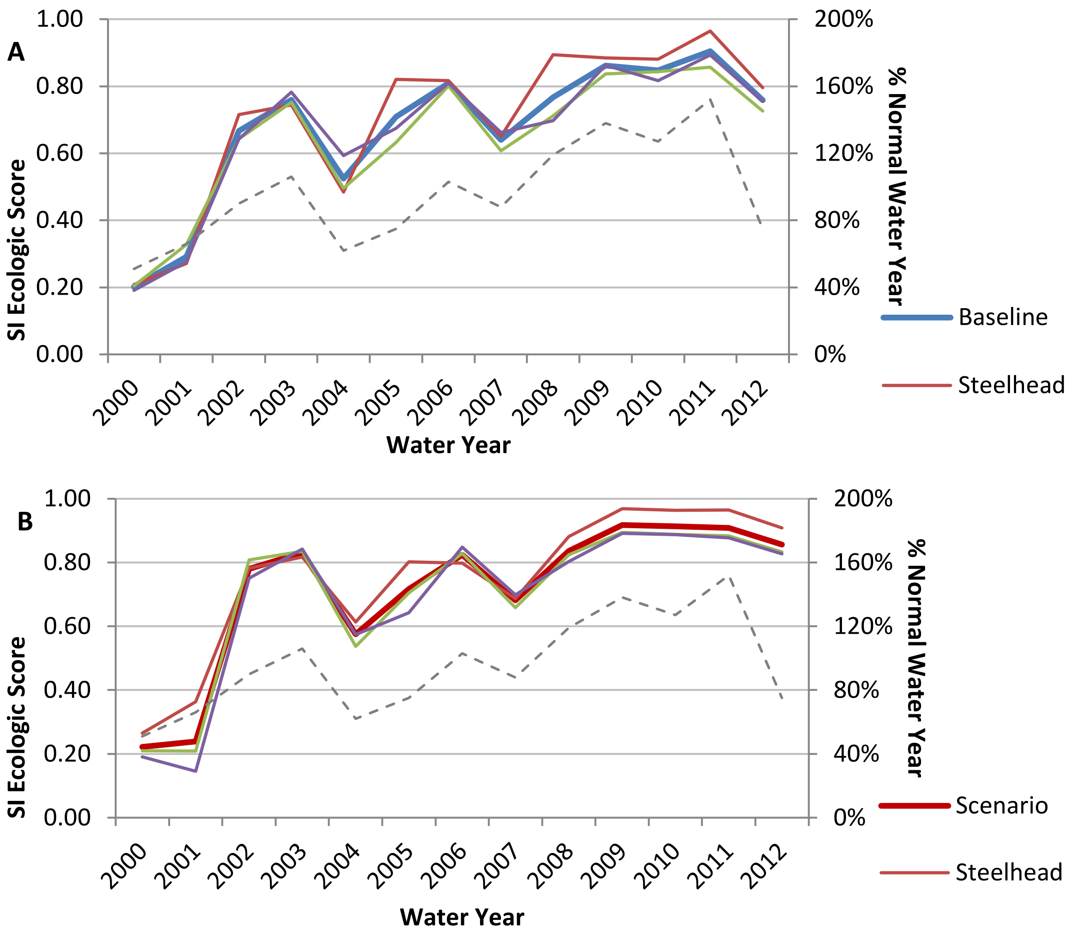


Figure 36. Ecological Index Scores and individual species SI Ecological Scores for the Baseline (A) and Optimized Irrigation (B) Scenarios in the LRB.

Limitation and future recommendations for the ecological analysis and computation of the Ecologic Index of the LRB include:

- The current allocation of sites used to evaluate habitat conditions is not well distributed throughout the basin, with sites concentrated near the headwaters where the PHABSIM studies have been conducted. Future efforts should extend the habitat analysis throughout the basin with more comprehensive and complex methods such as ELOHA (Poff et al. 2010).
- For this analysis, the sustainability criteria for all species equal across species and sites, future efforts should have local fisheries biologist refine the lower and upper thresholds and SS Flags.
- Similarly, the current assessment evenly weighs all levels in the Decision Trees evenly regardless of location, importance of habitat, and species. As fish use reaches differently

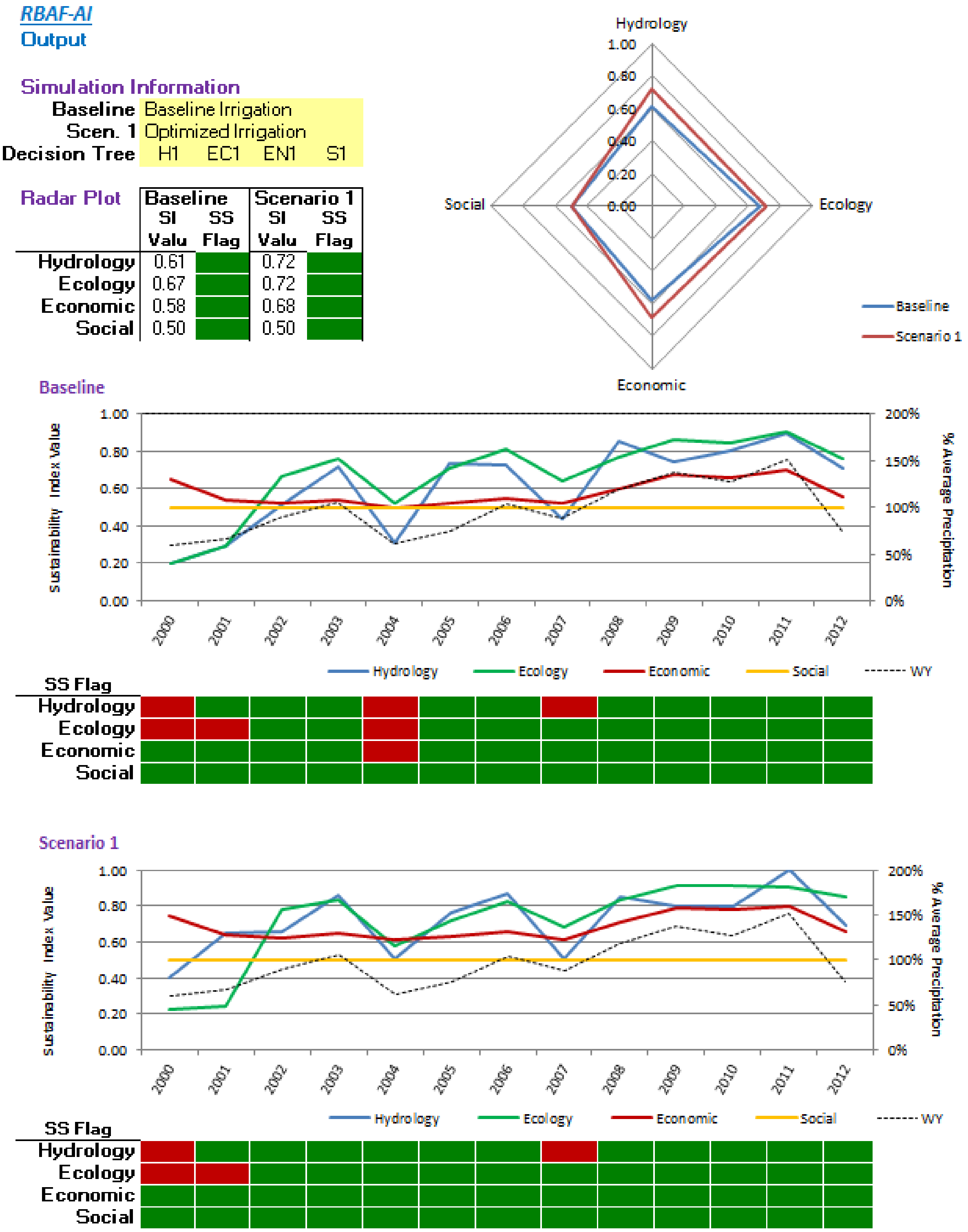
throughout the basin, future efforts should have local fisheries biologist refine the importance of these factors throughout the basin.

Table 31. Tabular results of the Ecological SI Scores and SS Flags for the Baseline and Optimized Irrigation Scenarios.

	Water Year	Baseline		Scenario	
Year	[% normal]	SI Score	SS Flag	SI Score	SS Flag
Overall	n/a	0.67	FALSE	0.72	FALSE
2000	51%	0.20	TRUE	0.22	TRUE
2001	66%	0.29	TRUE	0.24	TRUE
2002	90%	0.67	FALSE	0.78	FALSE
2003	106%	0.76	FALSE	0.83	FALSE
2004	62%	0.52	TRUE	0.57	FALSE
2005	75%	0.71	FALSE	0.72	FALSE
2006	103%	0.81	FALSE	0.82	FALSE
2007	88%	0.64	FALSE	0.68	FALSE
2008	119%	0.77	FALSE	0.84	FALSE
2009	138%	0.86	FALSE	0.92	FALSE
2010	127%	0.85	FALSE	0.91	FALSE
2011	152%	0.90	FALSE	0.91	FALSE
2012	75%	0.76	FALSE	0.86	FALSE

6.2.3.2 Result Interface

The RBAF-AI interface indicates that the increasing the sprinkler in the LRB to the levels in the Optimized Irrigation Scenario will result in an increase in the Hydrology, Ecologic, and Economic SI Indexes by 11, 5, and 10 points, respectively. While there are SS Flags in the annual data, none of the SI Indexes exhibit SS Flags (Figure 37). The Hydrologic and Ecologic SI Indexes are more sensitive to the water year than the Economic SI Index. That said, there is no drastic or significant change in the Baseline and Optimized Irrigation Scenario with regards to SS Flags. For this scenario, there are no trade-offs for increasing sprinklers as all Indexes show increase. However, that is most likely misleading as the Ecological SI Index is calculated only on sites from the upper basin. This exhibits a limitation with the interface as it provides an overview, but does not have the capability to drill down into the underlying numbers supporting the results. Future developments will allow data mining allowing greater depth of understanding into the final calculated values.



RBAF-AI
Output

Simulation Information

Baseline	Baseline Irrigation
Scen. 1	Optimized Irrigation
Decision Tree	H1 EC1 EN1 S1

Radar Plot

	Baseline		Scenario 1	
	SI Valu	SS Flag	SI Valu	SS Flag
Hydrology	0.61	🟩	0.72	🟩
Ecology	0.67	🟩	0.72	🟩
Economic	0.58	🟩	0.68	🟩
Social	0.50	🟩	0.50	🟩

Baseline

SS Flag

Hydrology	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
Ecology	🟥	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Economic	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Social	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Scenario 1

SS Flag

Hydrology	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
Ecology	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Economic	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Social	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Figure 37. Sustainability assessment of the Baseline and Optimized Irrigation Scenarios for the LRB case study.

6.3 Discussion

Important elements of effective frameworks and DSS that support IWRM analysis include the ability to frame water resource issues and related factors in the participatory setting; identify analyses and indicators to employ given water resource issues; be capable of evaluating a range of decisions, from simple to complex (Millington et al. 2011); support the organization of input and output data in evaluating alternatives; provide a flexible structure to accommodate evolution of decisions, issues, data, scenarios, and models (Millington et al. 2011); and produce reliable and transparent output that is linked to relevant indicators used in the evaluating policies and decisions directly or indirectly affecting water resources in a basin. The RBAF-AI has been developed to support the analytical assessment of WRM decisions with respect to these elements.

The strength of the RBAF-AI in supporting the IWRM process is its flexibility to accommodate different water resource issues, reliability and transparency in computing indexes, and the display in the Reporting Interface. RBAF-AI accepts results from a variety of analytical methods that allows for a variety of water resource issues and cultural settings. Based on the recommended impact indicators from the RBAF-CT, the RBAF-AI is able to apply a variety of data filters at different spatiotemporal scales through Decision Trees to derive discipline Indexes. This implies that the RBAF-AI can be adapted to changing understanding of basin systems, improved or new data and analytical methods, emerging water resource issues, and shifting social attitudes and preferences.

The accuracy and reliability of the RBAF-AI results are based on the discipline specific analyses; the SI thresholds, vulnerability duration period, and SS Flag value used by filters to compute the SI Indicators; and the weighting of the factors in the Decision Tree. The RBAF-AI results are no more accurate than the SC system analyses and understanding of the thresholds and capacities of the systems in the basin. Thus, results from basins with limited data and analytical methods have greater uncertainty in the results presented in the RBAF-AI Reporting Interface.

Uncertainty manifests in the general understanding of the discipline specific system processes, understanding of the interaction between discipline specific systems, the accuracy of algorithms used to simulate the systems, the spatiotemporal abundance and accuracy of the data used to support the analyses, and the ability to predict future conditions. These limitations are not unique to the RBAF-AI as they occur in any analytical framework being used to support decision-making.

Potential means of addressing uncertainty include sensitivity analysis through changing a parameter or series of parameters systematically or through a Monte Carlo analysis.

Extending sensitivity discussion further, the RBAF-AI Reporting Interface currently reports a basin wide analysis of the discipline Index scores. While this does show perturbations of sufficient magnitude, depending on the basin size, accuracy of analyses, and indicators used, the reporting Indexes may be insensitive to show the impact of local disturbances. For example, in the LRBM case study, changing operations of a single water user may not show changes in the basin-wide Indexes but may have influence is the downstream reaches of the tributary. As suggested later on, the RBAF-AI Reporting Interface could be expanded to show local results in order to address this limitation.

Knowledge of a system's capacity to endure and recover from disturbances is required for filtering the analytical data into SI values (ASCE 1997). Setting the SI thresholds, vulnerability duration period, and SS Flag value can result in systems being sustainable or unsustainable. Therefore, scientific knowledge and judgment of the SC disciplines is necessary for properly defining a system's is susceptibility to disturbances including the magnitude of change that the system can endure as well as tipping points from which there will be a permanent alteration to the system.

Weighting of SI values in the Decision Trees can influence the final SI Indexes. In the lower levels of the decision trees, the selection of weighting values tends to be more based in scientific reason, but the higher the level, the more societal values play a factor. For example, habitat modeling for a site may incorporate flow, stream temperature, and substrate as filtered data into the decision tree. The relative importance of these SI values for bull trout spawning conditions at the SI Indicator level can be based on scientific studies. Moving up to the Component Level, choices between the different life stages at the location becomes professional judgment for the fisheries biologist with expertise in the basin. Finally, choosing between the importance of steelhead, Chinook salmon, and bull trout to determine the SI Ecological Index becomes a societal judgment. Changing the weighting at any level can change results. As the weighting has greater societal influence, the more controversial the weights become and are open for interpretation between different user groups. The RBAF-AI can be used to test alternative weighting schemes between user groups to determine the impact to sustainability assessment and foster discussion between differing opinions.

The RBAF-AI Results Interface reports the water resources sustainability results in a reductionist manner as outcomes of are presented as Hydrologic, Ecologic, Economic, and Social Index scores. Cook & Spray (2012) suggests that a limitation of implementing IWRM has been the use of a reductionism approach, thus missing the complexity in the nonlinear spatiotemporal relations and feedback loops between ecological, economic, and social systems. While the RBAF-AI does report the results in a reductionist manner, it does support complex systems analysis is two means. First, the RBAF-AI receives the results from analysis and thus if the systems' analyses reflects the complex nature of their relationships, then these connects should be reflected in the Index scores. Second, the data from any analyses can be combined or used in multiple locations to reflect the importance in multiple disciplines. In the case study, water deficiency is used to calculate both the Hydrologic, and Economic Index scores. Thus, impact to the hydrological distribution directly affects the outcome in multiple Index scores.

Loucks (1985) reported that a major impediment to the acceptance of modeled solution is the inability to articulate the results to stakeholders in a relevant and useful manner. Conveying the assessment results of water resource sustainability in the basin, the current interface employs both graphs and flags. Displaying both overall and time series charts allows decision makers and stakeholders to easily assess the impacts and trade-offs associated with a change in water resource management in the discipline specific analyses. However, it is recognized that other displays will likely need to be created to support understanding of participants in other setting and cultures. As the tool is currently built in Microsoft EXCEL, a widely used program worldwide, the interface can be modified to accommodate participant requirements.

Another limitation in the Reporting Interface is that only the discipline indexes are displayed. As the output data and calculations supporting the assessment are within the RBAF-AI, the ability to display the assessment data used to generate the discipline indexes could be very helpful in understanding how the results were developed, identifying the limiting factors, evaluating local conditions in a basin, and examining how the systems responded through time. Expanding the Reporting Interface involves determining the participants' needs as well as what elements wish to be examined. To expand the interface, a solid knowledge of Microsoft EXCEL is required as is a rudimentary knowledge of the Visual Basic for Applications (VBA) for automatically loading results into Microsoft EXCEL from external result files and/or applying filters if modified from those in the RBAF-AI Reporting Interface for the LRB case study.

6.4 Future Development

The implementation of the RBAF-AI case study was intended as a proof of concept and therefore limited in development of its computational and interface capabilities. To extend the RBAF-AI usefulness and address limitation outlined above, future enhancements to the RBAF-AI could include:

- To support sensitivity analyses of the analyses, the results should include confidence boundaries on the SI Indexes based on sensitivity analyses, thus providing users an understanding of the range of results for each index.
- In the current RBAF-AI Reporting Interface only the Index level scores are presented and thus the data and logic supporting the final indexes is hidden to the user. This data is available and can be examined for a deeper understanding of the components benefiting and limiting conditions within each scenario. Future developments of the RBAF-AI Reporting Interface should enable the users to mine this supporting analysis in order to hone in on the greatest contributing factors in the analyses.
- Extending the previous bullet, the RBAF-AI Reporting Interface only reports the Index level scores in a graphic format. The interface results for the supporting analysis have spatial locations for many of the systems. The reporting tool could be extended to report the results spatially. For example, displaying the aquatic habitat throughout the LRB would provide users a better understanding of the habitat distribution in the basin. These results could also be presented with the RBAF-CT delineation as a backdrop for continuity between formation and analysis of the problem.
- As weighting of the analyses is independent of the analytical results and filter computation, a graph can be produced that shows the sensitivity of the each level to the weights chosen. This will show users if the weighting of an SI parameter differently will result in alternative results.
- To foster discussion amongst different stakeholder groups, a map comparing weights used in Decision Trees could be developed. This would allow for a quick evaluation of where groups agree and disagree, thus illuminating points of dissention for discussion.
- The RBAF-AI has been developed to support the IWRM process. However, it is envisioned that the tool could be modified to address other issues such as water- energy-food security, planned and autonomous adaptability, and build resilience studies.

6.5 Conclusion

The RBAF-AI is an interface that organizes output from hydrologic, ecologic, economic, and social systems analyses in order to assess the sustainability of water management alternatives. Its flexibility to accommodate different water resource issues, reliability and transparency in computing indexes, and the display in the Reporting Interface are important for supporting the IWRM process. When coupled with the RBAF-CT, the RBAF-AI provides a mechanism for water managers and stakeholders to develop and analyze water management alternatives. The sprinkler conversion case study in the LRB demonstrates that the RBAF-AI can be used to assess the water resources sustainability in basins. Due to the flexibility, the RBAF-AI has great potential to be applied in basins worldwide to assess other water resource management issue.

Chapter 7. Final Thoughts

Methodologies supporting IWRM implementation have largely focused on the overall process, but provide limited guidance on evaluation methods of ecologic, economic, social, and changing climatic conditions. Important elements of effective frameworks and DSS supporting IWRM analysis include the ability to frame water resource issues in the participatory setting; be capable of evaluating a range of decisions, from simple to complex; identify analyses and indicators to employ given water resource issues; support the organization of input and output data in evaluating alternatives; produce reliable and transparent output that is linked to relevant indicators used in the evaluating policies and decisions directly or indirectly affecting water resources in a basin; and provide a flexible structure to accommodate evolution of decisions, issues, data, scenarios, and models. The author is unfamiliar with any frameworks and DSS that have capacity to address all of these elements.

The River Basin Analysis Framework (RBAF) has been developed to identify and employ analytical processes for conducting assessments of water resource sustainability and policy alternatives in a structured, reliable, and transparent manner. The RBAF merges the UN GEO 4 DPSIR Framework, the MA Framework, and principles of sustainable development to enable users to better understand spatiotemporal interactions between hydrologic, socio-economic, and ecologic systems. The framework uses the UN GEO4 DPSIR Framework strength in linking causal-effects relationships in a basin coupled with the MA Framework's strength in linking impacts to EGS and human well-being, to evaluate water resource management according to the principles of sustainability. The RBAF supports the IWRM process by providing a structured means to frame and analyze water related issues and select appropriate indicators to assess the sustainability of water programs and policies in river basins.

The RBAF is composed of a Conceptual Template (RBAF-CT), for appraising the situation and guiding indicator selection, and an Analytical Interface (RBAF-AI) for organizing and processing analytical results. The RBAF-CT connects constituents of human well-being directly, or through ecological goods and services, to the relevant hydrologic cycle components. Associated with these constituents/components are relevant pressure, state, and impact indicators for use in assessing conditions and analyzing ecological, economic, and social conditions. Driver Templates for 9 pressure types (e.g. climate change, population growth) guide users on the potential changes to the hydrological cycle and associated systems. Given the pressure, state, and impact indicators identified by the RBAF-CT, the RBAF-AI organizes the output data from hydrologic, ecologic, economic, and social analyses and, with respect to time and space, computes the reliability, resilience, and vulnerability of the impact indicators for various water use scenarios and policies in the basin. Scenario results are presented in a timeline of sustainability indicators in ecologic, economic, and social conditions as well as a spider diagram for the overall conditions for easy comparison.

Demonstrating the applicability, the RBAF-CT was applied to the Lemhi River Basin, Idaho, US, and the Upper Bhima Basin, Maharashtra, India and the RBAF-AI to the Lemhi River Basin. Though in two distinct basins with different hydrological, ecological, economic, and social conditions, the RBAF-CT delineated areas of disturbance and indicates freshwater habitat, active EGS, and relevant EGSInfo to consider in each basin. In addition, applying scenarios indicated potential trends in EGS and EGSInfo in response to Drivers/Pressures as well as the indicators to use in formulating analysis. The RBAF-AI demonstrated that the results of the RBAF-CT could be used to formulate the analysis and that from these analyses, sustainability of water resources response to changing irrigation methods could be quantitatively analyzed.

Though the RBAF performed well, this study was a proof-of-concept and thus the RBAF needs further refinement. Suggestions for further refinement include:

- Testing in a participatory setting. While the RBAF was develop with consultation in the LRB, that consultation was limited. As the RBAF needs to support the participatory element of IWRM, a full participatory case study is needed.
- Test on basins with different types of water resources issues. The Driver Templates for climate change, water demand change, population increase, and infrastructure where used, others still need to be tested and refined.
- Develop a GIS interface for the RBAF-CT. As much of the base analysis is spatially based, it would greatly facilitate application of the RBAF-CT in a public meeting if it was built into a GIS platform.
- RBAF-AI presents top level results for water resource sustainability in basins. However, the limiting factor is commonly factors underlying the SC Indexes. The RBAF-AI interface should

be improved to allow water managers and stakeholders to more easily view the supporting data.

- The RBAF has been developed to support the IWRM process. However, it is envisioned that the tool could be modified to address other studies such as water- energy-food security, planned and autonomous adaptability, and build resilience.

Other suggestions for specific functionality are included in the RBAF-CT and RBAF-AI discussion sections in Chapters 5 and 6, respectively. With these improvements, a more robust RBAF can be used to manage water worldwide.

References

Acharya, Gayatri. 2000. Approaches to valuing the hidden hydrological services of wetland ecosystems. Ecological Economics, Vol. 35, pages 63-74.

Alessa, Lilian, Andrew Kliskey, Richard Lammers, Chris Arp, Dan White, Larry Hinzman, and Robert Busey. 2008. The Arctic Water Resource Vulnerability Index: An Integrated Assessment Tool for Community Resilience and Vulnerability with Respect to Freshwater. Environmental Management DOI 10.1007/s00267-008-9152-0.

Alessa, Lilian, Andrew Kliskey, and Mark Altaweel. 2009. Toward a typology for social-ecological systems. Sustainability: Science, Practice, and Policy, Vol. 5, Issue 1, Spring/Summer 2009, pages 31-41.

Alley, William M., Thomas Reilly, and O. Lehn Franke. 1999. Sustainability of Ground-Water Resources. U.S. Geological Survey Circular 1186, Denver, Colorado. 79 pages.

Alley, W.M., and S.A. Leake. 2004. The journey from safe yield to sustainability. Ground Water, Vol. 42, No. 1, pages 12-16.

ASCE. 1998. Sustainability Criteria for Water Resource Systems. Task Committee on Sustainability Criteria, Water Resources Planning and Management Division, ASCE and the Working Group of UNESCO/IHP IV Project M-4.3, D.P. Loucks, (committee chairman), Reston, VA: American Society of Civil Engineers, 1998. 253 pages.

Avriel, Mordecai. 2003. Nonlinear Programming: Analysis and Methods. Dover Publishing. 528 pages.

Azar, Christian, John Holmberg, and Kristian Lindgren. 1996. Socio-ecological indicators for sustainability. Ecological Economics, Vol. 18, pages 89-112.

Bangash, Rubab, Ana Passuello, María Sanchez-Canales, Marta Terrado, Alfredo López, F. Javier Elorza, Guy Ziv, Vicenç Acuña, and Marta Schuhmacher. 2012. Ecosystem services in Mediterranean river basin: climate change impact on water provisioning and erosion. Science of Total Environment, Vol. 458-460, pages 246-255.

Bateman, Ian J., Georgina M Mace, Carlo Fezzi, Giles Atkinson, and Terry Turner. 2010. Economic Analysis for Ecosystem Service Assessments. Environment Resource Economics. Springer Science + Business Media. Published online October 2010.

Batker, David K. 2005. Tolt River Watershed Asset Management Plan. Supplemental Ecological Services Study Report, Earth Economics, Seattle Washington, December 16, 2005, 64 Pages.

Bangash, Rubab F., Ana Passuello, María Sanchez-Canales, Marta Terrado, Alfredo López, F. Javier Elorza, Guy Ziv, Vicenç Acuña, and Marta Schuhmacher. 2012. Ecosystem services in Mediterranean river basin: climate change impact on water provisioning and erosion control. Science of the Total Environment, Vol. 458–460, pages 246-255.

Baumgärnter, Stefan and Martin Quaas. 2010. What is sustainability economics? Ecological Economics, Vol. 69, pages 445-450.

Bélair C., Ichikawa K., Wong B.Y. L., and Mulongoy K.J. (Editors). 2010. *Sustainable use of biological diversity in socio-ecological production landscapes*. Background to the 'Satoyama Initiative for the benefit of biodiversity and human well-being.' Secretariat of the Convention on Biological Diversity, Montreal, Technical Series No. 52. 184 pages.

Bell, Simon and Stephen Morse. 2008. Sustainability Indicators, Measuring the Immeasurable? Second Edition. Earthscan, Sterling, Virginia. 228 pages.

Bizikov, Livia, Dimple Roy, Darren Swanson, Henry David Venema, and Matthew McCandless. 2013. The Water–Energy–Food Security Nexus: Towards a practical planning and decision-support framework for landscape investment and risk management. IISD Report, Winnipeg, Canada, February 2013. 25 pages.

Blöschl, G. and M. Sivapalan. 1995. Scale issues in hydrologic modelling: a review. Hydrological Processes 9: pages 251-290.

Booker, James F., Richard E. Howitt, Ari M. Michelsen, and Robert A. Young. 2012. Economics and the Modeling of Water Resources Policy. Natural Resources Modeling, Vol. 25, No. 1, February 2012, pages 168-218.

Brauman, Kate A., Gretchen C. Daily, T. Ka'eo Duarte, and Harold A. Mooney. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. Annual Review of Environment and Resources. Vol. 32, pages 67-98.

Brunner, N. and M. Starkl. 2004. Decision aid systems for evaluating sustainability: a critical survey. Environmental Impact Assessment Review, Vol. 24, Issue 4, pages 441-469.

Burton, Jean. 2003. Integrated Water Resource Management on a Basin Level: A Training Manual. UNESCO Report. 241 pages.

Cai et al. 2002. A framework for sustainability analysis in water resources management and application to the Syr Darya Basin. Water Resources Research, Vol. 38, No. 6, pages 21-1 to 21-14.

Cap-Net. 2005. Integrated Water Resources Management Plans Training Manual and Operational Guide. UNDP Cap-Net Report, June 2005. 97 pages.

Cap-Net. 2008. Integrated Water Resources Management for River Basin Organisations Training Manual. UNDP Cap-Net Manual, June 2008. 93 pages.

Chaves, Henrique M. L. and Suzanna Alipaz. 2007. An Integrated Indicator for Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index. Water Resources Management, Vol. 21, Issue 5, pages 883-895.

CBD. 2000. Sustaining life on earth, how the Convention on Biological Diversity promotes nature and human well-being. Convention of Biological Diversity Report, April 2000. 20 pages.

Collins, Scott L., Stephen R Carpenter, Scott M Swinton, Daniel E Orenstein, Daniel L Childers, Ted L Gragson, Nancy B Grimm, J Morgan Grove, Sharon L Harlan, Jason P Kaye, Alan K Knapp, Gary P Kofinas, John J Magnuson, William H McDowell, John M Melack, Laura A Ogden, G Philip Robertson, Melinda D Smith, and Ali C Whitmer. 2010. An integrated conceptual framework for long-term social–ecological research. Frontiers Ecological Environ, Vol. 9, Issue 6, pages 351-357.

Contor, Bruce. 2008. Demand-PriceEffects.xls. Spreadsheet, Idaho Water Resources Research Institute (USA), Idaho. March 2008.

Cook, Brian R. and Christopher J. Spray. 2012. Ecosystem services and integrated water resource management: Different paths to the same end? Journal of Environmental Management, Vol. 109, 30 October 2012, pages 93-100.

Costanza Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387, 15 May 1997, pages 253-260.

Daily, G. 1997. <u>Nature’s Services: Societal Dependence on Natural Ecosystems</u>. Island Press, Washington, DC.

Daily, G.C., S. Alexander, P.R. Ehrlich, L. Goulder, J. Lubchenco, P.A. Matson, H.A. Mooney, S. Postel, S.H. Schneider, D. Tilman, and G.M. Woodwell. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues in Ecology No. 2. Ecological Society of America. 16 pages.

de Groot, R.S., M.A. Wilson, and R.M.J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, Vol. 41, pages 393–408.

de Groot, R.S., Brendan Fisher, and Mike Christie. 2010. Chapter 1, integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In <u>The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations</u>. March 2010, pages 1-33.

DHI. 2003. Evaluation of Diversion Operations Plans to Meet Negotiated Flow Targets for Salmon and Steelhead in the Lemhi River Basin Using the MIKE BASIN Model. DHI Water and Environment, Inc. report prepared for U.S. Bureau of Reclamation and Idaho Department of Water Resources. DHI Water and Environment, Inc., Boise, ID, April 2003, 41 pages.

DHI. 2006. The Lemhi River MIKE BASIN Model: A Tool for Evaluating Stream Flows, Diversion Operations and Surface Water – Ground Water Relationships in the Lemhi River. DHI Water and Environment, Inc. Report prepared for Idaho Department of Water Resources, Boise, Idaho. 32 pages.

DHI. 2009. Development of Decision Support System for Integrated Water Resources Development and Management, Hydrology Project-II, Volume VIII Needs Assessment – Maharashtra. DHI Water and Environment, Inc. Report prepared for National Institute of Hydrology, September 2009. 44 pages.

Diamond, Jared. 2006. Collapse: How Societies Choose to Fail or Succeed. Penguin Publishing. 575 pages.

Dong, Zhengju, Yan Yan, Jing Duan, Xiao Fu, Qingrong Zhou, Xiang Huang, Xiangen Zhu, and Jingzhu Zhao. 2011. Computing payment for ecosystem services in watersheds: An analysis of the Middle Route Project of South-to-North Water Diversion in China. Journal of Environmental Sciences, Vol. 23, No. 12, pages 2005–2012.

Dresner, Simon. 2008. The Principles of Sustainability, 2nd Edition. Earthscan, Sterling, Virginia. 205 pages.

European Environmental Agency (EEA). 1997 "Environmental Terminology and Discovery Service". http://glossary.eea.europa.eu/terminology/concept_html?term=dpsir. Viewed May, 2013.

Falkenmark, Malin and Carl Folke. 2002. The ethics of socio-ecohydrological catchment management: towards hydrosolidarity. Hydrology and Earth System Sciences, Vol. 2, No. 1, pages 1-9.

Fanai, Nick and Donald H. Burn. 1997. Reversibility as a sustainability criterion for project selection. In International Journal of Sustainable Development and World Ecology, Vol.4, Issue 4, pages 259-273.

Forslund, Anna ,Birgitta Malm Renöfält, Karen Meijer, Karin Krchnak, Katharine Cross, Mark Smith, Michael McClain, Sarah Davidson, Stefano Barchiesi, and Tracy Farrell. 2009. Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows. Swedish Water House Report 24, SIWI. 52 pages.

Frissell, Christopher A. , William J. Liss, Charles E. Warren, and Michael D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management, Vol. 10, Issue 2, pages 199-214.

Garrick, D., M.A. Siebentritt, B. Aylward, C.J. Bauer, and A. Purkey. 2009. Water markets and freshwater ecosystem services: Policy reform and implementation in the Columbia and Murray-Darling Basins. Ecological Economics, Vol. 69, pages 366–379.

Gilvear David J., Chris J. Spray, and Roser Casas-Mulet. 2013. River rehabilitation for the delivery of multiple ecosystem services at the river network scale. Journal of Environmental Management Vol. 126, pages 30-43.

Giupponi, Carlo, Anthony J. Jakeman, Derek Karssenberg, and Matt P. Hare (editors). 2006. Sustainable Management of Water Resources: An Integrated Approach. Edward Elgar Publishing. 384 pages.

Gleick, P. H. 1995. Global water resources in the 21st Century; where should we go and how should we get there? In water quality management, heading for a new epoch. Proceedings of the fifth Stockholm Water Symposium, Stockholm Water Company, Stockholm Sweden, pages 73-78.

Gowan, Charles, Kurt Stephenson, and Leonard Shabman. 2006. The role of ecosystem valuation in environmental decision making: Hydropower relicensing and dam removal on the Elwha River. Ecological Economics, Vol. 56, pages 508–523.

GWP. 2004. Global Water Partnership Strategy 2004-2008. Global Water Partnership Report. http://www.gwp.org/About-GWP/Publications/Strategy-Documents/.

GWP. 2008. IWRM toolbox. http://www.gwp.org/en/ToolBox/. Viewed June 2008.

GWP. 2009. A Handbook for Integrated Water Resources Management in Basins. Global Water Partnership Report. 104 pages.

Gosain, A. K., Rao, S., and Basuray, D. 2006. Climate change impact assessment on hydrology of 25 Indian River Basins. Current Science India Journal, Vol. 90, pages 346–353.

Government of Canada. 2007. Canadian Water Sustainability Index. Government of Canada Sustainable Development Briefing Note. 4 pages.

Grossman, Malte. 2012. Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin. Ecological Economics, Vol. 83, pages 108-117.

Haines-Young, Roy and Marion Potschin. 2010. The links between biodiversity, ecosystem services and human well-being, *Ecosystem Ecology*. 1st ed. Cambridge: Cambridge University Press, pages 110-139.

Hardi, Peter and Terrence Zdan. 1997. Assessing Sustainable Development, Principles and Practice. International Institute for Sustainable Development (IISD) Report, Winnipeg, Manitoba, Canada. 167 pages.

Harou, Julien J., Manuel Pulido-Velazquez, David E. Rosenberg, Josué Medellín-Azuara, Jay R. Lund, and Richard E. Howitt. 2009. Hydro-economic models: Concept, design, applications, and future prospects. Journal of Hydrology, Vol. 375, pages 627-643

Hauer, F. Richard and Mark S. Lorang. 2004. River regulation, decline of ecological resources, and potential for restoration in a semi-arid lands river in the western USA. Aquatic Sciences, Vol. 66, pages 388-401.

Hein, Lars. 2006. Cost-efficient eutrophication control in a shallow lake ecosystem subject to two steady states. Ecological Economics, Vol. 59, pages 429-439.

Hoehn, John P., Frank Lupi, and Michael C. Kaplowitz. 2003. Untying a Lancastrian bundle: valuing ecosystems and ecosystem services for wetland mitigation. Journal of Environmental management, Vol. 68, pages 273-272.

Hoff, H. 2011. Understanding the Nexus (Background paper for the Bonn2011 Nexus Conference).

Holmes, Thomas P, John C. Bergstrom, Eric Huszar, Susan B. Kask, and Fritz Orr III. 2004. Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. Ecological Economics, Vol. 49, pages 19-30.

Hooper, Bruce P. 2005. Integrated River Basin Governance: Learning from International Experience. IWA Publishing, London, United Kingdom. 306 pages.

Hsu, A., J. Emerson, M. Levy, A. de Sherbinin, L. Johnson, O. Malik, J. Schwartz, and M. Jaiteh. 2014. The 2014 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law and Policy. Available: http://www.epi.yale.edu.

ICIMOD. 2012. Contribution of Himalayan Ecosystems to Water, Energy, and Food Security in South Asia: A nexus approach. International Centre for Integrated Mountain Development (ICIMOD) Report, 2012.

Idaho Soil Conservation Commission. 1995. Model Watershed Plan: Lemhi, Pahsimeroi, and East Fork of the Salmon River. Idaho Soil Conservation Commission Report for the Bonneville Power Administration, November 1995, page 2-18.

Iovanna, Richard and Charles Griffiths. 2006. Clean water, ecological benefits, and benefits transfer: A work in progress at the U.S. EPA. Ecological Economics, Vol. 60, pages 472-482.

IWMI. 2011. Ecosystems for water and food security. International Water Management Institute Report. 178 pages.

Jager, Jill, Dale Rothman, Chris Anastasi, Sivan Kartha, and Philip van Notten. 2008. GEO Resource Book: A training manual on integrated environmental assessment and reporting, Training Module 6, Scenario development and analysis. International Institute of Sustainable Development (IISD) Report, Winnipeg, Manitoba, Canada. 54 pages.

Jansson, ÅÅsa, Carl Folke, Johan Rockström, and Line Gordon. 1999. Linking Freshwater Flows and Ecosystem Services Appropriated by People: The Case of the Baltic Sea Drainage Basin. Ecosystems, Vol. 2, pages 351-366.

Jakeman, A.J. and R.A. Letcher. 2003. Integrated assessment and modeling: features, principles and examples of catchment management. Environmental Modeling and Software, Volume 18 2003, pages 491-501.

Jax, Kurt. 2005. Function and "functioning" in ecology: what does it mean? Oikos, Vol. 111, Fasc. 3, December 2005, pages 641-648.

Jenerette, G. Darrel, Wanli Wu, Susan Goldsmith, Wendy A. Marussich, and W. John Roach. 2006a. Contrasting water footprints of cities in China and the United States. Ecological Economics, Vol. 57, pages 346– 358.

Jenerette, G. Darrel, Wendy A. Marussich, and Joshua P. Newell. 2006b. Linking ecological footprints with ecosystem valuation in the provisioning of urban freshwater. Ecological Economics, Vol. 59, pages 38-47.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. p. 110-127. In D.P. Dodge [ed.] Proceedings of the International Large River Symposium. Canadian Special Publication in Fisheries and Aquatic Sciences, 106.

Juwana, I., B. J. C. Perera, and N. Muttil. 2009. Conceptual framework for the development of West Java water sustainability index. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009.

Juwana, I., B. J. C. Perera, and N. Muttil. 2010a. A water sustainability index for West Java. Part 1: developing the conceptual framework. Water Science and Technology, Vol. 62, No. 7, pages 1629–1640.

Juwana, I., B. J. C. Perera, and N. Muttil. 2010b. A water sustainability index for West Java – Part 2: refining the conceptual framework using Delphi technique. Water Science and Technology, Vol. 62. No. 7, pages 1641–1652.

Juwana, I., N. Muttil, and B.J.C. Perera. 2012. Indicator-based water sustainability assessment — A review. Science of the Total Environment, Vol. 438, pages 357–371.

Kløve, Bjørn, Andrew Allan, Guillaume Bertrand, Elzbieta Druzynska, Ali Ertürk, Nico Goldscheider, Sarah Henry, Nusret Karakaya, Timo P. Karjalainen, Phoebe Koundouri, Hans Kupfersberger, Jens Kvoerner, Angela Lundberg, Timo Muotka, Elena Preda, Manuel Pulido-Velazquez, and Peter Schipper. 2011. Groundwater dependent ecosystems. Part II. Ecosystem services and management in Europe under risk of climate change and land use intensification. Environmental Science and Policy, Vol. 11, pages 782-793.

Kroeger, Heidelore I. and Slobodan P. Simonović. 1997. Development of a risk measure as a sustainable project selection criterion. International Journal of Sustainable Development and World Ecology, Vol. 4, Issue 4, pages 275-285.

Kondolf, G. Matthias. 2000. Historical Changes to the San Francisco Bay-Delta Watershed: Implications for Ecosystems Restoration. Nijland HJ and Cal MJR (Eds), River Restoration in Europe: Practical Applications-Conference on River Restoration: Proceedings. ECRR: Wageningen, The Netherlands, pages 327-338.

Kosoy, Nicolas, Miguel Martinez-Tuna, Roldan Muradian, and Joan Martinez-Alier. 2007. Payments for environmental services in watersheds: Insights from a comparative study of three cases in Central America. Ecological Economics, Vol. 61, pages 446-455.

Kumar, Rupa, K., Sahai, A. K., Krishna Kumar, K., Patwardhan, S. K., Mishra, P. K., Re Vadekar, J. V., Kamala, K., and Pant, G. B. 2006. High-resolution climate change scenarios for India for the 21st century. Current Science India Journal, Vol. 90, pages 334–345.

Leauthaud, Crystele, Stéphanie Duvail, Olivier Hamerlynck, Jean-Luc Paul, Hubert Cochet, Judith Nyunja, Jean Albergel, and Olivier Grünberger. 2013. Floods and livelihoods: The impact of changing water resources on wetland agro-ecological production systems in the Tana River Delta, Kenya. Global Environmental Change, Vol. 23, pages 252–263.

Limaye, S. D. 2010. Groundwater development and management in the Deccan Traps (basalts) of Western India. Hydrogeological Journal, Vol. 18, pages 543–558.

Liquete, Camino, Joachim Maes, Alessandra La Notte, and Giovanni Bidoglio. 2011. Securing water as a resource for society: an ecosystem services perspective. Ecohydrology and Hydrobiology, Vol. 11, No. 3-4, pages 247-259.

Liu, Shuang, Robert Costanza, Stephen Farber, and Austin Troy. 2010. Valuing ecosystem services - Theory, practice, and the need for a transdisciplinary synthesis. Annals of the New York Academy of Sciences 1185, pages 54-78.

Loucks, Daniel P. 1997. Quantifying trends in system sustainability. Hydrological Sciences Journal, Vol. 42:4, pages 513-530.

Loucks, Daniel P., Eelco van Beek, Jery R. Stedinger, Jozef P. M. Dijkman, and Monique T. Villars. 2005. Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications. Studies and Reports in Hydrology, UNESCO Publishing.

Lund, Jay R., Ximing Cai, and Gregory W. Characklis. 2006. Economic Engineering of Environmental and Water Resource Systems. Journal of Water Resources Planning and Management, November/December 2006, pages 399-402.

MA. 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, DC.

MA. 2005a. Ecosystems and Human Well-being: Current States and Trends. Millennium Ecosystem Assessment, Island Press, Washington, DC.

MA. 2005b. Ecosystems and Human Well-being: Scenarios Assessment. Millennium Ecosystem Assessment, Island Press, Washington, DC.

MA. 2005c. Ecosystems and Human Well-being: Responses Assessment. Millennium Ecosystem Assessment, Island Press, Washington, DC.

MA. 2006. Global and Multiscale Assessment Reports. Millennium Ecosystem Assessment, Island Press, Washington, DC.

Malkina-Pykh, Irina. 2002. Integrated assessment models and response function models: pros and cons for sustainable development indexes design. Ecological Indicators, Vol. 3, pages 93-108.

Matheson, Sam, Barbara Lence, and Josef Fürst. 1997. Distributive fairness considerations in sustainable project selection. Hydrological Sciences Journal, Vol. 42, Issue 4, August 1997, pages 531-548.

Mays, Larry. 2007a. Chapter 1: Introduction: Water Sustainability. In Water Resources Sustainability, ed. Larry Mays, WEF Press, Alexandria, VA. Pages 2-15.

Mays, Larry. 2007b. Chapter 2: Water Sustainability: Parallels of Past Civilizations and the Present. In Water Resources Sustainability, ed. Larry Mays, WEF Press, Alexandria, VA. Pages 16-36.

Miller, G. A. 1956. "The magical number seven, plus or minus two: Some limits on our capacity for processing information". Psychological Review, Vol. 63 (2), pages 81–97.

Millington, Peter, Douglas Olson, and Shelley McMillian. 2011. Briefing Note #6, IRBM from Concepts to Good Practice: Systems Modeling in River Basin Management. Bank-Netherlands Water Partnership Program Briefing Note. 20 pages

Milly, P. C. D. Milly, Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer. 2008. Stationarity Is Dead: Whither Water Management? Science, Vol. 319, No. 5863, pages 573-574.

Milon, Walter J. and David Scrogin. 2006. Latent preferences and valuation of wetland ecosystem restoration. Ecological Economics, Vol. 56, pages 162– 175.

Morris, Chelsie and Ron Sutton. 2007. Flow Characterization Study Instream Flow Assessment Hawley Creek and Eighteenmile Creek, Idaho. US Bureau of Reclamation Report, June 2007. 161 pages.

National Capital, 2011. InVEST: Integrated Valuation of Environmental Services and Tradeoffs. Viewed: 2 December 2011. http://www.naturalcapitalproject.org/InVEST.html.

Nedkov, Stoyan and Benjamin Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand in the Etropole municipality, Bulgaria. Ecological Indicators, Vol. 21, pages 67–79.

Nobriga M., 2008. Aquatic habitat conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Núñez, Daisy, Laura Nahuelhual, and Carlos Oyarzún. 2006. Forests and water: the value of native temperate forests in supplying water for human consumption. Ecological Economics, Vol. 58, pages 606-616.

OECD. 2008. Handbook on Constructing Composite Indicators Methodology and User Guide. OECD Publishing. http://www.oecd.org/std/42495745.pdf. 160 pages. Viewed online on June 2013.

OECD, 2013. *OECD Guidelines on Measuring Subjective Well-being*. OECD Publishing. 290 pages. doi: 10.1787/9789264191655-en

Ostrom, Elinor. 2007. Sustainable Social-Ecological Systems: An Impossibility? Presented at the 2007 Annual Meetings of the American Association for the Advancement of Science, "Science and Technology for Sustainable Well-Being," 15–19 February in San Francisco, pages 1-29.

OSU. 2012. ENVISION Integrated Modeling Platform, Version 6, A Guide to Application Development. Oregon State University (OSU), http://envision.bioe.orst.edu/. Viewed November 2012.

Ojeda, Monica Ilija, Alex S. Mayer, and Barry D. Solomon. 2008. Economic valuation of environmental services sustained by water flows in the Yaqui River Delta. Ecological Economics, Vol. 65, pages 155-166.

Pagiola, Stefano. 2008. Payments for environmental services in Costa Rica. Ecological Economics, Volume 65, pages 712-724.

Paranjpye, Vijay and Parineeta Dandekar. Negotiating our way through Livelihoods and Ecosystems: The Bhima River Basin Experience. IUCN Water Programme, NEGOTIATE Toolkit: Case Study. Website: http://cmsdata.iucn.org/downloads/bhimariver.pdf. Accessed September 14, 2013.

Peterson, Larry C. and Gerald H. Haug. 2005. Climate and the Collapse of Maya Civilization. American Scientist, Vol. 93, pages 322-329.

Pínter, Laszlo, Darren Swanson, Ibrahma Abdel-Jelil, Kakuko Nagatani-Yashida, Atiq Rahman, and Marcel Kok. 2008. GEO Resource Book: A training manual on integrated environmental assessment and reporting, Training Module 5, Integrated analysis of environmental trends and policies. International Institute of Sustainable Development (IISD) Report, Winnipeg, Manitoba, Canada. 68 pages.

Pittock, J., S. Cork, and S. Maynard. 2012. The state of the application of ecosystems services in Australia. Ecosystem Services, Vol. 1, pages 111-120.

Poff, N.L., J.D. Allan, Mark Bain, James Karr, Karen L. Prestegaard, Brian .D. Richter, Richard E. Sparks, Julie C. Stromberg. 1997. The Natural Flow Regime: A paradigm for river conservation and restoration. Biosciences Vol. 47, No. 11, pages 769-784.

Poff, N. L., B.D. Richter, A. H. Arthington, S. E. Bunn, R. J. Naiman, E. Kendy, M. Acreman, C. Apse, B. P. Bledsoe, M.C. Freeman, J. Henriksen, R. B. Jacobson, J.G. Kennen, D.M. Merritt, J.H. O'Keefe, J.D. Olden, K. Rogers, R. E. Tharme, and A. Warner. 2010. The Ecological Limits of Hydrologic Alteration (ELOHA): A new framework for developing regional environmental flow standards. Freshwater Biology, Vol. 55, pages 147-170.

Postel, Sandra and S. Carpenter. 1997. “Chapter 11 Freshwater Ecosystem Services” in Nature’s Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC. Pages 195-214.

Postel, Sandra and Brian Richter. 2003. Rivers for Life, Managing Water for People and Nature. Island Press, Washington, D.C. 41 pages.

Prato, Tony. 2004. Multiple-attribute evaluation of ecosystem management for the Missouri River system. Ecological Economics, Vol. 45, pages 297-309.

Prescott-Allen R. 2001. The Wellbeing of Nations: A Country-by-Country Index of Quality of Life and the Environment. Island Press, Washington, DC.

Ramsar. 2007. *Ramsar Handbook 6 for the wise use of wetlands: Water-related guidance. 3rd Edition.* Ramsar Convention Secretariat, Gland, Switzerland. 28 pages.

Raymond, Christopher M., Brett A. Bryan, Darla Hatton MacDonald, Andrea Cast, Sarah Strathearn, Agnes Grandgirard, and Tina Kaliva. 2009. Mapping community values for natural capital and ecosystem services. Ecological Economics, Vol. 68, pages 1301-1315.

Rebelo Lisa-Maria Rebelo, Robyn Johnston, Thomas Hein, Gabriele Weigelhofer, Tom DHaeyer, Bakary Kone, and Jan Cools. 2013. Challenges to the integration of wetlands into IWRM: The case of the Inner Niger Delta (Mali) and the Lobau Floodplain (Austria). Environmental Science and Policy, Vol. 34, December 2013, pages 58-68.

Rogers, Peter P., Kazi F. F. Jalal, and John A. A. Boyd. 2008. <u>An Introduction to Sustainable Development.</u> Routledge Press. 416 pages.

Russi, D., P.ten Brink, A. Farmer, T. Badura, D. Coates, J. Förster, R. Kumar, and N. Davidson. 2012. *The Economics of Ecosystems and Biodiversity for Water and Wetlands.* Final Consultation Draft. 105 pages.

Sandoval-Solis, S., D.C. McKinney, and D.P. Loucks. 2011. Sustainability Index for Water Resources Planning and Management. Journal of Water Resource Planning and Management, Vol. 137, September/October 2011, pages 381-390.

Sánchez-Canales, María, Alfredo López Benito, Ana Passuello, Marta Terrado, Guy Ziv, Vicenç Acuña, Marta Schuhmacher, and F. Javier Elorza. 2012. Sensitivity analysis of ecosystem service valuation in a Mediterranean watershed. Science of the Total Environment, Vol. 440, pages 140–153.

Segnestam, Lisa. 2002. Indicators of Environmental and Sustainable Development: Theories and Practical Experience. The World Bank Environment Department, Environmental Economics Series, Paper No. 89, 61 pages.

Simonović, Slobodan P., Donald H. Burn and Barbara J. Lence. 1997. Practical sustainability criteria for decision-making. International Journal of Sustainable Development and World Ecology, Vol. 4, Issue 4, pages 231-244.

Simonović, Slobadan P. 2009. <u>Managing Water Resources: Methods and Tools for a Systems Approach.</u> UNESCO Publishing, London, England. 640 pages.

Snyman, Jan A. 2005. Practical Mathematical Optimization: An Introduction to Basic Optimization Theory and Classical and New Gradient-Based Algorithms. Springer Publishing. http://en.wikipedia.org/wiki/Special:BookSources/0387243488 . 257 pages.

Spash, Clive L., Kevin Urama, Rob Burton, Wendy Kenyon, Peter Shannon, and Gary Hill. 2009. Motives behind willingness to pay for improving biodiversity in a water ecosystem: Economics, ethics and social psychology. Ecological Economics, Vol. 68, pages 955-964.

Stiglitz, Joseph E., Amartya Sen, and Jean-Paul Fitoussi. 2009. *Report by the Commission on the Measurement of Economic Performance and Social Progress*. Document obtained from http://www.stiglitz-sen-fitoussi.fr/en/index.htm, viewed 16 January 2012.

Surinaidu, L., C. G. D. Bacon, and P. Pavelic. 2012. Agricultural groundwater management in the Upper Bhima Basin, India: current status and future scenarios. Hydrology and Earth System Sciences Discussions, Vol. 9, pages 10657-10686.

Sullivan, C.A., J.R. Meigh and A.M. Giacomello. 2003. The Water Poverty Index: Development and application at the community scale. Natural Resources Forum, Vol. 27, Issue 3, August 2003, pages 189-199.

Sutton, Ron and Chelsie Morris. 2004. Flow Characterization Study Instream Flow Assessment Big Timber Creek, Idaho. US Bureau of Reclamation Report, Boise, Idaho, June 2004. 119 pages.

Sutton, Ron and Chelsie Morris. 2005. Flow Characterization Study Instream Flow Assessment Big Eightmile Creek, Bohannon Creek, and Hayden Creek, Idaho. US Bureau of Reclamation Report, Boise, Idaho, June 2005. 183 pages.

Sutton, Ron and Chelsie Morris. 2006. Flow Characterization Study Instream Flow Assessment Upper Lemhi River and Canyon Creek, Idaho. US Bureau of Reclamation Report, Boise, Idaho, July 2006. 167 pages.

Swanson, Darren and Lássló Pintér. 2007. Chapter 4, Governance Structures for National Sustainable Development Strategies. In OECD publication “Sustainable Development Studies Institutionalising Sustainable Development”, March 21, 2007, pages 33-66.

SWRR. 2005. Sustainable Water Resources Roundtable Preliminary Report. Sustainable Water Resources Roundtable (SWRR), September 30, 2005. 108 pages.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2013. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. Ecological Indicators, Vol. 37, Part A, February 2014, pages 199-209.

Tietenberg, Tom. 2006. Environmental and Natural Resource Economics, 7th Edition. Pearson Education, Inc., New York, New York. 654 pages.

Thieme, M.L., J. Rudulph, J. Higgins, and J.A. Takats. 2012. Protected areas and freshwater conservation: A survey of protected area managers in the Tennessee and Cumberland River Basins, USA. Journal of Environmental Management, Vol. 109, pages 189-199.

Townsend, C.R. 1989. The patch dynamics concept of stream community ecology. Journal of the North American Benthological Society, Vol. 8, pages 36-50, Vol. 14, pages 2851-2883.

Trabucchi Mattia, Phumza Ntshotsho, Patrick O'Farrell, and Francisco A. Comín. 2012. Ecosystem service trends in basin-scale restoration initiatives: A review. Journal of Environmental Management, Vol. 111, pages 18-23.

Turpie, J.K., C. Marais, and J.N. Blignaut. 2008. The working for water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecological Economics, Vol. 65, pages 788-798.

UN. 1987. Our Common Future. United Nations Report of the World Commission on Environment and Development. 287 pages.

UN Water Report. 2012. Status report on the Application of the Integrated Approaches to Water Resources Management. UN Report. http://www.un.org/waterforlifedecade/pdf/un_water_status_report_2012.pdf. 119 pages.

UNEP. 2005. Addressing Environmental Aspects and Ecosystems Issues in IWRM: Merging IWRM and the Ecosystem Approach. UNEP IWRM 2005 Concepts and Issues Paper No. 1. United Nations Environmental Programme (UNEP), Nairobi, Kenya. 33 pages.

UNEP. 2007. Global Environment Outlook (GEO) 4 Environment for Development. United Nations Environmental Programme (UNEP), Malta Program Press Company Ltd, Valletta, Malta 2007. 572 pages.

UNEP. 2009. Water Security and Ecosystem Services, the Critical Connection. United Nations Environmental Programme (UNEP), Nairobi, Kenya. 53 pages.

UNEP. 2011. IEA Training Manual - Module 5, 3. Analytical framework for integrated environmental assessment, Presentation and Discussion. Viewed 2 December 2011, http://www.unep.org/ieacp/iea/training/manual/module5/1214.aspx.

UNESCO. 2009a. IWRM Guidelines at River Basin Level. Part 1: Principles. UNESCO-International Hydrological Programme (IHP), World Water Assessment Programme (WWAP), Network of Asian River Basin Organizations (NARBO). 173 pages.

UNESCO. 2009b. IWRM Guidelines at River Basin Level. Part 2-1: The Guidelines for IWRM Coordination. UNESCO-International Hydrological Programme (IHP), World Water Assessment Programme (WWAP), Network of Asian River Basin Organizations (NARBO). 173 pages.

UVM. 2011. MIMES: Multiscale Integrated Models of Ecosystems Services. University of Vermont, The Gund Institute of Ecological Economics (UVM), Viewed 2 December 2011. http://www.uvm.edu/giee/mimes/.

Vallance, Suzanne, Harvey C. Perkins, and Jennifer E. Dixon. 2011. What is social sustainability? A clarification of concepts. Geoforum, Vol. 42, 2011, pages 342-348.

Vannote, R.L., G. W. Minshall. ,W . Cummins, J., R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 37, pages 130-137.

Walker, B. and J. A. Meyers. 2004. Thresholds in ecological and social–ecological systems: a developing database. Ecology and Society, Vol. 9(2), page 3.

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, Vol. 9(2): page 5.

Walker, B. H., J. M. Anderies, A. P. Kinzig, and P. Ryan. 2006. Exploring resilience in social-ecological systems through comparative studies and theory development: introduction to the special issue. Ecology and Society 11(1): 12

Ward, J. V. 1989. The four-dimensional nature of lotic ecosystems. Journal of the North American Benthological Society, Vol. 8, pages 2-8, Vol. 37, pages 130-137.

Ward, J. V., and B. A. Stanford. 1983. The serial discontinuity concept lotic ecosystems, p. 29-42. In T. D. Fontaine and S.M. Bartell [ed.] *Dynamics of lotic ecosystems*. Ann Arbor Science Publishers Inc., Ann Arbor, MI. 494 pages.

Watanbe, Marcos D.B. and Enrigue Ortega. 2014. Dynamic emergy accounting of water and carbon ecosystem services: A model to simulate the impacts of land-use change. Ecological Modelling, Vol. 271, January 2014, pages 113-131.

Wendland, Kelly J., Miroslav Honzák, Rosimeiry Portela, Benjamin Vitale, Samuel Rubinoff, Jeannicq Randrianarisoa. 2010. Targeting and implementing payments for ecosystem services: Opportunities for bundling biodiversity conservation with carbon and water services in Madagascar. Ecological Economics, Vol. 69, 2010, pages 2093–2107.

Willaarts, Bárbara A., Martin Volk, Pedro A. Aguilera. 2012. Assessing the ecosystem services supplied by freshwater flows in Mediterranean agroecosystems. Agricultural Water Management, Vol. 105, 2012, pages 21– 31.

Winograd, Manuel and Andrew Farrow. 2011. Sustainable Development Indicators for Decision Making: Concepts, Methods, Definition and Use. Dimensions of Sustainable Development – Volume I. www.eolss.net/sample-chapters/c13/e1-46b-02.pdf. Accessed November 2011.

Winograd, Manuel, Marta Aguilar, Andrew Farrow, Lisa Segnestam, Michael Linddal, and John Dixon. 1999. Conceptual Framework to Develop and Use Water Indicators. CIAT/World Bank/UNEP Project Rural Sustainability Indicators: Outlook for Central America Technical Note, CIAT, Cali, Colombia, August 1999. 12 pages.

Woerden, Jaap van, Carissa Wieler, Edgar Gutierrez-Espeleta, Richard Grosshans, Ahmed Abdelrehim, Purna Chandra Lall Rajbhandari, 2008. GEO Resource Book: A training manual on integrated environmental assessment and reporting, Training Module 4, Monitoring, Data, and Indicators. IISD report, Winnipeg, Manitoba. 68 pages.

WEF. 2011. Global Risks 2011, 6th Edition. World Economic Forum Report, Geneva, Switzerland. Viewed 2 December 2012. http://riskreport.weforum.org/.

World Bank. 2000. Economic development and environmental sustainability: policies and principles for a durable equilibrium. Edited by Furtado, J. I. dos R., T.Belt ; R. Jammi, World Bank Institute, WBI Learning Resources Series, Washington, D.C., February 2000. 123 pages.

Young, Robert A. 1996. Measuring Economic Benefits for Water Investments and Policies. World Bank Technical Paper No. 338. The World Bank. Washington DC.

Young, Robert A. 2005. Determining the Economic Value of Water: Concepts and Methods. Resources for the Future, Washington, DC. 357 pages.

Zander, Kerstin K. and Anna Straton. 2010. An economic assessment of the value of tropical river ecosystem services: Heterogeneous preferences among Aboriginal and non-Aboriginal Australians. Ecological Economics, Vol. 69, 2010, pages 2417–2426.

Appendix A. Economic Analysis

As cattle production is the primary economic driver in the LRB, the economic analysis used in the LRB case study focused on agricultural production. The economic analysis, as linked to water delivery, was determined by the benefit-cost analysis of grass hay and alfalfa production under various irrigation methods in the LRB. The benefit-cost analysis was implemented by two means for the case study: i) to create the test conditions for the case study, and ii) to compute the economic conditions for computing the Economic SI. The test condition involved determining the sprinkler and flood irrigation distribution that maximized economic output, irrespective of ecological or social aspect (a.k.a. Optimal Sprinkler Scenario). Using the sprinkler and flood irrigation distributions for the Baseline (current conditions) and Optimal Sprinkler Scenarios, the LRBM simulated the water allocation over a 13 year simulation period with the results used to compute the economic production as input to the Economic SI. This appendix outlines the methodology, cost and benefit curves, input data and results supporting the case study conditions development and the analytical basis for computing the economic output for use in the computing the Ecological SI. Note, this economic analysis was developed to illustrate how the RBAF-A incorporates economic results, thus the results are preliminary as further refinement is needed before taking management decisions.

A.1 Computations

A.1.1 Optimization Computations

The optimal allocation of flood and sprinkler irrigation in the LRB was determined using a partial equilibrium solution of a benefit-cost analysis of crop production. The partial equilibrium solution solves a constrained set of non-linear equations to determine the allocation of water within the LRB that results in the maximum consumer and producer surpluses. The equation to find the optimal solution is:

$$\textit{Max Net Basin (revenue) Benefit} = \Sigma MB_i - \Sigma MC_i \quad \text{subject to} \quad \textit{Transportation Cost}$$

Where

MB_i = Marginal Benefit of the i^th^ interval

MC_i = Marginal cost of the i^th^ interval

A non-linear optimizing routine was used to determine the net agricultural production benefit for the basin. The solution algorithm used was a Gradient Descent Methodology (Snyman 2005), with constraints on maximum and minimum water usage incorporated into the iterative solution. This technique uses the marginal rate of substitution as defined by supply and demand curves to calculate the net benefit per different conversion rates from flood to sprinkler irrigation.

For this analysis, water users in the LRB were aggregated into 5 paired demand nodes receiving water from 3 supply nodes (Figure 27, Table 21). The demand nodes represented 5 areas, each with a pair of nodes representing flood and sprinkler irrigation (Section 6.2.1.2). To constrain the partial equilibrium data set, a “transportation” cost was imposed which equates to the capacity of the river system to deliver water between the supply and demand node. The transportation cost was determined using the LRBM under the average annual flow volumes in the hydrologic network of the 13 year simulation period. This analysis assumes the supply and demand curves are fixed as are the cropping pattern and irrigated area. In addition, for land converted to sprinkler scenarios, who converts to sprinkler is not predetermined within a zone. The output from the effort is the net revenue per demand node.

A.1.2 Annual Economic Output Computations

To determine the impact of this irrigation conversion on the SC disciplines, a Baseline Scenario, representing current conditions, and an Optimized Irrigation Scenario, representing the distribution of flood and sprinkler for maximum economic production, were analyzed. This analysis assumes the supply and demand curves are fixed as are the crops produced and irrigated area. Benefits and costs were adjusted over the simulation period using a discount rate of 5%.

A.2 Development of Marginal Demand and Marginal Supply Curves

A.2.1 Demand Curves

For demand curve calculations, benefits (revenues) were determined by the production of grass hay and alfalfa and the rental rates of pasture for grazing cattle. On average in the LRB, if full water is supplied 2 crops are harvest, and in the lower basin, a third crop is grown as forage for cattle (Loucks, personal communication 2012, Mulkey, personal communication 2012). The selling prices of grass hay and alfalfa were assumed to be \$110/ton and \$140/ton as per the 2012 irrigation season (Table A.1). Pasture rental rates were assumed to be \$22/acre and added to the grass hay benefits as the “third crop”. For both grass hay and alfalfa, the production rate is typically 2.7 and 4.0 acres per ton for flood and sprinkler irrigation, respectively (ibid).

Costs were computed per unit area based on the crop type and irrigation method, then scaled to the area under irrigation to derive total costs for the area (Table A.1, Table A.2, Table A.3). Production costs were obtained from the crop enterprise databases generated by the University of Idaho, Department of Agricultural Economics and Rural Sociology (http://web.cals.uidaho.edu/idahoagbiz/). No data was available for production costs for flood irrigation, so costs were assumed to be the same with the exception of the sprinkler system and labor.

Sprinkler system installations were assumed to be $120,000 per section (120 acres) (Don Olsen, Bob Loucks, Rick Sager, personal communication 2012). These costs were introduced in a stepwise fashion as $120,000 was added to the total cost with the introduction of 120 acres of irrigated land represented by a sprinkler demand node. Care was not taken to determine if the land under cultivation was contiguous and under the same water right when developing the curves. Note, the water source for sprinkler irrigation in the LRB is the stream network, so consideration of the extra power required for the lifting of deeper ground water is not necessary for the cost curves, only the additional amount pumped based on rate that is being pumped.

Table A.1. Factors considered in the cost estimates for hay and alfalfa production for flood and sprinkler irrigation.

Crop	**Yield [/ac]**	**Cuttings [/season]**	**Price [/ton]**	**Benefit [/ac]**	**Cost [/ac]**	**Net [/ac]**
Flood						
Alfalfa	2.7	2	$ 140.00	$ 756.00	$ 655.72	$100.28
Hay	2.7	2	$ 110.00	$ 594.00	$ 563.96	$52.04
Pasture (rental)				$ 22.00		$22.00
Sprinkler						
Alfalfa	4	2	$ 140.00	$ 1,120.00	$ 888.32	$231.68
Hay	4	2	$ 110.00	$ 880.00	$ 796.56	$105.44
Pasture (rental)				$ 22.00		$22.00

To compute the marginal benefit of each demand curve for each node, the benefit was determined at 11 intervals, each representing a 10% increase in land under production within the zone by at irrigation method, and the difference calculated between successive intervals. Area was aggregated in order of priority date and by association the crops being grown. There was no effort to determine spatial location of the irrigated place of use within the zone. Thus, though irrigation is increasing, the rate of marginal benefit will vary depending on the newly introduced crop type and the number of sprinkler irrigation schemes added. Table A.4 presents the marginal demand curves for the 10 demand nodes.

Table A.2. Production costs for alfalfa production for flood and sprinkler irrigation as derived from the enterprise crop budget by the University of Idaho Department of Agricultural Economics and Rural Sociology.

	Flood				**Sprinkler**			
Item	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**
Gross Returns								
Alfalfa Hay	5.4	ton	$ 140.00	$ 756.00	8	ton	$ 140.00	$ 1,120.00
Operating Inputs								
Seed:				**$ -**				**$ -**
Fertilizer:				**$ 110.95**				**$ 110.95**
Dry P2O5	75	lb	$ 0.60	$ 45.00	75	lb	$ 0.60	$ 45.00
Dry Nitrogen	15	lb	$ 0.69	$ 10.35	15	lb	$ 0.69	$ 10.35
K2O	80	lb	$ 0.57	$ 45.60	80	lb	$ 0.57	$ 45.60
Sulfur	40	lb	$ 0.25	$ 10.00	40	lb	$ 0.25	$ 10.00
Pesticides:				**$ 50.50**				**$ 50.50**
Furadan 4F	1	qt	$ 20.10	$ 20.10	1	qt	$ 20.10	$ 20.10
Velpar Alfamax	2	lb	$ 15.20	$ 30.40	2	lb	$ 15.20	$ 30.40
Custom & Consultants:				**$ 152.00**				**$ 210.50**
Custom Fertilize	1	ac	$ 7.50	$ 7.50	1	ac	$ 7.50	$ 7.50
Custom Swath & Rake	1	ac	$ 23.00	$ 23.00	1	ac	$ 23.00	$ 23.00
Custom Bale: 1-ton	5.4	ton	$ 17.00	$ 91.80	8	ton	$ 17.00	$ 136.00
Custom Stack: 1-ton	5.4	ton	$ 5.50	$ 29.70	8	ton	$ 5.50	$ 44.00
Irrigation:				**$ 41.30**				**$ 44.05**
Water Assessment	1	ac	$ 41.30	$ 41.30	1	ac	$ 41.30	$ 41.30
Irrigation Repairs - CD	0	ac	$ 2.75	$ -	1	ac	$ 2.75	$ 2.75
Machinery:				**$ 16.09**				**$ 16.09**
Fuel - Gas	1.25	gal	$ 3.50	$ 4.38	1.25	gal	$ 3.50	$ 4.38
Fuel - Diesel	1.7	gal	$ 3.45	$ 5.87	1.7	gal	$ 3.45	$ 5.87
Lube	1	ac	$ 0.95	$ 0.95	1	ac	$ 0.95	$ 0.95
Machinery Repairs	1	ac	$ 4.90	$ 4.90	1	ac	$ 4.90	$ 4.90
Labor:				**$ 63.83**				**$ 84.14**
Labor (machine)	1.35	hr	$ 17.50	$ 23.63	1.35	hr	$ 17.50	$ 23.63
Labor (irrigation - cd)	0	hr	$ 12.35	$ -	4.9	hr	$ 12.35	$ 60.52
Labor (other)	4	hr	$ 10.05	$ 40.20	0	hr	$ 10.05	$ -
Storage:				**$ -**				**$ -**
Other:				**$ 10.05**				**$ 45.89**
Crop Insurance	1	ac	$ 10.05	$ 10.05	1	ac	$ 10.05	$ 10.05
Power	0	ac	$ 1.28	$ -	28	ac	$ 1.28	$ 1.28
Operating Interest @ 6.75%				$ 13.15				$ 13.15
Total Operating Costs				**$ 457.87**				**$ 540.71**

	Flood				Sprinkler			
Item	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**
Operating Costs per Unit				**$ 84.79**				**$ 67.59**
Net Returns Above Operating Expenses				**$ 298.14**				**$ 544.73**
Ownership Costs:								
Tractors & Equipment Insurance				$ 1.05				$ 1.05
Tractors & Equipment Depreciation & Interest				$ 17.00				$ 17.00
Irrigation Equipment Depreciation & Interest				$ -				$ 104.00
Land **				$ 100.00				$ 100.00
Overhead				$ 15.00				$ 15.00
Management Fee				$ 40.00				$ 40.00
Amortized Establishment Cost				$ 65.00				$ 65.00
Total Ownership Costs				**$ 238.05**				**$ 386.05**
Ownership Costs per Unit				**$ 44.08**				**$ 42.76**
Total Costs per Acre				**$ 695.92**				**$ 926.76**
Total Cost per Unit				**$ 128.87**				**$ 115.85**
Net Return per acre				**$ 60.08**				**$ 193.24**

Table A.3. Production costs for grass hay production for flood and sprinkler irrigation. No data was directly available for the Lemhi River Basin for pasture, so the enterprise crop budget by the University of Idaho Department of Agricultural Economics and Rural Sociology was adapted for hay pasture specific costs (e.g. fertilizer, pesticides) from south Idaho.

	Flood				Sprinkler			
Item	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**
Gross Returns								
Grass Pasture	5.4	ton	$ 110.00	$ 594.00	8	ton	$ 110.00	$ 880.00
Operating Inputs								
Seed:				**$ -**				**$ -**
Fertilizer:				**$ 69.00**				**$ 69.00**
Dry Nitrogen	100	lb	$ 0.69	$ 69.00	100	lb	$ 0.69	$ 69.00
Pesticides:				**$ 0.69**				**$ 0.69**
2,4-D Amine	0.14	qt	$4.94	$0.69	0.14	qt	$4.94	$0.69
Custom & Consultants:				**$ 152.00**				**$ 210.50**
Custom Fertilize	1	ac	$ 7.50	$ 7.50	1	ac	$ 7.50	$ 7.50
Custom Swath & Rake	1	ac	$ 23.00	$ 23.00	1	ac	$ 23.00	$ 23.00
Custom Bale: 1-ton	5.4	ton	$ 17.00	$ 91.80	8	ton	$ 17.00	$ 136.00
Custom Stack: 1-ton	5.4	ton	$ 5.50	$ 29.70	8	ton	$ 5.50	$ 44.00
Irrigation:				**$ 41.30**				$ 44.05
Water Assessment	1	ac	$ 41.30	$ 41.30	1	ac	$ 41.30	$ 41.30
Irrigation Repairs - CD	0	ac	$ 2.75	$ -	1	ac	$ 2.75	$ 2.75
Machinery:				**$ 16.09**				$ 16.09
Fuel - Gas	1.25	gal	$ 3.50	$ 4.38	1.25	gal	$ 3.50	$ 4.38
Fuel - Diesel	1.7	gal	$ 3.45	$ 5.87	1.7	gal	$ 3.45	$ 5.87
Lube	1	ac	$ 0.95	$ 0.95	1	ac	$ 0.95	$ 0.95

	Flood				Sprinkler			
Item	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**	**Quantity Per Acre**	**Unit**	**Cost**	**Value - Cost/Acre**
Machinery Repairs	1	ac	$ 4.90	$ 4.90	1	ac	$ 4.90	$ 4.90
Labor:				**$ 63.83**				**$ 84.14**
Labor (machine)	1.35	hr	$ 17.50	$ 23.63	1.35	hr	$ 17.50	$ 23.63
Labor (irrigation - cd)	0	hr	$ 12.35	$ -	4.9	hr	$ 12.35	$ 60.52
Labor (other)	4	hr	$ 10.05	$ 40.20	0	hr	$ 10.05	$ -
Storage:				**$ -**				$ -
Other:				**$ 10.05**				$ 45.89
Crop Insurance	1	ac	$ 10.05	$ 10.05	1	ac	$ 10.05	$ 10.05
Power	0	ac	$ 1.28	$ -	1	ac	$ 1.28	$ 1.28
Operating Interest @ 6.75%				$ 13.15				$ 13.15
Total Operating Costs				**$325.91**				**$ 483.51**
Operating Costs per Unit				**$60.35**				**$ 60.44**
Net Returns Above Operating Expenses				**$ 298.14**				**$ 396.49**
Ownership Costs:								
Tractors & Equipment Insurance				$ 1.05				$ 1.05
Tractors & Equipment Depreciation & Interest				$ 17.00				$ 17.00
Irrigation Equipment Depreciation & Interest				$ -				$ 104.00
Land **				$ 100.00				$ 175.00
Overhead				$ 15.00				$ 15.00
Management Fee				$ 40.00				$ 40.00
Amortized Establishment Cost				$ 65.00				$ 65.00
Total Ownership Costs				**$ 238.05**				**$ 313.05**
Ownership Costs per Unit				**$ 44.08**				**$ 39.13**
Total Costs per Acre				**$ 695.92**				$ 926.76
Total Cost per Unit				**$ 128.87**				$ 115.85
Net Return per acre				**$ 60.08**				$ 193.24

Table A.4. Demand curves for the LRB analysis. All values are in USD x 10,000.

		Interval										
Node	**Crop**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
D1	Alfa	0.00	51	51	573	832	1304	1304	1304	1304	1597	1668
	Hay/Pasture	0.00	498	998	998	1162	1362	1820	2354	3040	3340	3838
D2	Alfa	0.00	71	364	364	364	364	836	1095	1617	1617	1668
	Hay/Pasture	0.00	598	898	1584	2117	2575	2775	2940	2940	3440	3938
D3	Alfa	0.00	320	644	710	1560	1896	2414	2811	2855	3843	3843
	Hay/Pasture	0.00	2065	4530	6580	7234	9601	11379	13037	14826	14844	15888
D4	Alfa	0.00	0	988	1032	1429	1947	2283	3133	3199	3523	3843
	Hay/Pasture	0.00	1043	1061	2851	4509	6287	8653	9308	11358	13823	15888
D5	Alfa	0.00	0	0	0	0	171	246	392	614	689	835
	Hay/Pasture	0.00	868	1646	2585	2899	3475	4159	4860	5551	6343	7052
D6	Alfa	0.00	146	222	443	589	665	835	835	835	835	835
	Hay/Pasture	0.00	758	1550	2241	2942	3626	4202	4515	5454	6232	7101

		Interval										
Node	**Crop**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
D7	Alfa	0.00	110	272	312	669	732	859	1004	1041	1041	1041
	Hay/Pasture	0.00	932	1778	2707	3258	4537	5714	6613	7577	7577	7577
D8	Alfa	0.00	0	0	37	182	309	372	729	769	932	1041
	Hay/Pasture	0.00	0	0	964	1863	3041	4320	4870	5799	6645	7577
D9	Alfa	0.00	474	912	1002	2982	3769	4505	4911	4984	5973	5976
	Hay/Pasture	0.00	3617	7983	12076	14904	19398	22873	26121	29488	30666	33383
D10	Alfa	0.00	3	992	1065	1471	2207	2994	4974	5064	5501	5976
	Hay/Pasture	0.00	2717	3895	7262	10510	13985	18478	21307	25400	29766	33383

A.2.2 Supply Curve

Supply curves were the amount of water available as inflow to the system. These were determined as the average annual inflow from the 13 year simulation of the LRBM. The full supply for S1, S2, and S3 is 29,304, 42,370, and 4,307 Million acre-ft. per year (Mac-ft per year). The associated monetary value from each curve was set above the total economic production of the LRB so the supply curve would not limit the economic production.

A.2.3 Transport Cost

Transport cost, somewhat a misnomer, is the physical amount of water that can be delivered from the supply to the demand as determined by the RBM. These relationships take into account both the feasibility of water delivery as well as the water losses associated with transmission between the source and the place of use (POU). For infeasible solutions (e.g. in the Lemhi S1 supplying to D5, D6), the supply = 0 for all demands. To derive these rates, the LRBM simulate a 13 year period that was run 11 times with varying degrees of sprinkler conversion (0, 10 20, 30, . . . 100%). Water available for each zone will be aggregated from the respective sources; catchment inflows for the upper catchments and mainstem flow for the Lemhi River (Zones 2 and 3). The Lemhi River supply for Zones 2 and 3 will incorporate the upstream diversions and return flows as depicted in the LRBM. Table A.5 presents the transport cost curves.

Table A.5. Transport cost curves. The sprinkler % is the varying degrees of sprinkler conversion. The S1, S2, S3 denotes the supply nodes and D1-D10 denotes the demand nodes. All units are in Million acre-ft. per year.

	Sprinkler %	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Unit**
T1	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D1	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T2	S2	42370	42370	Mac-ft
	D1	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T9	S3	4307	4307	Mac-ft
	D3	0	0	Mac-ft

	Sprinkler %	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Unit**
T4	S1	0	0	0	0	0	0	0	0	0	0	0	Mac-ft
	D2	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T5	S2	42370	42370	Mac-ft
	D2	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T6	S3	4307	4307	Mac-ft
	D2	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T7	S1	29304	29304	Mac-ft
	D3	0	0	Mac-ft

	Sprinkler %	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Unit**
T8	S2	424	424	424	424	424	424	424	424	424	424	424	Mac-ft
	D3	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	**0**	**100**	**Unit**
T9	S3	4307	4307	Mac-ft
	D3	0	0	Mac-ft

	Sprinkler %	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Unit**
T10	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D4	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T11	S2	42370	42370	Mac-ft
	D4	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T12	S3	4307	4307	Mac-ft
	D4	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T13	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D5	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T14	S2	424	424	424	424	424	424	424	424	424	424	424	Mac-ft
	D5	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T15	S3	4307	4307	Mac-ft
	D5	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T16	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D6	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T17	S2	424	424	424	424	424	424	424	424	424	424	424	Mac-ft
	D6	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T18	S3	4307	4307	Mac-ft
	D6	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T19	S1	29304	29304	Mac-ft
	D7	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T20	S2	42370	42370	Mac-ft
	D7	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T21	S3	43	43	43	43	43	43	43	43	43	43	43	Mac-ft
	D7	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T22	S1	29304	29304	Mac-ft
	D8	0	0	Mac-ft

	Sprinkler %	0	100	Unit
T23	S2	42370	42370	Mac-ft
	D8	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T24	S3	43	43	43	43	43	43	43	43	43	43	43	Mac-ft
	D8	0	0	0	0	0	0	0	0	0	0	0	

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T25	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D9	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T26	S2	424	424	424	424	424	424	424	424	424	424	424	Mac-ft
	D9	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T27	S3	43	43	43	43	43	43	43	43	43	43	43	Mac-ft
	D9	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T28	S1	293	293	293	293	293	293	293	293	293	293	293	Mac-ft
	D10	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T29	S2	424	424	424	424	424	424	424	424	424	424	424	Mac-ft
	D10	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

	Sprinkler %	0	10	20	30	40	50	60	70	80	90	100	Unit
T30	S3	43	43	43	43	43	43	43	43	43	43	43	Mac-ft
	D10	0	0	0	0	0	0	0	0	0	0	0	Mac-ft

A.2.4 Computing Economic SI

For both grass hay and alfalfa, the production rate is typically 2.7 and 4.0 acres per ton for flood and sprinkler irrigation, respectively (Loucks, personal communication 2012, Mulkey, personal communication 2012). However, in the annual economic output computations, shortages of irrigation water results in reduced production which was scaled via the equation (Martin et al. 1989, Contor 2008):

$$Y = Y_d + (Y_m - Y_d)\,(1 - I/I_m)^a$$

where: Y = crop yield, tons per acre

Y_d = dryland crop yield, tons per acre

Y_m = crop yield at full irrigation, tons per acre

I = irrigation depth, feet

I_m = irrigation depth at full yield, feet

$a = 1/B$ and B = consumptive use fraction of applied irrigation water at full yield ($(ET - ET_d)/I_m$) where ET, ET_d are evapotranspiration depth are dryland irrigation depth, feet.

The equation assumes a volumetric application and does not account for when the irrigation water shortage occurs in the growing cycle. The irrigation depth is determined by the depth of water applied for 2 crops per year (Table A.6). A full seasonal usage rate of 3.94 and 3.78 ac-ft/ac was used for alfalfa and grass pasture, respectively.

The irrigation depth per zone for the simulations was determined by the sum of the volume of water delivered to all water user nodes in the LRBM in the zone divided by the area under production. As water was volumetrically determined on an annual basis from the LRBM results, it was assumed that shortages occurred in the second cutting. Once the production is determined in tons/ac per zone, it was multiplied by the price of the crop to determine the benefit. Then net value was difference between the benefit and cost of acres under production. The cost of sprinklers is a one-time purchase at onset of the simulation with all other expenses occurring annually.

Table A.6. Crop water requirement from ETIdaho and Idaho Attorney General.

	ETIdaho			**Idaho Attorney General**		
	Per crop		**Season**	**Per crop**		**Season**
Crop	**(ac-ft/ac)**	**Crops**	**ac-ft/ac**	**(ac-ft/ac)**	**Crops**	**ac-ft/ac**
Alfalfa	1.89	2.00	3.78	2.05	2.00	4.10
Grass Pasture	1.96	2.00	3.92	1.80	2.00	3.60

A.3 Results

A.3.1 Optimization Results

The results generated from the optimization simulation are presented in Table A.8. These were translated back into acres under production per irrigation type and then percentage of each irrigation method in each zone (Table 24) to define the sprinkler and flood irrigation distribution in the Optimized Irrigation Scenario.

Table A.7. Annual net revenues from the Optimized Irrigation Scenario as computed by the hydroeconomic model used to determine the overall distribution of flood and sprinkler irrigation around LRB. All values are in USD x 10,000.

Zone	**Irrigation**	**Demand Node**	**Supply 1**	**Supply 2**	**Supply 3**	**Sum**
1	Flood	1	$ -	$ -	$ -	$ -
1	Sprinkler	2	$ 38.05	$ -	$ -	$ 38.05
2T	Flood	3	$ -	$ 26.69	$ -	$ 26.69
2T	Sprinkler	4	$ -	$ 62.40	$ -	$ 62.40
2	Flood	5	$ -	$ 0.01	$ -	$ 0.01
2	Sprinkler	6	$ 39.75	$ 79.43	$ -	$ 119.18
3T	Flood	7	$ -	$ -	$ 1.15	$ 1.15
3T	Sprinkler	8	$ -	$ -	$ 10.81	$ 10.81
3	Flood	9	$ 19.90	$ 39.67	$ 3.25	$ 62.82
3	Sprinkler	10	$ 136.10	$ 271.45	$ 22.22	$ 429.77
		Sum	$ 233.80	$ 479.64	$ 37.43	$ 750.87

A.3.2 Annual Economic Output Results

The results generated from the annual economic output are presented in Table A.8 and Table A.9.

Table A.8. Revenues per economic zone for the Baseline Scenario.

Year	1	2	2t	3	3t	Total
2000	$ 19	$ 61	$ 45	$ 251	$ 6	$ 383
2001	$ 25	$ 79	$ 59	$ 325	$ 8	$ 496
2002	$ 34	$ 107	$ 80	$ 443	$ 11	$ 676
2003	$ 40	$ 126	$ 94	$ 522	$ 13	$ 796
2004	$ 24	$ 74	$ 55	$ 305	$ 7	$ 466
2005	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563
2006	$ 39	$ 123	$ 92	$ 507	$ 12	$ 773
2007	$ 33	$ 105	$ 78	$ 433	$ 11	$ 661
2008	$ 45	$ 142	$ 106	$ 586	$ 14	$ 894
2009	$ 53	$ 164	$ 123	$ 680	$ 17	$ 1,036
2010	$ 48	$ 151	$ 113	$ 626	$ 15	$ 954
2011	$ 58	$ 181	$ 135	$ 749	$ 18	$ 1,141
2012	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563

Table A.9. Revenues per economic zone for the Optimized Irrigation Scenario.

Year	1	2	2t	3	3t	Total
2000	$ 19	$ 61	$ 45	$ 251	$ 6	$ 383
2001	$ 25	$ 79	$ 59	$ 325	$ 8	$ 496
2002	$ 34	$ 107	$ 80	$ 443	$ 11	$ 676
2003	$ 40	$ 126	$ 94	$ 522	$ 13	$ 796
2004	$ 24	$ 74	$ 55	$ 305	$ 7	$ 466
2005	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563
2006	$ 39	$ 123	$ 92	$ 507	$ 12	$ 773
2007	$ 33	$ 105	$ 78	$ 433	$ 11	$ 661
2008	$ 45	$ 142	$ 106	$ 586	$ 14	$ 894
2009	$ 53	$ 164	$ 123	$ 680	$ 17	$ 1,036
2010	$ 48	$ 151	$ 113	$ 626	$ 15	$ 954
2011	$ 58	$ 181	$ 135	$ 749	$ 18	$ 1,141
2012	$ 29	$ 89	$ 67	$ 369	$ 9	$ 563

The criteria for evaluating the resilience, reliability, and vulnerability of the economic SI are presented in Table 29 and the results, when applied to the economic output, are presented in Table A.11 and Table A.12. Final results are published in Chapter 6.

Table A.11 Economic SI scores for the Baseline Scenario

	Zone 1					Zone 2					Zone 2T					Zone 3					Zone 3T				
Year	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS
2000	0.38	0.07	0.93	0.81	FALSE	0.44	0.11	0.89	0.88	FALSE	0.00	0.02	0.98	0.00	TRUE	0.00	0.04	0.96	0.00	TRUE	0.15	0.06	0.94	0.06	TRUE
2001	0.38	0.07	0.93	0.81	FALSE	0.44	0.11	0.89	0.88	FALSE	0.00	0.01	0.99	0.00	TRUE	0.31	0.05	0.95	0.64	FALSE	0.35	0.06	0.94	0.78	FALSE
2002	0.00	1.00	0.00	0.98	FALSE	1.00	1.00	1.00	1.00	FALSE	0.16	0.01	0.99	0.46	TRUE	0.42	0.25	0.75	0.41	FALSE	1.00	1.00	1.00	1.00	FALSE
2003	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.16	0.01	0.99	0.50	TRUE	0.44	0.14	0.86	0.68	FALSE	1.00	1.00	1.00	1.00	FALSE
2004	0.35	0.07	0.93	0.66	FALSE	0.60	0.67	0.33	0.98	FALSE	0.00	0.00	1.00	0.00	TRUE	0.28	0.04	0.96	0.59	TRUE	0.34	0.05	0.95	0.82	FALSE
2005	0.42	0.09	0.91	0.91	FALSE	1.00	1.00	1.00	1.00	FALSE	0.25	0.04	0.96	0.39	TRUE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2006	0.62	0.50	0.50	0.97	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.54	TRUE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2007	0.28	0.04	0.96	0.63	TRUE	1.00	1.00	1.00	1.00	FALSE	0.00	0.01	0.99	0.00	TRUE	0.35	0.08	0.92	0.55	TRUE	0.57	0.25	0.75	0.98	FALSE
2008	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.25	0.03	0.97	0.50	TRUE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2009	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.23	0.02	0.98	0.66	FALSE	0.50	0.15	0.85	0.96	FALSE	1.00	1.00	1.00	1.00	FALSE
2010	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.54	TRUE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2011	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.48	0.14	0.86	0.91	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2012	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.12	0.01	0.99	0.19	TRUE	0.43	0.11	0.89	0.83	FALSE	1.00	1.00	1.00	1.00	FALSE

Table A.12 Economic SI scores for the Optimized Irrigation Scenario

	Zone 1					Zone 2					Zone 2T					Zone 3					Zone 3T				
Year	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS	SI	Res.	Rel.	Vul.	SS
2000	0.62	0.50	0.50	0.93	FALSE	1.00	1.00	1.00	1.00	FALSE	0.15	0.02	0.98	0.23	TRUE	0.25	0.11	0.89	0.16	TRUE	0.00	0.07	0.93	0.00	TRUE
2001	0.62	0.50	0.50	0.93	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.36	TRUE	0.62	0.45	0.55	0.98	FALSE	1.00	1.00	1.00	1.00	FALSE
2002	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.31	0.04	0.96	0.69	TRUE	0.00	1.00	0.00	0.93	FALSE	1.00	1.00	1.00	1.00	FALSE
2003	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.33	0.05	0.95	0.78	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2004	0.54	0.22	0.78	0.93	FALSE	1.00	1.00	1.00	1.00	FALSE	0.12	0.01	0.99	0.18	TRUE	0.26	0.02	0.98	0.87	FALSE	0.62	0.60	0.40	0.99	FALSE
2005	0.62	0.50	0.50	0.97	FALSE	1.00	1.00	1.00	1.00	FALSE	0.21	0.02	0.98	0.59	TRUE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2006	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.33	0.05	0.95	0.79	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2007	0.55	0.22	0.78	0.95	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.14	TRUE	0.00	0.00	1.00	0.83	TRUE	1.00	1.00	1.00	1.00	FALSE
2008	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.25	0.02	0.98	0.79	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2009	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.91	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2010	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.00	0.00	1.00	0.78	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2011	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE
2012	1.00	1.00	1.00	1.00	FALSE	1.00	1.00	1.00	1.00	FALSE	0.16	0.01	0.99	0.44	TRUE	0.31	0.03	0.97	0.87	FALSE	1.00	1.00	1.00	1.00	FALSE

Appendix B. Ecological Analysis

The ecological analysis informs how the change in flow conditions associated with a conversion to sprinklers effects the aquatic habitat. This appendix provides the habitat curves, SI time series for each simulation, and final results from the ecological analysis. Note, in the following tables the terms "Ave" is the average, "SI" is sustainability index, "SS" is show stopper, "Res." is resilience, "Rel." is reliability, "Vul." is vulnerability, and "%WUA" is the percent weighted usable area.

Table B.1. Thresholds, duration, and show stopper criteria used in calculating the SI Ecology values for all sites.

	Steelhead			**Chinook**			**Bull Trout**		
Parameter	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
Lower Threshold [%WUA]	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Lower Duration [Days]	5.0	7.0	14.0	5.0	7.0	14.0	5.0	14.0	14.0
Upper Threshold [%WUA]	101.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0
Upper Duration [Days]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lower Show Stopper [%WUA]	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Upper Show Stopper [%WUA]	101.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0
Start [Day-Month]	1-Apr	1-Mar	1-Oct	1-Jul	1-May	1-Oct	1-Sep	1-Mar	1-Oct
End [Day-Month]	30-Jun	30-Jun	30-Sep	31-Oct	31-Oct	30-Sep	31-Oct	31-Oct	30-Sep

Big Eighteenmile Creek, Site 1

Table B.2. Percent weighted usable area (% WUA) for a given discharge for Big Eighteenmile Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	0
0.40	26.00	8.90		26.00	8.90		14.80	12.00	0.40
0.60	33.70	17.40		33.70	17.40		25.30	20.00	0.60
0.80	43.80	26.30		43.80	26.30		37.40	29.10	0.80
1.00	48.70	35.10		48.70	35.10		45.50	35.80	1.00
1.40	55.20	59.20		55.20	59.20		55.20	58.20	1.40
1.80	60.00	64.60		60.00	64.60		62.70	71.00	1.80
2.00	64.40	67.20		64.40	67.20		65.10	75.80	2.00
2.20	67.60	69.10		67.60	69.10		67.00	80.40	2.20
2.40	69.80	71.40		69.80	71.40		69.20	84.70	2.40
2.60	71.60	73.50		71.60	73.50		71.20	87.90	2.60
2.80	73.30	75.70		73.30	75.70		72.90	90.70	2.80
3.00	78.20	77.70		78.20	77.70		76.90	92.60	3.00
3.20	81.40	81.50		81.40	81.50		80.00	93.90	3.20
3.40	83.70	84.00		83.70	84.00		81.90	95.00	3.40
3.60	85.60	86.20		85.60	86.20		83.60	96.10	3.60
3.80	87.30	90.60		87.30	90.60		85.20	97.00	3.80
4.00	88.90	93.60		88.90	93.60		86.50	97.80	4.00
4.20	90.20	95.90		90.20	95.90		87.70	98.60	4.20
4.40	97.00	98.00		97.00	98.00		96.60	99.30	4.40
4.60	100.00	100.00		100.00	100.00		100.00	100.00	4.60

Table B.3. Site summary results for Big Eighteenmile Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.19	TRUE	0.29	TRUE	0.18	TRUE	0.27	TRUE	0.21	FALSE	0.30	TRUE
Chinook	0.08	TRUE	0.18	TRUE	0.06	TRUE	0.20	TRUE	0.10	TRUE	0.17	TRUE
Bull Trout	0.08	TRUE	0.21	TRUE	0.05	TRUE	0.24	TRUE	0.11	TRUE	0.18	TRUE

Table B.4. Baseline Scenario results from Big Eighteenmile Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.09	TRUE	0.00	63.81	0.10	0.90	0.00	TRUE	0.17	53.39	0.07	0.93	0.08	TRUE
2001	0.09	TRUE	0.00	64.52	0.05	0.95	0.00	TRUE	0.17	53.39	0.07	0.93	0.08	TRUE
2002	0.24	TRUE	0.24	66.14	0.15	0.85	0.10	TRUE	0.23	66.06	0.14	0.86	0.11	TRUE
2003	0.21	TRUE	0.22	76.01	0.17	0.83	0.07	TRUE	0.21	74.67	0.16	0.84	0.07	TRUE
2004	0.14	TRUE	0.12	58.90	0.09	0.91	0.02	TRUE	0.16	64.54	0.08	0.92	0.05	TRUE
2005	0.23	TRUE	0.23	64.57	0.17	0.83	0.08	TRUE	0.23	66.93	0.15	0.85	0.09	TRUE
2006	0.23	TRUE	0.24	83.84	0.11	0.89	0.14	TRUE	0.22	78.72	0.10	0.90	0.13	TRUE
2007	0.14	TRUE	0.12	58.90	0.09	0.91	0.02	TRUE	0.16	68.36	0.08	0.92	0.05	TRUE
2008	0.16	TRUE	0.16	69.16	0.13	0.88	0.04	TRUE	0.15	65.18	0.06	0.94	0.06	TRUE
2009	0.00	TRUE	0.00	88.55	1.00	0.00	0.35	TRUE	0.00	87.45	1.00	0.00	0.38	TRUE
2010	0.00	TRUE	0.00	84.54	0.25	0.75	0.00	TRUE	0.00	82.14	0.25	0.75	0.00	TRUE
2011	1.00	FALSE	1.00	89.15	1.00	1.00	1.00	FALSE	1.00	84.96	1.00	1.00	1.00	FALSE
2012	0.00	TRUE	0.00	75.37	0.00	1.00	0.07	TRUE	0.00	80.56	0.00	1.00	0.04	TRUE
Chinook														
2000	0.03	TRUE	0.00	0.31	0.00	1.00	0.01	TRUE	0.05	18.67	0.02	0.98	0.01	TRUE
2001	0.03	TRUE	0.00	1.90	0.00	1.00	0.05	TRUE	0.06	19.07	0.01	0.99	0.02	TRUE
2002	0.06	TRUE	0.03	23.87	0.01	0.99	0.00	TRUE	0.09	35.96	0.03	0.97	0.02	TRUE
2003	0.08	TRUE	0.06	24.51	0.01	0.99	0.02	TRUE	0.09	38.21	0.04	0.96	0.02	TRUE
2004	0.04	TRUE	0.00	23.77	0.01	0.99	0.00	TRUE	0.08	28.26	0.03	0.97	0.01	TRUE
2005	0.05	TRUE	0.00	24.12	0.02	0.98	0.00	TRUE	0.10	32.44	0.04	0.96	0.03	TRUE
2006	0.05	TRUE	0.03	23.85	0.01	0.99	0.00	TRUE	0.06	42.89	0.02	0.98	0.01	TRUE
2007	0.04	TRUE	0.00	23.77	0.01	0.99	0.00	TRUE	0.08	28.26	0.03	0.97	0.01	TRUE
2008	0.08	TRUE	0.07	25.28	0.04	0.96	0.01	TRUE	0.09	40.06	0.03	0.97	0.02	TRUE
2009	0.09	TRUE	0.07	21.99	0.03	0.97	0.01	TRUE	0.11	42.77	0.06	0.94	0.02	TRUE
2010	0.17	TRUE	0.17	11.05	0.06	0.94	0.09	TRUE	0.17	34.08	0.05	0.95	0.09	TRUE
2011	0.19	TRUE	0.19	64.36	0.06	0.94	0.13	TRUE	0.20	74.82	0.05	0.95	0.16	TRUE
2012	0.17	TRUE	0.19	77.96	0.12	0.88	0.06	TRUE	0.15	72.09	0.04	0.96	0.08	TRUE
Bull Trout														
2000	0.07	TRUE	0.05	0.35	0.02	0.98	0.01	TRUE	0.09	28.61	0.02	0.98	0.03	TRUE
2001	0.05	TRUE	0.00	2.31	0.00	1.00	0.06	TRUE	0.09	29.00	0.02	0.98	0.04	TRUE
2002	0.07	TRUE	0.06	48.45	0.03	0.97	0.01	TRUE	0.09	45.97	0.03	0.97	0.02	TRUE
2003	0.10	TRUE	0.11	49.29	0.03	0.97	0.05	TRUE	0.09	51.50	0.04	0.96	0.02	TRUE
2004	0.04	TRUE	0.00	48.33	0.03	0.97	0.00	TRUE	0.08	45.40	0.03	0.97	0.02	TRUE
2005	0.05	TRUE	0.00	48.21	0.03	0.97	0.00	TRUE	0.11	47.60	0.04	0.96	0.03	TRUE
2006	0.06	TRUE	0.05	48.43	0.03	0.97	0.00	TRUE	0.07	52.12	0.02	0.98	0.01	TRUE
2007	0.04	TRUE	0.00	48.33	0.03	0.97	0.00	TRUE	0.08	46.28	0.03	0.97	0.02	TRUE
2008	0.05	TRUE	0.01	48.33	0.03	0.97	0.00	TRUE	0.09	45.60	0.03	0.97	0.03	TRUE
2009	0.06	TRUE	0.00	0.00	0.00	1.00	0.00	TRUE	0.11	57.17	0.06	0.94	0.03	TRUE
2010	0.09	TRUE	0.00	0.51	0.00	1.00	0.01	TRUE	0.17	48.86	0.05	0.95	0.10	TRUE
2011	0.19	TRUE	0.18	27.72	0.06	0.94	0.12	TRUE	0.20	78.59	0.05	0.95	0.17	TRUE
2012	0.18	TRUE	0.20	57.51	0.08	0.92	0.11	TRUE	0.15	79.15	0.04	0.96	0.08	TRUE

Table B.5. Optimized Irrigation Scenario results from Big Eighteenmile Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.10	TRUE	0.05	78.86	0.08	0.92	0.00	TRUE	0.14	64.34	0.03	0.97	0.10	TRUE
2001	0.07	TRUE	0.00	79.74	0.00	1.00	0.00	TRUE	0.14	64.34	0.03	0.97	0.10	TRUE
2002	0.14	TRUE	0.16	78.28	0.09	0.91	0.05	TRUE	0.11	75.51	0.09	0.91	0.02	TRUE
2003	0.00	TRUE	0.00	83.75	0.09	0.91	0.00	TRUE	0.00	80.83	0.09	0.91	0.00	TRUE
2004	0.08	TRUE	0.00	79.68	0.00	1.00	0.04	TRUE	0.15	79.90	0.06	0.94	0.06	TRUE
2005	0.00	TRUE	0.00	84.20	0.00	1.00	0.00	TRUE	0.00	81.78	0.00	1.00	0.00	TRUE
2006	0.00	TRUE	0.00	88.63	0.00	1.00	0.13	TRUE	0.00	82.61	0.00	1.00	0.07	TRUE
2007	0.08	TRUE	0.00	74.32	0.00	1.00	0.10	TRUE	0.16	79.41	0.04	0.96	0.10	TRUE
2008	0.00	TRUE	0.00	81.10	0.00	1.00	0.13	TRUE	0.00	74.20	0.00	1.00	0.07	TRUE
2009	1.00	FALSE	1.00	98.91	1.00	1.00	1.00	FALSE	1.00	95.18	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	94.31	1.00	1.00	1.00	FALSE	1.00	89.19	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	89.54	1.00	1.00	1.00	FALSE	1.00	85.22	1.00	1.00	1.00	FALSE
2012	0.27	TRUE	0.31	89.25	0.09	0.91	0.36	TRUE	0.23	90.49	0.09	0.91	0.15	TRUE
Chinook														
2000	0.02	TRUE	0.00	0.31	0.00	1.00	0.01	TRUE	0.04	25.91	0.01	0.99	0.01	TRUE
2001	0.00	TRUE	0.00	1.90	0.00	1.00	0.05	TRUE	0.00	26.31	0.00	1.00	0.02	TRUE
2002	0.34	TRUE	0.36	56.73	0.23	0.77	0.26	TRUE	0.32	62.02	0.16	0.84	0.23	TRUE
2003	0.29	TRUE	0.26	60.03	0.21	0.79	0.11	TRUE	0.31	65.49	0.20	0.80	0.19	TRUE
2004	0.02	TRUE	0.00	24.20	0.00	1.00	0.00	TRUE	0.04	38.68	0.01	0.99	0.01	TRUE
2005	0.11	TRUE	0.14	43.60	0.04	0.96	0.06	TRUE	0.09	54.77	0.04	0.96	0.02	TRUE
2006	0.34	TRUE	0.36	56.55	0.23	0.77	0.26	TRUE	0.33	65.07	0.15	0.85	0.27	TRUE
2007	0.04	TRUE	0.00	24.14	0.00	1.00	0.00	TRUE	0.08	35.72	0.02	0.98	0.03	TRUE
2008	0.38	TRUE	0.43	62.83	0.26	0.74	0.41	TRUE	0.34	68.77	0.15	0.85	0.32	TRUE
2009	0.23	TRUE	0.31	44.47	0.10	0.90	0.33	TRUE	0.14	59.33	0.01	0.99	0.22	TRUE
2010	0.16	TRUE	0.17	51.40	0.08	0.92	0.07	TRUE	0.16	67.21	0.08	0.92	0.06	TRUE
2011	0.00	TRUE	0.00	71.51	0.00	1.00	0.00	TRUE	0.00	80.50	0.00	1.00	0.00	TRUE
2012	0.42	TRUE	0.52	88.41	0.30	0.70	0.68	TRUE	0.32	85.44	0.12	0.88	0.33	TRUE
Bull Trout														
2000	0.06	TRUE	0.05	0.35	0.02	0.98	0.01	TRUE	0.07	33.45	0.01	0.99	0.03	TRUE
2001	0.03	TRUE	0.00	2.31	0.00	1.00	0.06	TRUE	0.07	33.84	0.01	0.99	0.04	TRUE
2002	0.43	TRUE	0.53	71.41	0.56	0.44	0.59	TRUE	0.33	65.92	0.16	0.84	0.26	TRUE
2003	0.45	TRUE	0.58	77.46	0.67	0.33	0.89	FALSE	0.32	72.77	0.20	0.80	0.20	TRUE
2004	0.02	TRUE	0.00	49.19	0.00	1.00	0.00	TRUE	0.04	53.18	0.01	0.99	0.01	TRUE
2005	0.10	TRUE	0.10	48.83	0.03	0.97	0.03	TRUE	0.10	64.26	0.04	0.96	0.02	TRUE
2006	0.43	TRUE	0.52	71.23	0.56	0.44	0.58	TRUE	0.34	69.30	0.15	0.85	0.30	TRUE
2007	0.09	TRUE	0.10	48.99	0.03	0.97	0.03	TRUE	0.08	51.72	0.02	0.98	0.03	TRUE
2008	0.41	TRUE	0.46	65.09	0.28	0.72	0.50	TRUE	0.35	67.74	0.15	0.85	0.35	TRUE
2009	0.18	TRUE	0.21	12.82	0.04	0.96	0.28	TRUE	0.15	69.22	0.01	0.99	0.26	TRUE
2010	0.13	TRUE	0.10	24.53	0.05	0.95	0.02	TRUE	0.16	74.09	0.08	0.92	0.06	TRUE
2011	0.00	TRUE	0.00	41.66	0.00	1.00	0.00	TRUE	0.00	83.17	0.00	1.00	0.00	TRUE
2012	0.40	TRUE	0.47	74.72	0.23	0.77	0.58	TRUE	0.34	89.67	0.12	0.88	0.38	TRUE

Big Timber Creek, Site 1

Table B.6. Percent weighted usable area (% WUA) for a given discharge for Big Timber Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.4	8.40	65.10	68.70	8.40	65.10	91.10	21.90	74.20	77.40
2	21.80	70.50	81.00	21.80	70.50	95.00	34.10	84.10	87.30
3	40.80	76.50	91.40	40.80	76.50	98.70	51.40	92.30	95.20
4	53.30	80.30	97.10	53.30	80.30	100.00	64.80	96.30	98.60
5	69.20	83.40	100.00	69.20	83.40	100.00	74.80	98.30	100.00
6	76.60	86.20	99.10	76.60	86.20	99.30	82.50	97.8b0	98.70
6.5	79.80	87.70	99.20	79.80	87.70	98.80	86.60	97.70	98.20
7	82.20	89.20	99.20	82.20	89.20	98.90	90.10	98.30	98.60
8	85.90	91.30	96.80	85.90	91.30	97.70	94.80	98.80	98.50
9	91.70	93.00	93.30	91.70	93.00	95.90	98.20	100.00	99.30
10	95.40	94.30	93.30	95.40	94.30	94.00	100.00	99.70	98.40
11	97.50	95.50	92.00	97.50	95.50	92.00	100.00	99.80	97.90
12	98.70	96.90	89.90	98.70	96.90	90.50	99.60	99.00	96.60
13	99.60	97.60	87.00	99.60	97.60	89.30	99.30	98.70	95.70
14	100.00	98.30	83.20	100.00	98.30	87.50	98.20	98.60	95.10
15	99.40	98.30	79.40	99.40	98.30	86.50	96.90	98.90	94.90
16	98.00	98.70	77.60	98.00	98.70	85.40	93.80	99.10	94.60
17	97.50	99.30	76.70	97.50	99.30	83.40	90.30	98.90	94.00
18	96.70	100.00	74.70	96.70	100.00	81.70	88.00	98.60	93.20
19	95.20	100.00	73.00	95.20	100.00	80.70	84.70	97.30	91.40
20	90.60	99.60	70.60	90.60	99.60	80.10	82.00	96.60	90.30

Table B.7. Site summary results for Big Timber Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		**Optimized**		**Base**		**Optimized**		**Base**		**Optimized**	
Steelhead	0.48	TRUE	0.93	TRUE	0.51	TRUE	0.92	TRUE	0.47	FALSE	1.00	FALSE
Chinook	0.42	TRUE	0.87	TRUE	0.40	TRUE	0.86	TRUE	0.45	TRUE	0.88	TRUE
Bull Trout	0.59	TRUE	0.87	TRUE	0.86	TRUE	0.86	TRUE	0.45	TRUE	0.87	TRUE

Table B.8. Baseline Scenario results from Big Timber Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.10	TRUE	0.20	81.37	0.09	0.91	0.09	TRUE	0.00	85.02	0.00	1.00	0.08	TRUE
2001	0.00	TRUE	0.00	82.27	0.00	1.00	0.10	TRUE	0.00	85.02	0.00	1.00	0.08	TRUE
2002	0.12	TRUE	0.24	83.31	0.29	0.71	0.07	TRUE	0.00	90.34	0.33	0.67	0.00	TRUE
2003	0.00	TRUE	0.00	82.74	0.11	0.89	0.00	TRUE	0.00	90.28	0.11	0.89	0.00	TRUE
2004	0.00	TRUE	0.00	60.38	0.00	1.00	0.04	TRUE	0.00	74.76	0.00	1.00	0.02	TRUE
2005	1.00	FALSE	1.00	91.45	1.00	1.00	1.00	FALSE	1.00	99.33	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.57	1.00	1.00	1.00	FALSE	1.00	96.73	1.00	1.00	1.00	FALSE
2007	0.00	TRUE	0.00	62.69	0.00	1.00	0.00	TRUE	0.00	76.58	0.00	1.00	0.02	TRUE
2008	1.00	FALSE	1.00	88.98	1.00	1.00	1.00	FALSE	1.00	94.46	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	91.50	1.00	1.00	1.00	FALSE	1.00	98.46	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	91.43	1.00	1.00	1.00	FALSE	1.00	97.56	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.30	1.00	1.00	1.00	FALSE	1.00	97.79	1.00	1.00	1.00	FALSE
2012	0.14	TRUE	0.14	70.36	0.05	0.95	0.06	TRUE	0.14	84.41	0.06	0.94	0.05	TRUE
Chinook														
2000	0.16	TRUE	0.15	50.49	0.05	0.95	0.06	TRUE	0.17	65.16	0.05	0.95	0.10	TRUE
2001	0.14	TRUE	0.13	51.16	0.04	0.96	0.06	TRUE	0.15	65.65	0.04	0.96	0.10	TRUE
2002	0.39	TRUE	0.44	90.51	0.40	0.60	0.36	TRUE	0.33	93.44	0.44	0.56	0.15	TRUE
2003	0.10	TRUE	0.00	91.83	1.00	0.00	0.42	TRUE	0.20	93.35	0.20	0.80	0.05	TRUE
2004	0.09	TRUE	0.11	62.94	0.03	0.97	0.05	TRUE	0.07	63.36	0.03	0.97	0.01	TRUE
2005	0.43	TRUE	0.40	91.56	0.67	0.33	0.30	TRUE	0.46	96.89	0.50	0.50	0.40	TRUE
2006	1.00	FALSE	1.00	92.71	1.00	1.00	1.00	FALSE	1.00	99.34	1.00	1.00	1.00	FALSE
2007	0.07	TRUE	0.06	62.03	0.03	0.97	0.01	TRUE	0.09	62.05	0.02	0.98	0.04	TRUE
2008	0.17	TRUE	0.17	84.64	0.08	0.92	0.07	TRUE	0.17	92.15	0.08	0.92	0.06	TRUE
2009	0.75	TRUE	0.51	93.51	0.50	0.50	0.52	TRUE	1.00	98.30	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	95.70	1.00	1.00	1.00	FALSE	1.00	99.02	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.91	1.00	1.00	1.00	FALSE	1.00	99.09	1.00	1.00	1.00	FALSE
2012	0.19	TRUE	0.19	86.08	0.11	0.89	0.07	TRUE	0.19	84.84	0.08	0.92	0.10	TRUE
Bull Trout														
2000	0.15	TRUE	0.16	51.12	0.03	0.97	0.13	TRUE	0.14	73.70	0.04	0.96	0.07	TRUE
2001	0.07	TRUE	0.00	52.62	0.00	1.00	0.14	TRUE	0.14	74.10	0.04	0.96	0.08	TRUE
2002	0.67	TRUE	1.00	90.02	1.00	1.00	1.00	FALSE	0.35	94.18	0.44	0.56	0.17	TRUE
2003	0.60	TRUE	1.00	88.63	1.00	1.00	1.00	FALSE	0.20	93.77	0.20	0.80	0.05	TRUE
2004	0.53	TRUE	1.00	85.08	1.00	1.00	1.00	FALSE	0.07	73.71	0.03	0.97	0.01	TRUE
2005	0.74	TRUE	1.00	92.18	1.00	1.00	1.00	FALSE	0.48	96.95	0.50	0.50	0.46	TRUE
2006	1.00	FALSE	1.00	86.07	1.00	1.00	1.00	FALSE	1.00	97.42	1.00	1.00	1.00	FALSE
2007	0.54	TRUE	1.00	85.75	1.00	1.00	1.00	FALSE	0.09	72.06	0.02	0.98	0.05	TRUE
2008	0.59	TRUE	1.00	91.41	1.00	1.00	1.00	FALSE	0.18	93.07	0.08	0.92	0.07	TRUE
2009	1.00	FALSE	1.00	93.66	1.00	1.00	1.00	FALSE	1.00	97.68	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	94.54	1.00	1.00	1.00	FALSE	1.00	98.03	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	91.57	1.00	1.00	1.00	FALSE	1.00	97.61	1.00	1.00	1.00	FALSE
2012	0.60	TRUE	1.00	84.67	1.00	1.00	1.00	FALSE	0.20	87.10	0.08	0.92	0.11	TRUE

Table B.9. Optimized Irrigation Scenario results from Big Timber Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.50	TRUE	0.00	90.92	1.00	0.00	0.00	TRUE	1.00	92.58	1.00	1.00	1.00	FALSE
2001	1.00	FALSE	1.00	91.93	1.00	1.00	1.00	FALSE	1.00	92.58	1.00	1.00	1.00	FALSE
2002	1.00	FALSE	1.00	90.26	1.00	1.00	1.00	FALSE	1.00	95.88	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	91.57	1.00	1.00	1.00	FALSE	1.00	97.69	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	91.59	1.00	1.00	1.00	FALSE	1.00	98.50	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	90.60	1.00	1.00	1.00	FALSE	1.00	99.50	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.57	1.00	1.00	1.00	FALSE	1.00	96.73	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	90.93	1.00	1.00	1.00	FALSE	1.00	98.97	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	88.81	1.00	1.00	1.00	FALSE	1.00	94.48	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	91.50	1.00	1.00	1.00	FALSE	1.00	98.46	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	91.43	1.00	1.00	1.00	FALSE	1.00	97.56	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.30	1.00	1.00	1.00	FALSE	1.00	97.79	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	90.60	1.00	1.00	1.00	FALSE	1.00	99.55	1.00	1.00	1.00	FALSE
Chinook														
2000	0.16	TRUE	0.12	72.32	0.03	0.97	0.05	TRUE	0.20	85.56	0.04	0.96	0.19	TRUE
2001	0.10	TRUE	0.00	73.12	0.00	1.00	0.05	TRUE	0.20	86.09	0.04	0.96	0.20	TRUE
2002	1.00	FALSE	1.00	91.99	1.00	1.00	1.00	FALSE	1.00	99.61	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	91.27	1.00	1.00	1.00	FALSE	1.00	99.62	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	95.06	1.00	1.00	1.00	FALSE	1.00	98.18	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	93.45	1.00	1.00	1.00	FALSE	1.00	99.49	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.78	1.00	1.00	1.00	FALSE	1.00	99.60	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	94.25	1.00	1.00	1.00	FALSE	1.00	97.47	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	92.63	1.00	1.00	1.00	FALSE	1.00	99.60	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	92.78	1.00	1.00	1.00	FALSE	1.00	99.40	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	92.44	1.00	1.00	1.00	FALSE	1.00	99.66	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.76	1.00	1.00	1.00	FALSE	1.00	99.40	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	90.73	1.00	1.00	1.00	FALSE	1.00	99.61	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.17	TRUE	0.16	51.87	0.03	0.97	0.13	TRUE	0.18	86.51	0.05	0.95	0.14	TRUE
2001	0.09	TRUE	0.00	53.53	0.00	1.00	0.14	TRUE	0.19	86.92	0.05	0.95	0.15	TRUE
2002	1.00	FALSE	1.00	84.79	1.00	1.00	1.00	FALSE	1.00	97.15	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	83.27	1.00	1.00	1.00	FALSE	1.00	97.24	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	91.00	1.00	1.00	1.00	FALSE	1.00	97.83	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	89.50	1.00	1.00	1.00	FALSE	1.00	97.13	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	82.40	1.00	1.00	1.00	FALSE	1.00	97.09	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	90.93	1.00	1.00	1.00	FALSE	1.00	97.67	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	86.38	1.00	1.00	1.00	FALSE	1.00	97.31	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	89.49	1.00	1.00	1.00	FALSE	1.00	97.33	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	85.33	1.00	1.00	1.00	FALSE	1.00	97.48	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	89.45	1.00	1.00	1.00	FALSE	1.00	97.48	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	82.15	1.00	1.00	1.00	FALSE	1.00	96.78	1.00	1.00	1.00	FALSE

Bohannon Creek, Site 1

Table B.10. Percent weighted usable area (% WUA) for a given discharge for Bohannon Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
0	0.00	0.00		0.00	0.00		0.00	0.00	
0.2	37.90	5.60		37.90	5.60		31.80	0.00	
0.7	49.10	15.10		49.10	15.10		46.00	0.00	
1	54.90	19.20		54.90	19.20		49.80	0.00	
2	65.40	29.80		65.40	29.80		60.40	0.00	
3	72.80	47.80		72.80	47.80		68.80	42.40	
4.5	79.90	71.00		79.90	71.00		76.60	87.30	
5	81.90	73.80		81.90	73.80		78.70	89.00	
6	85.00	78.10		85.00	78.10		82.90	91.80	
7	87.60	83.00		87.60	83.00		86.30	93.50	
8	89.80	87.40		89.80	87.40		89.10	94.90	
9	91.60	91.20		91.60	91.20		91.80	96.20	
10	93.10	94.10		93.10	94.10		94.60	97.30	
11	94.40	96.50		94.40	96.50		96.60	98.30	
12	97.10	98.40		97.10	98.40		98.40	99.20	
13	100.00	100.00		100.00	100.00		100.00	100.00	

Table B.11. Site summary results for Bohannon Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		**Optimized**		**Base**		**Optimized**		**Base**		**Optimized**	
Steelhead	0.83	TRUE	0.84	TRUE	0.85	TRUE	0.85	TRUE	0.82	FALSE	0.83	TRUE
Chinook	0.87	TRUE	0.87	TRUE	0.91	TRUE	0.91	TRUE	0.82	TRUE	0.83	TRUE
Bull Trout	0.82	TRUE	0.82	TRUE	0.85	TRUE	0.85	TRUE	0.79	TRUE	0.80	TRUE

Table B.12. Baseline Scenario results from Bohannon Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.09	TRUE	0.00	60.5	0.13	0.88	0.00	TRUE	0.18	34.0	0.03	0.97	0.20	TRUE
2001	0.09	TRUE	0.00	61.2	0.07	0.93	0.00	TRUE	0.18	34.0	0.03	0.97	0.20	TRUE
2002	0.66	TRUE	1.00	85.2	1.00	1.00	1.00	FALSE	0.32	61.2	0.07	0.93	0.48	TRUE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
Chinook														
2000	0.31	TRUE	0.42	43.5	0.22	0.78	0.44	TRUE	0.21	30.9	0.02	0.98	0.38	TRUE
2001	0.30	TRUE	0.42	43.6	0.22	0.78	0.44	TRUE	0.18	31.0	0.02	0.98	0.39	TRUE
2002	0.64	TRUE	1.00	88.4	1.00	1.00	1.00	FALSE	0.27	80.1	0.03	0.97	0.66	TRUE
2003	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE	1.00	98.3	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.03	TRUE	0.00	36.1	0.13	0.88	0.00	TRUE	0.06	18.0	0.01	0.99	0.03	TRUE
2001	0.03	TRUE	0.00	36.9	0.07	0.93	0.00	TRUE	0.06	18.0	0.01	0.99	0.03	TRUE
2002	0.60	TRUE	1.00	77.1	1.00	1.00	1.00	FALSE	0.20	67.2	0.06	0.94	0.13	TRUE
2003	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	98.6	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE

Table B.13. Optimized Irrigation Scenario results from Bohannon Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.12	TRUE	0.00	55.4	0.13	0.88	0.00	TRUE	0.24	24.3	0.04	0.96	0.32	TRUE
2001	0.12	TRUE	0.00	56.0	0.07	0.93	0.00	TRUE	0.24	24.3	0.04	0.96	0.32	TRUE
2002	0.66	TRUE	1.00	84.8	1.00	1.00	1.00	FALSE	0.31	60.6	0.07	0.93	0.49	TRUE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
Chinook														
2000	0.31	TRUE	0.39	42.6	0.19	0.81	0.38	TRUE	0.24	23.8	0.03	0.97	0.42	TRUE
2001	0.31	TRUE	0.39	42.7	0.19	0.81	0.38	TRUE	0.22	23.9	0.03	0.97	0.43	TRUE
2002	0.63	TRUE	1.00	88.5	1.00	1.00	1.00	FALSE	0.27	79.8	0.03	0.97	0.66	TRUE
2003	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.05	TRUE	0.00	35.7	0.13	0.88	0.00	TRUE	0.09	8.1	0.02	0.98	0.04	TRUE
2001	0.05	TRUE	0.00	36.6	0.07	0.93	0.00	TRUE	0.09	8.1	0.02	0.98	0.04	TRUE
2002	0.60	TRUE	1.00	77.1	1.00	1.00	1.00	FALSE	0.20	66.8	0.06	0.94	0.14	TRUE
2003	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	98.6	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	100	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE

Canyon Creek, Site 1

Table B.14. Percent weighted usable area (% WUA) for a given discharge for Canyon Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.4	8.40	65.10	68.70	8.40	65.10	91.10	21.90	74.20	77.40
2	21.80	70.50	81.00	21.80	70.50	95.00	34.10	84.10	87.30
3	40.80	76.50	91.40	40.80	76.50	98.70	51.40	92.30	95.20
4	53.30	80.30	97.10	53.30	80.30	100.00	64.80	96.30	98.60
5	69.20	83.40	100.00	69.20	83.40	100.00	74.80	98.30	100.00
6	76.60	86.20	99.10	76.60	86.20	99.30	82.50	97.8b0	98.70
6.5	79.80	87.70	99.20	79.80	87.70	98.80	86.60	97.70	98.20
7	82.20	89.20	99.20	82.20	89.20	98.90	90.10	98.30	98.60
8	85.90	91.30	96.80	85.90	91.30	97.70	94.80	98.80	98.50
9	91.70	93.00	93.30	91.70	93.00	95.90	98.20	100.00	99.30
10	95.40	94.30	93.30	95.40	94.30	94.00	100.00	99.70	98.40
11	97.50	95.50	92.00	97.50	95.50	92.00	100.00	99.80	97.90
12	98.70	96.90	89.90	98.70	96.90	90.50	99.60	99.00	96.60
13	99.60	97.60	87.00	99.60	97.60	89.30	99.30	98.70	95.70
14	100.00	98.30	83.20	100.00	98.30	87.50	98.20	98.60	95.10
15	99.40	98.30	79.40	99.40	98.30	86.50	96.90	98.90	94.90
16	98.00	98.70	77.60	98.00	98.70	85.40	93.80	99.10	94.60
17	97.50	99.30	76.70	97.50	99.30	83.40	90.30	98.90	94.00
18	96.70	100.00	74.70	96.70	100.00	81.70	88.00	98.60	93.20
19	95.20	100.00	73.00	95.20	100.00	80.70	84.70	97.30	91.40
20	90.60	99.60	70.60	90.60	99.60	80.10	82.00	96.60	90.30

Table B.15. Site summary results for Canyon Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		**Optimized**		**Base**		**Optimized**		**Base**		**Optimized**	
Steelhead	0.48	TRUE	0.93	TRUE	0.51	TRUE	0.92	TRUE	0.47	FALSE	1.00	FALSE
Chinook	0.42	TRUE	0.87	TRUE	0.40	TRUE	0.86	TRUE	0.45	TRUE	0.88	TRUE
Bull Trout	0.59	TRUE	0.87	TRUE	0.86	TRUE	0.86	TRUE	0.45	TRUE	0.87	TRUE

B.16. Baseline Scenario results from Canyon Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.09	TRUE	0.04	47.4	0.02	0.98	0.00	TRUE	0.14	53.3	0.02	0.98	0.16	TRUE
2001	0.07	TRUE	0.00	47.9	0.00	1.00	0.00	TRUE	0.14	53.3	0.02	0.98	0.16	TRUE
2002	0.00	TRUE	0.00	39.2	0.00	1.00	0.00	TRUE	0.00	52.1	0.00	1.00	0.00	TRUE
2003	0.14	TRUE	0.28	56.6	0.09	0.91	0.28	TRUE	0.00	76.8	0.21	0.79	0.00	TRUE
2004	0.00	TRUE	0.00	42.0	0.00	1.00	0.00	TRUE	0.00	56.3	0.00	1.00	0.00	TRUE
2005	0.04	TRUE	0.08	42.1	0.02	0.98	0.03	TRUE	0.00	55.8	0.00	1.00	0.01	TRUE
2006	0.00	TRUE	0.00	51.2	0.00	1.00	0.00	TRUE	0.00	61.3	0.00	1.00	0.00	TRUE
2007	0.00	TRUE	0.00	50.2	0.00	1.00	0.02	TRUE	0.00	63.5	0.00	1.00	0.00	TRUE
2008	1.00	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE	1.00	91.1	1.00	1.00	1.00	FALSE
2012	0.79	FALSE	0.57	77.0	0.50	0.50	0.76	FALSE	1.00	90.9	1.00	1.00	1.00	FALSE
Chinook														
2000	0.05	TRUE	0.07	7.1	0.01	0.99	0.04	TRUE	0.03	17.4	0.01	0.99	0.00	TRUE
2001	0.05	TRUE	0.07	7.1	0.01	0.99	0.04	TRUE	0.03	17.4	0.01	0.99	0.00	TRUE
2002	0.05	TRUE	0.04	23.9	0.01	0.99	0.01	TRUE	0.05	20.5	0.01	0.99	0.01	TRUE
2003	0.35	TRUE	0.25	46.3	0.06	0.94	0.27	TRUE	0.45	68.4	0.38	0.62	0.38	TRUE
2004	0.00	TRUE	0.00	23.5	0.00	1.00	0.00	TRUE	0.00	21.0	0.00	1.00	0.00	TRUE
2005	0.01	TRUE	0.00	23.1	0.01	0.99	0.00	TRUE	0.03	21.5	0.01	0.99	0.00	TRUE
2006	0.08	TRUE	0.07	24.7	0.01	0.99	0.03	TRUE	0.08	29.0	0.02	0.98	0.02	TRUE
2007	0.00	TRUE	0.00	23.2	0.01	0.99	0.00	TRUE	0.00	24.8	0.01	0.99	0.00	TRUE
2008	0.29	TRUE	0.58	68.3	0.33	0.67	0.86	TRUE	0.00	88.0	1.00	0.00	0.00	TRUE
2009	0.70	TRUE	0.40	45.0	0.14	0.86	0.53	TRUE	1.00	84.0	1.00	1.00	1.00	FALSE
2010	0.46	TRUE	0.32	56.4	0.10	0.90	0.38	TRUE	0.60	84.2	0.40	0.60	0.88	FALSE
2011	0.50	FALSE	0.00	84.4	0.00	1.00	0.80	FALSE	1.00	93.5	1.00	1.00	1.00	FALSE
2012	0.79	TRUE	0.57	52.9	0.37	0.63	0.79	TRUE	1.00	81.9	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.10	TRUE	0.14	17.6	0.04	0.96	0.07	TRUE	0.07	35.3	0.01	0.99	0.02	TRUE
2001	0.09	TRUE	0.11	17.6	0.02	0.98	0.07	TRUE	0.07	35.3	0.01	0.99	0.02	TRUE
2002	0.08	TRUE	0.10	48.0	0.03	0.97	0.04	TRUE	0.06	40.2	0.01	0.99	0.01	TRUE
2003	0.16	TRUE	0.00	82.4	1.00	0.00	0.00	TRUE	0.33	81.8	0.39	0.61	0.15	TRUE
2004	0.00	TRUE	0.00	44.6	0.00	1.00	0.00	TRUE	0.00	40.6	0.00	1.00	0.00	TRUE
2005	0.01	TRUE	0.00	48.3	0.03	0.97	0.00	TRUE	0.03	41.6	0.01	0.99	0.00	TRUE
2006	0.14	TRUE	0.21	51.0	0.07	0.93	0.16	TRUE	0.07	46.8	0.02	0.98	0.02	TRUE
2007	0.00	TRUE	0.00	43.6	0.03	0.97	0.00	TRUE	0.00	43.3	0.01	0.99	0.00	TRUE
2008	0.00	TRUE	0.00	89.7	1.00	0.00	0.00	TRUE	0.00	97.2	1.00	0.00	0.00	TRUE
2009	0.77	TRUE	0.55	53.1	0.31	0.69	0.78	TRUE	1.00	95.2	1.00	1.00	1.00	FALSE
2010	0.20	TRUE	0.40	67.4	0.25	0.75	0.34	TRUE	0.00	94.3	1.00	0.00	0.89	FALSE
2011	1.00	FALSE	1.00	84.7	1.00	1.00	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE
2012	0.76	FALSE	0.52	69.6	0.22	0.78	0.82	FALSE	1.00	95.9	1.00	1.00	1.00	FALSE

Table B.17. Optimized Irrigation Scenario results from Canyon Creek, Site 1.

	Overall		Spawn						Adult					
Year	SI	SS	SI	Ave	Res.	Rel.	Vul.	SS	SI	Ave	Res.	Rel.	Vul.	SS
Steelhead														
2000	0.11	TRUE	0.07	47.6	0.02	0.98	0.02	TRUE	0.14	53.6	0.02	0.98	0.16	TRUE
2001	0.07	TRUE	0.00	48.2	0.00	1.00	0.02	TRUE	0.14	53.6	0.02	0.98	0.16	TRUE
2002	0.00	TRUE	0.00	39.2	0.00	1.00	0.00	TRUE	0.00	52.1	0.00	1.00	0.00	TRUE
2003	0.23	TRUE	0.26	74.9	0.13	0.87	0.15	TRUE	0.21	83.4	0.18	0.82	0.06	TRUE
2004	0.00	TRUE	0.00	42.0	0.00	1.00	0.00	TRUE	0.00	56.3	0.00	1.00	0.00	TRUE
2005	0.04	TRUE	0.09	42.3	0.02	0.98	0.03	TRUE	0.00	56.4	0.00	1.00	0.01	TRUE
2006	0.00	TRUE	0.00	51.3	0.00	1.00	0.00	TRUE	0.00	61.4	0.00	1.00	0.00	TRUE
2007	0.00	TRUE	0.00	50.5	0.00	1.00	0.00	TRUE	0.00	63.5	0.00	1.00	0.00	TRUE
2008	1.00	FALSE	1.00	94.9	1.00	1.00	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE	1.00	91.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE	1.00	96.0	1.00	1.00	1.00	FALSE
Chinook														
2000	0.06	TRUE	0.07	7.2	0.01	0.99	0.04	TRUE	0.05	18.0	0.02	0.98	0.01	TRUE
2001	0.06	TRUE	0.07	7.2	0.01	0.99	0.04	TRUE	0.05	18.0	0.01	0.99	0.01	TRUE
2002	0.10	TRUE	0.14	29.2	0.04	0.96	0.08	TRUE	0.07	28.9	0.02	0.98	0.02	TRUE
2003	0.13	TRUE	0.00	78.9	1.00	0.00	0.05	TRUE	0.26	83.6	0.25	0.75	0.09	TRUE
2004	0.00	TRUE	0.00	23.8	0.00	1.00	0.00	TRUE	0.00	21.0	0.00	1.00	0.00	TRUE
2005	0.06	TRUE	0.05	23.4	0.01	0.99	0.01	TRUE	0.07	23.0	0.01	0.99	0.03	TRUE
2006	0.09	TRUE	0.14	33.7	0.04	0.96	0.06	TRUE	0.04	37.2	0.02	0.98	0.00	TRUE
2007	0.06	TRUE	0.07	24.3	0.01	0.99	0.04	TRUE	0.04	28.5	0.02	0.98	0.01	TRUE
2008	0.00	TRUE	0.00	89.0	1.00	0.00	0.00	TRUE	0.00	93.9	1.00	0.00	0.00	TRUE
2009	1.00	FALSE	1.00	78.4	1.00	1.00	1.00	FALSE	1.00	91.3	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	90.3	1.00	1.00	1.00	FALSE	1.00	93.8	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	91.1	1.00	1.00	1.00	FALSE	1.00	93.8	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.12	TRUE	0.15	18.1	0.04	0.96	0.08	TRUE	0.09	35.9	0.03	0.97	0.03	TRUE
2001	0.10	TRUE	0.12	18.1	0.02	0.98	0.08	TRUE	0.08	35.9	0.02	0.98	0.03	TRUE
2002	0.22	TRUE	0.37	63.0	0.15	0.85	0.40	TRUE	0.07	47.6	0.02	0.98	0.02	TRUE
2003	0.13	TRUE	0.00	92.2	1.00	0.00	0.14	TRUE	0.27	93.5	0.25	0.75	0.10	TRUE
2004	0.00	TRUE	0.00	45.1	0.00	1.00	0.00	TRUE	0.00	40.6	0.00	1.00	0.00	TRUE
2005	0.10	TRUE	0.12	49.5	0.03	0.97	0.06	TRUE	0.07	42.9	0.02	0.98	0.02	TRUE
2006	0.23	TRUE	0.42	72.0	0.22	0.78	0.42	TRUE	0.04	54.2	0.02	0.98	0.00	TRUE
2007	0.14	TRUE	0.23	48.1	0.07	0.93	0.18	TRUE	0.05	46.6	0.02	0.98	0.01	TRUE
2008	0.00	TRUE	0.00	94.7	1.00	0.00	0.00	TRUE	0.00	98.4	1.00	0.00	0.00	TRUE
2009	1.00	FALSE	1.00	80.1	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	94.8	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE

Eighteenmile Creek, Site 1

Table B.18. Percent weighted usable area (% WUA) for a given discharge for Eighteenmile Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	
1	32.10	24.80		32.10	24.80		34.50	22.70	
1.2	36.60	33.30		36.60	33.30		41.40	29.20	
2	51.30	56.10		51.30	56.10		64.40	51.10	
2.5	57.70	65.50		57.70	65.50		72.70	62.80	
3	63.10	67.90		63.10	67.90		75.70	68.90	
4	71.00	75.30		71.00	75.30		87.60	80.20	
5	76.70	79.80		76.70	79.80		94.70	88.40	
6.1	82.00	84.70		82.00	84.70		96.20	95.90	
7	85.10	88.10		85.10	88.10		96.60	99.00	
8	88.30	91.00		88.30	91.00		95.30	100.00	
9	90.40	92.30		90.40	92.30		98.80	98.90	
10	93.30	93.80		93.30	93.80		99.90	95.20	
11	96.70	96.10		96.70	96.10		99.70	91.40	
12	97.60	97.50		97.60	97.50		97.10	86.90	
13	98.00	97.80		98.00	97.80		97.30	82.10	
14	99.10	99.00		99.10	99.00		99.00	76.70	
15	100.00	100.00		100.00	100.00		100.00	72.50	

Table B.19. Site summary results for Canyon Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.89	TRUE	0.90	TRUE	0.89	TRUE	0.91	TRUE	0.89	FALSE	0.90	TRUE
Chinook	0.90	TRUE	0.91	TRUE	0.90	TRUE	0.91	TRUE	0.90	TRUE	0.91	TRUE
Bull Trout	0.90	TRUE	0.89	TRUE	0.90	TRUE	0.89	TRUE	0.89	TRUE	0.90	TRUE

Table B.20. Baseline Scenario results from Eighteenmile Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.26	TRUE	0.25	69.3	0.07	0.93	0.24	TRUE	0.27	63.3	0.06	0.94	0.38	TRUE
2001	0.27	TRUE	0.26	70.1	0.08	0.92	0.26	TRUE	0.27	63.3	0.06	0.94	0.38	TRUE
2002	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	96.3	1.00	1.00	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	93.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Chinook														
2000	0.33	TRUE	0.31	59.1	0.06	0.94	0.53	TRUE	0.35	65.5	0.11	0.89	0.45	TRUE
2001	0.37	TRUE	0.36	62.5	0.07	0.93	0.74	TRUE	0.37	68.0	0.09	0.91	0.62	TRUE
2002	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	92.1	1.00	1.00	1.00	FALSE	1.00	94.4	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	94.0	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.26	TRUE	0.23	73.0	0.17	0.83	0.09	TRUE	0.29	64.2	0.07	0.93	0.36	TRUE
2001	0.38	TRUE	0.47	82.1	0.20	0.80	0.64	TRUE	0.29	66.0	0.06	0.94	0.44	TRUE
2002	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	76.9	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	74.5	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	85.5	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	77.9	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	75.2	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	82.6	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	78.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	73.6	1.00	1.00	1.00	FALSE

Table B.21. Optimized Irrigation Scenario results from Eighteenmile Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.37	TRUE	0.40	57.6	0.17	0.83	0.46	TRUE	0.33	54.4	0.09	0.91	0.44	TRUE
2001	0.36	TRUE	0.38	58.2	0.14	0.86	0.48	TRUE	0.33	54.4	0.09	0.91	0.44	TRUE
2002	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	93.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Chinook														
2000	0.40	TRUE	0.41	45.1	0.13	0.88	0.63	TRUE	0.39	48.5	0.12	0.88	0.55	TRUE
2001	0.41	TRUE	0.43	46.9	0.13	0.88	0.70	TRUE	0.39	49.8	0.11	0.89	0.60	TRUE
2002	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	87.6	1.00	1.00	1.00	FALSE	1.00	91.4	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	91.9	1.00	1.00	1.00	FALSE	1.00	94.9	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.28	TRUE	0.23	70.0	0.17	0.83	0.09	TRUE	0.33	49.4	0.09	0.91	0.45	TRUE
2001	0.34	TRUE	0.36	75.2	0.10	0.90	0.51	TRUE	0.33	50.3	0.08	0.92	0.48	TRUE
2002	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE	1.00	77.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	74.5	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	79.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	75.5	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	85.1	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE	1.00	79.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	72.5	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE	1.00	77.4	1.00	1.00	1.00	FALSE

Hawley Creek, Site 1

Table B.22. Percent weighted usable area (% WUA) for a given discharge for Hawley Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
0	0.00	0.00		0.00	0.00		0.00	0.00	
0.5	16.20	1.80		16.20	1.80		12.60	9.80	
1	23.80	12.10		23.80	12.10		22.20	27.80	
3	43.40	61.20		43.40	61.20		41.70	71.30	
5	55.60	81.60		55.60	81.60		56.30	90.90	
7	64.60	91.40		64.60	91.40		66.20	96.90	
9	72.70	96.30		72.70	96.30		73.50	99.00	
11	79.60	98.90		79.60	98.90		79.70	100.00	
13	84.70	99.90		84.70	99.90		84.00	98.50	
14.1	87.20	100.00		87.20	100.00		87.30	96.60	
15	89.00	99.90		89.00	99.90		89.20	94.50	
17	94.50	99.10		94.50	99.10		94.50	89.50	
19	100.00	97.60		100.00	97.60		100.00	83.90	

Table B.23. Site summary results for Hawley Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		**Optimized**		**Base**		**Optimized**		**Base**		**Optimized**	
Steelhead	0.84	TRUE	0.88	TRUE	0.87	TRUE	0.89	TRUE	0.82	FALSE	0.87	TRUE
Chinook	0.52	TRUE	0.68	TRUE	0.44	TRUE	0.68	TRUE	0.59	TRUE	0.67	TRUE
Bull Trout	0.55	TRUE	0.68	TRUE	0.42	TRUE	0.66	TRUE	0.67	TRUE	0.70	TRUE

Table B.24. Baseline Scenario results from Hawley Creek.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.08	TRUE	0.00	79.0	1.00	0.00	0.00	TRUE	0.17	75.8	0.04	0.96	0.11	TRUE
2001	0.58	TRUE	1.00	79.9	1.00	1.00	1.00	FALSE	0.17	75.8	0.04	0.96	0.11	TRUE
2002	1.00	FALSE	1.00	87.7	1.00	1.00	1.00	FALSE	1.00	92.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.2	1.00	1.00	1.00	FALSE	1.00	94.8	1.00	1.00	1.00	FALSE
2004	0.30	TRUE	0.33	77.3	0.07	0.93	0.53	TRUE	0.28	85.1	0.08	0.92	0.29	TRUE
2005	1.00	FALSE	1.00	89.7	1.00	1.00	1.00	FALSE	1.00	91.9	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE	1.00	94.0	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	88.8	1.00	1.00	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	90.4	1.00	1.00	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
Chinook														
2000	0.26	TRUE	0.27	47.0	0.04	0.96	0.58	TRUE	0.25	75.5	0.06	0.94	0.28	TRUE
2001	0.27	TRUE	0.27	46.9	0.03	0.97	0.59	TRUE	0.26	75.7	0.06	0.94	0.32	TRUE
2002	0.00	FALSE	0.00	78.9	1.00	0.00	0.77	FALSE	0.00	97.6	1.00	0.00	0.74	FALSE
2003	1.00	FALSE	1.00	93.1	1.00	1.00	1.00	FALSE	1.00	98.3	1.00	1.00	1.00	FALSE
2004	0.19	TRUE	0.19	42.4	0.01	0.99	0.48	TRUE	0.19	52.8	0.03	0.97	0.29	TRUE
2005	0.00	TRUE	0.00	73.7	1.00	0.00	0.00	TRUE	0.00	96.1	1.00	0.00	0.00	TRUE
2006	1.00	FALSE	1.00	83.2	1.00	1.00	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE
2007	0.50	FALSE	0.00	66.1	0.00	1.00	0.98	FALSE	1.00	88.5	1.00	1.00	1.00	FALSE
2008	0.50	FALSE	0.00	91.9	1.00	0.00	0.94	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	88.0	1.00	1.00	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	84.6	1.00	1.00	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	93.3	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2012	0.00	TRUE	0.00	51.2	0.00	1.00	0.27	TRUE	0.00	72.0	0.00	1.00	0.16	TRUE
Bull Trout														
2000	0.25	TRUE	0.26	33.9	0.03	0.97	0.56	TRUE	0.23	75.1	0.06	0.94	0.23	TRUE
2001	0.25	TRUE	0.26	34.4	0.03	0.97	0.59	TRUE	0.24	75.2	0.06	0.94	0.24	TRUE
2002	0.50	FALSE	0.00	75.0	1.00	0.00	0.73	FALSE	1.00	93.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE	1.00	89.2	1.00	1.00	1.00	FALSE
2004	0.11	TRUE	0.00	55.5	0.00	1.00	0.29	TRUE	0.22	64.0	0.03	0.97	0.35	TRUE
2005	0.00	TRUE	0.00	69.6	1.00	0.00	0.00	TRUE	0.00	93.1	1.00	0.00	0.00	TRUE
2006	1.00	FALSE	1.00	80.9	1.00	1.00	1.00	FALSE	1.00	92.6	1.00	1.00	1.00	FALSE
2007	0.50	FALSE	0.00	71.4	0.00	1.00	0.95	FALSE	1.00	89.3	1.00	1.00	1.00	FALSE
2008	0.50	FALSE	0.00	84.4	1.00	0.00	0.89	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	80.2	1.00	1.00	1.00	FALSE	1.00	91.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	74.6	1.00	1.00	1.00	FALSE	1.00	91.7	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	86.7	1.00	1.00	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE
2012	0.00	TRUE	0.00	50.4	0.00	1.00	0.02	TRUE	0.00	74.3	0.00	1.00	0.15	TRUE

Table B.25. Optimized Irrigation Scenario results from Hawley Creek.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.08	TRUE	0.00	81.7	0.00	1.00	0.00	TRUE	0.17	76.6	0.04	0.96	0.11	TRUE
2001	0.58	TRUE	1.00	82.6	1.00	1.00	1.00	FALSE	0.17	76.6	0.04	0.96	0.11	TRUE
2002	1.00	FALSE	1.00	88.5	1.00	1.00	1.00	FALSE	1.00	92.0	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.2	1.00	1.00	1.00	FALSE	1.00	94.8	1.00	1.00	1.00	FALSE
2004	0.78	FALSE	0.56	83.2	0.25	0.75	0.93	FALSE	1.00	91.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE	1.00	91.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	93.1	1.00	1.00	1.00	FALSE	1.00	93.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	91.9	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	90.4	1.00	1.00	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
Chinook														
2000	0.23	TRUE	0.28	55.1	0.06	0.94	0.42	TRUE	0.19	83.1	0.08	0.92	0.10	TRUE
2001	0.24	TRUE	0.28	55.1	0.06	0.94	0.42	TRUE	0.20	83.5	0.08	0.92	0.10	TRUE
2002	1.00	FALSE	1.00	83.7	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE
2004	0.33	FALSE	0.30	58.3	0.03	0.97	0.85	FALSE	0.35	75.6	0.06	0.94	0.78	FALSE
2005	0.00	FALSE	0.00	79.1	1.00	0.00	0.71	FALSE	0.00	97.6	1.00	0.00	0.59	FALSE
2006	1.00	FALSE	1.00	87.6	1.00	1.00	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	73.6	1.00	1.00	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	93.9	1.00	1.00	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	91.2	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	88.3	1.00	1.00	1.00	FALSE	1.00	98.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	94.5	1.00	1.00	1.00	FALSE	1.00	97.7	1.00	1.00	1.00	FALSE
2012	0.00	TRUE	0.00	61.3	0.00	1.00	0.47	TRUE	0.00	80.4	0.00	1.00	0.26	TRUE
Bull Trout														
2000	0.25	TRUE	0.26	41.4	0.05	0.95	0.37	TRUE	0.23	79.3	0.06	0.94	0.23	TRUE
2001	0.26	TRUE	0.27	42.2	0.06	0.94	0.39	TRUE	0.24	79.6	0.06	0.94	0.24	TRUE
2002	1.00	FALSE	1.00	78.9	1.00	1.00	1.00	FALSE	1.00	93.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	90.7	1.00	1.00	1.00	FALSE	1.00	88.3	1.00	1.00	1.00	FALSE
2004	0.30	FALSE	0.00	68.3	0.00	1.00	0.84	FALSE	0.60	81.4	0.33	0.67	0.96	FALSE
2005	0.00	FALSE	0.00	74.1	1.00	0.00	0.67	FALSE	0.00	93.1	1.00	0.00	0.95	FALSE
2006	1.00	FALSE	1.00	84.3	1.00	1.00	1.00	FALSE	1.00	91.5	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	78.2	1.00	1.00	1.00	FALSE	1.00	92.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE	1.00	89.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	84.3	1.00	1.00	1.00	FALSE	1.00	90.7	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	79.4	1.00	1.00	1.00	FALSE	1.00	91.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	88.9	1.00	1.00	1.00	FALSE	1.00	90.0	1.00	1.00	1.00	FALSE
2012	0.00	TRUE	0.00	58.4	0.00	1.00	0.42	TRUE	0.00	80.5	0.00	1.00	0.30	TRUE

Hayden Creek, Site 1

Table B.26. Percent weighted usable area (% WUA) for a given discharge for Hayden Creek, Site 1.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	
9	65.50	4.00		65.50	4.00		68.30	0.00	
20	84.00	4.40		84.00	4.40		88.70	0.00	
23.3	87.10	4.40		87.10	4.40		95.10	0.00	
30	92.10	17.80		92.10	17.80		99.30	0.00	
40	97.00	27.10		97.00	27.10		100.00	0.00	
50	99.40	43.90		99.40	43.90		94.80	0.00	
60	100.00	52.90		100.00	52.90		85.60	0.00	
69.2	99.20	56.80		99.20	56.80		71.00	0.00	
70	99.30	56.90		99.30	56.90		70.00	0.00	
80	99.80	60.90		99.80	60.90		67.30	0.00	
90	99.50	64.60		99.50	64.60		64.60	0.00	
100	98.40	77.30		98.40	77.30		59.80	0.00	
110	96.60	86.80		96.60	86.80		58.20	0.00	
120	94.10	92.00		94.10	92.00		55.90	0.00	
127.7	90.60	95.00		90.60	95.00		52.50	0.00	
130	89.30	95.40		89.30	95.40		50.60	0.00	
140	81.00	97.40		81.00	97.40		48.90	0.00	
150	71.30	99.00		71.30	99.00		47.70	43.90	
160	64.20	99.40		64.20	99.40		45.90	60.50	
170	57.90	99.50		57.90	99.50		45.40	70.90	
180	52.50	98.00		52.50	98.00		44.50	78.80	
190	50.6	98.7		50.60	98.70		43.00	85.40	
200	48.9	99.1		48.90	99.10		41.30	90.80	
210	46.2	99.2		46.20	99.20		39.60	95.60	
220	44.8	100.0		44.80	100.00		39.60	100.00	

Table B.27. Site summary results for Hayden Creek, Site 1.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.55	TRUE	0.55	TRUE	0.92	TRUE	0.92	TRUE	0.17	FALSE	0.18	TRUE
Chinook	0.44	TRUE	0.46	TRUE	0.85	TRUE	0.85	TRUE	0.04	TRUE	0.07	TRUE
Bull Trout	0.44	TRUE	0.44	TRUE	0.85	TRUE	0.85	TRUE	0.03	TRUE	0.03	TRUE

Table B.28. Baseline Scenario results from Hayden Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.06	TRUE	0.00	77.4	1.00	0.00	0.00	TRUE	0.13	48.0	0.02	0.98	0.12	TRUE
2001	0.56	TRUE	1.00	78.2	1.00	1.00	1.00	FALSE	0.13	48.0	0.02	0.98	0.12	TRUE
2002	0.57	TRUE	1.00	68.0	1.00	1.00	1.00	FALSE	0.14	40.0	0.01	0.99	0.24	TRUE
2003	0.57	TRUE	1.00	68.8	1.00	1.00	1.00	FALSE	0.15	60.8	0.02	0.98	0.14	TRUE
2004	0.59	TRUE	1.00	82.8	1.00	1.00	1.00	FALSE	0.18	65.8	0.04	0.96	0.17	TRUE
2005	0.58	TRUE	1.00	70.3	1.00	1.00	1.00	FALSE	0.16	51.0	0.02	0.98	0.24	TRUE
2006	0.57	TRUE	1.00	61.9	1.00	1.00	1.00	FALSE	0.15	64.7	0.03	0.97	0.13	TRUE
2007	0.66	TRUE	1.00	64.7	1.00	1.00	1.00	FALSE	0.33	83.8	0.08	0.92	0.50	TRUE
2008	0.57	TRUE	1.00	64.2	1.00	1.00	1.00	FALSE	0.14	54.0	0.02	0.98	0.15	TRUE
2009	0.62	TRUE	1.00	60.4	1.00	1.00	1.00	FALSE	0.23	69.0	0.02	0.98	0.52	TRUE
2010	0.56	TRUE	1.00	67.3	1.00	1.00	1.00	FALSE	0.13	56.5	0.02	0.98	0.11	TRUE
2011	0.58	TRUE	1.00	67.7	1.00	1.00	1.00	FALSE	0.15	47.5	0.01	0.99	0.24	TRUE
2012	0.62	TRUE	1.00	69.3	1.00	1.00	1.00	FALSE	0.25	73.2	0.04	0.96	0.37	TRUE
Chinook														
2000	0.00	TRUE	0.00	71.1	0.00	1.00	0.02	TRUE	0.00	41.5	0.00	1.00	0.29	TRUE
2001	0.00	TRUE	0.00	71.2	0.00	1.00	0.02	TRUE	0.00	41.5	0.00	1.00	0.29	TRUE
2002	0.59	TRUE	1.00	89.6	1.00	1.00	1.00	FALSE	0.18	54.1	0.01	0.99	0.47	TRUE
2003	0.50	TRUE	1.00	93.3	1.00	1.00	1.00	FALSE	0.00	62.1	0.00	1.00	0.58	TRUE
2004	0.50	TRUE	1.00	92.5	1.00	1.00	1.00	FALSE	0.00	46.8	0.00	1.00	0.37	TRUE
2005	0.50	TRUE	1.00	87.6	1.00	1.00	1.00	FALSE	0.00	57.0	0.00	1.00	0.37	TRUE
2006	0.50	TRUE	1.00	91.8	1.00	1.00	1.00	FALSE	0.00	60.8	0.00	1.00	0.47	TRUE
2007	0.50	TRUE	1.00	93.7	1.00	1.00	1.00	FALSE	0.00	47.4	0.00	1.00	0.46	TRUE
2008	0.50	TRUE	1.00	85.8	1.00	1.00	1.00	FALSE	0.00	64.9	0.00	1.00	0.39	TRUE
2009	0.50	TRUE	1.00	86.4	1.00	1.00	1.00	FALSE	0.00	65.4	0.00	1.00	0.53	TRUE
2010	0.50	TRUE	1.00	79.8	1.00	1.00	1.00	FALSE	0.00	57.7	0.00	1.00	0.20	TRUE
2011	0.59	TRUE	1.00	79.6	1.00	1.00	1.00	FALSE	0.19	64.2	0.01	0.99	0.45	TRUE
2012	0.57	TRUE	1.00	88.3	1.00	1.00	1.00	FALSE	0.15	44.6	0.01	0.99	0.29	TRUE
Bull Trout														
2000	0.02	TRUE	0.00	47.9	0.00	1.00	0.02	TRUE	0.03	8.1	0.00	1.00	0.01	TRUE
2001	0.02	TRUE	0.00	49.4	0.00	1.00	0.02	TRUE	0.03	8.1	0.00	1.00	0.01	TRUE
2002	0.51	TRUE	1.00	93.7	1.00	1.00	1.00	FALSE	0.02	19.0	0.01	0.99	0.00	TRUE
2003	0.51	TRUE	1.00	99.2	1.00	1.00	1.00	FALSE	0.03	20.0	0.01	0.99	0.00	TRUE
2004	0.53	TRUE	1.00	95.8	1.00	1.00	1.00	FALSE	0.05	8.3	0.00	1.00	0.03	TRUE
2005	0.52	TRUE	1.00	92.6	1.00	1.00	1.00	FALSE	0.03	21.9	0.01	0.99	0.01	TRUE
2006	0.51	TRUE	1.00	97.9	1.00	1.00	1.00	FALSE	0.03	26.9	0.01	0.99	0.00	TRUE
2007	0.51	TRUE	1.00	97.7	1.00	1.00	1.00	FALSE	0.03	20.7	0.01	0.99	0.00	TRUE
2008	0.51	TRUE	1.00	94.0	1.00	1.00	1.00	FALSE	0.03	28.5	0.01	0.99	0.00	TRUE
2009	0.52	TRUE	1.00	99.2	1.00	1.00	1.00	FALSE	0.03	34.7	0.01	0.99	0.00	TRUE
2010	0.52	TRUE	1.00	86.1	1.00	1.00	1.00	FALSE	0.04	25.9	0.01	0.99	0.01	TRUE
2011	0.52	TRUE	1.00	98.3	1.00	1.00	1.00	FALSE	0.04	32.9	0.01	0.99	0.01	TRUE
2012	0.52	TRUE	1.00	86.6	1.00	1.00	1.00	FALSE	0.03	18.7	0.01	0.99	0.01	TRUE

Table B.29. Optimized Irrigation Scenario results from Hayden Creek, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.06	TRUE	0.00	77.4	0.00	1.00	0.00	TRUE	0.13	48.0	0.02	0.98	0.12	TRUE
2001	0.56	TRUE	1.00	78.2	1.00	1.00	1.00	FALSE	0.13	48.0	0.02	0.98	0.12	TRUE
2002	0.59	TRUE	1.00	68.0	1.00	1.00	1.00	FALSE	0.18	40.0	0.03	0.97	0.25	TRUE
2003	0.57	TRUE	1.00	68.9	1.00	1.00	1.00	FALSE	0.15	60.8	0.02	0.98	0.14	TRUE
2004	0.59	TRUE	1.00	82.8	1.00	1.00	1.00	FALSE	0.18	65.8	0.04	0.96	0.17	TRUE
2005	0.58	TRUE	1.00	70.3	1.00	1.00	1.00	FALSE	0.16	51.0	0.02	0.98	0.24	TRUE
2006	0.57	TRUE	1.00	61.9	1.00	1.00	1.00	FALSE	0.15	64.7	0.03	0.97	0.13	TRUE
2007	0.66	TRUE	1.00	64.7	1.00	1.00	1.00	FALSE	0.33	83.8	0.08	0.92	0.50	TRUE
2008	0.57	TRUE	1.00	64.2	1.00	1.00	1.00	FALSE	0.14	54.0	0.02	0.98	0.15	TRUE
2009	0.62	TRUE	1.00	60.4	1.00	1.00	1.00	FALSE	0.23	69.0	0.02	0.98	0.52	TRUE
2010	0.56	TRUE	1.00	67.3	1.00	1.00	1.00	FALSE	0.13	56.5	0.02	0.98	0.11	TRUE
2011	0.58	TRUE	1.00	67.7	1.00	1.00	1.00	FALSE	0.15	47.5	0.01	0.99	0.24	TRUE
2012	0.62	TRUE	1.00	69.4	1.00	1.00	1.00	FALSE	0.25	73.1	0.04	0.96	0.37	TRUE
Chinook														
2000	0.00	TRUE	0.00	71.1	0.00	1.00	0.02	TRUE	0.00	41.5	0.00	1.00	0.29	TRUE
2001	0.00	TRUE	0.00	71.2	0.00	1.00	0.02	TRUE	0.00	41.5	0.00	1.00	0.29	TRUE
2002	0.61	TRUE	1.00	89.6	1.00	1.00	1.00	FALSE	0.23	54.1	0.03	0.98	0.48	TRUE
2003	0.60	TRUE	1.00	93.3	1.00	1.00	1.00	FALSE	0.20	62.1	0.02	0.98	0.57	TRUE
2004	0.50	TRUE	1.00	92.5	1.00	1.00	1.00	FALSE	0.00	46.8	0.00	1.00	0.37	TRUE
2005	0.50	TRUE	1.00	87.6	1.00	1.00	1.00	FALSE	0.00	57.0	0.00	1.00	0.37	TRUE
2006	0.50	TRUE	1.00	91.8	1.00	1.00	1.00	FALSE	0.00	60.8	0.00	1.00	0.47	TRUE
2007	0.58	TRUE	1.00	93.7	1.00	1.00	1.00	FALSE	0.16	47.4	0.01	0.99	0.46	TRUE
2008	0.50	TRUE	1.00	85.8	1.00	1.00	1.00	FALSE	0.00	64.9	0.00	1.00	0.39	TRUE
2009	0.50	TRUE	1.00	86.4	1.00	1.00	1.00	FALSE	0.00	65.4	0.00	1.00	0.53	TRUE
2010	0.50	TRUE	1.00	79.8	1.00	1.00	1.00	FALSE	0.00	57.7	0.00	1.00	0.19	TRUE
2011	0.59	TRUE	1.00	79.6	1.00	1.00	1.00	FALSE	0.19	64.2	0.01	0.99	0.45	TRUE
2012	0.57	TRUE	1.00	88.4	1.00	1.00	1.00	FALSE	0.15	44.6	0.01	0.99	0.29	TRUE
Bull Trout														
2000	0.02	TRUE	0.00	47.9	0.00	1.00	0.02	TRUE	0.03	8.1	0.00	1.00	0.01	TRUE
2001	0.02	TRUE	0.00	49.4	0.00	1.00	0.02	TRUE	0.03	8.1	0.00	1.00	0.01	TRUE
2002	0.52	TRUE	1.00	93.7	1.00	1.00	1.00	FALSE	0.03	19.0	0.01	0.99	0.01	TRUE
2003	0.51	TRUE	1.00	99.2	1.00	1.00	1.00	FALSE	0.03	20.0	0.01	0.99	0.00	TRUE
2004	0.52	TRUE	1.00	95.8	1.00	1.00	1.00	FALSE	0.05	8.3	0.00	1.00	0.03	TRUE
2005	0.52	TRUE	1.00	92.6	1.00	1.00	1.00	FALSE	0.03	22.0	0.01	0.99	0.01	TRUE
2006	0.51	TRUE	1.00	97.9	1.00	1.00	1.00	FALSE	0.03	26.9	0.01	0.99	0.00	TRUE
2007	0.51	TRUE	1.00	97.7	1.00	1.00	1.00	FALSE	0.03	20.7	0.01	0.99	0.00	TRUE
2008	0.51	TRUE	1.00	94.0	1.00	1.00	1.00	FALSE	0.03	28.5	0.01	0.99	0.00	TRUE
2009	0.52	TRUE	1.00	99.2	1.00	1.00	1.00	FALSE	0.03	34.7	0.01	0.99	0.00	TRUE
2010	0.52	TRUE	1.00	86.1	1.00	1.00	1.00	FALSE	0.04	25.9	0.01	0.99	0.01	TRUE
2011	0.52	TRUE	1.00	98.3	1.00	1.00	1.00	FALSE	0.04	32.9	0.01	0.99	0.01	TRUE
2012	0.52	TRUE	1.00	86.6	1.00	1.00	1.00	FALSE	0.03	18.7	0.01	0.99	0.01	TRUE

Upper Lemhi River, Site 1

Table B.30. Percent weighted usable area (% WUA) for a given discharge for Upper Lemhi River, Site 1.

Discharge [cfs]	**Steelhead**			**Chinook**			**Bull Trout**		
	Spawn	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**	**Spawn**	**Adult**	**Juvenile**
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
40	79.30	77.40		79.30	77.40		90.50	79.30	
45	83.00	82.50		83.00	82.50		93.70	84.20	
47	84.40	84.20		84.40	84.20		94.90	85.50	
50	86.20	86.60		86.20	86.60		95.30	87.90	
56	89.80	89.80		89.80	89.80		98.00	89.80	
60	90.70	92.50		90.70	92.50		96.50	92.90	
65	92.60	94.30		92.60	94.30		96.90	94.70	
70	94.10	95.60		94.10	95.60		96.90	96.30	
75	95.30	96.90		95.30	96.90		97.20	97.50	
80	96.40	98.00		96.40	98.00		97.10	98.50	
85	97.40	98.90		97.40	98.90		97.10	99.30	
90	98.40	99.40		98.40	99.40		96.70	99.80	
95	99.10	99.80		99.10	99.80		96.00	100.00	
100	99.70	100.00		99.70	100.00		95.50	99.80	
105	100.00	100.00		100.00	100.00		96.30	99.50	
110	99.70	99.30		99.70	99.30		96.90	99.00	
115	99.40	98.60		99.40	98.60		98.10	97.90	
120	99.20	98.00		99.20	98.00		98.60	96.70	
125	98.60	96.70		98.60	96.70		99.40	95.80	
130	98.50	96.00		98.50	96.00		100.00	94.80	

Table B.31. Site summary results for Upper Lemhi River, Site 1.

	Site Overview				**Spawning**				**Adult**			
	Base		**Optimized**		**Base**		**Optimized**		**Base**		**Optimized**	
Steelhead	0.82	TRUE	0.86	TRUE	0.83	TRUE	0.88	TRUE	0.82	FALSE	0.84	TRUE
Chinook	0.85	TRUE	0.88	TRUE	0.86	TRUE	0.90	TRUE	0.85	TRUE	0.86	TRUE
Bull Trout	0.85	TRUE	0.86	TRUE	0.86	TRUE	0.86	TRUE	0.84	TRUE	0.85	TRUE

Table B.32. Baseline Scenario results from Upper Lemhi River, Site 1.

	Overall		Spawn						Adult					
Year	SI	SS	SI	Ave	Res.	Rel.	Vul.	SS	SI	Ave	Res.	Rel.	Vul.	SS
Steelhead														
2000	0.25	TRUE	0.25	70.6	0.06	0.94	0.31	TRUE	0.24	58.2	0.05	0.95	0.30	TRUE
2001	0.25	TRUE	0.26	71.5	0.06	0.94	0.33	TRUE	0.24	58.5	0.05	0.95	0.31	TRUE
2002	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE	1.00	79.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE	1.00	89.6	1.00	1.00	1.00	FALSE
2004	0.21	TRUE	0.21	64.4	0.03	0.97	0.32	TRUE	0.21	69.6	0.03	0.97	0.31	TRUE
2005	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	89.7	1.00	1.00	1.00	FALSE	1.00	92.4	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	84.8	1.00	1.00	1.00	FALSE	1.00	88.1	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE	1.00	96.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE	1.00	97.7	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.6	1.00	1.00	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
Chinook														
2000	0.34	TRUE	0.34	40.5	0.08	0.92	0.54	TRUE	0.34	49.9	0.09	0.91	0.48	TRUE
2001	0.37	TRUE	0.39	45.1	0.08	0.92	0.74	TRUE	0.36	53.1	0.08	0.92	0.64	TRUE
2002	1.00	FALSE	1.00	90.6	1.00	1.00	1.00	FALSE	1.00	91.3	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
2004	0.39	TRUE	0.47	65.6	0.16	0.84	0.76	TRUE	0.32	58.7	0.08	0.92	0.48	TRUE
2005	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE	1.00	88.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	85.8	1.00	1.00	1.00	FALSE	1.00	85.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	81.7	1.00	1.00	1.00	FALSE	1.00	80.7	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	89.4	1.00	1.00	1.00	FALSE	1.00	91.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	95.0	1.00	1.00	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	89.7	1.00	1.00	1.00	FALSE	1.00	91.8	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.25	TRUE	0.21	45.5	0.03	0.97	0.27	TRUE	0.30	49.6	0.07	0.93	0.44	TRUE
2001	0.17	TRUE	0.00	56.9	0.00	1.00	0.74	FALSE	0.33	52.2	0.07	0.93	0.56	TRUE
2002	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE	1.00	85.9	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE	1.00	93.5	1.00	1.00	1.00	FALSE
2004	0.66	TRUE	1.00	91.1	1.00	1.00	1.00	FALSE	0.32	67.4	0.08	0.92	0.48	TRUE
2005	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE	1.00	89.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE	1.00	85.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	93.4	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE	1.00	96.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE

Table B.33. Optimized Irrigation Scenario results from Upper Lemhi River, Site 1.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.40	TRUE	0.53	82.6	0.40	0.60	0.61	TRUE	0.28	66.6	0.07	0.93	0.34	TRUE
2001	0.40	TRUE	0.52	83.5	0.25	0.75	0.76	FALSE	0.28	66.6	0.07	0.93	0.35	TRUE
2002	1.00	FALSE	1.00	93.7	1.00	1.00	1.00	FALSE	1.00	81.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.2	1.00	1.00	1.00	FALSE	1.00	90.3	1.00	1.00	1.00	FALSE
2004	0.41	TRUE	0.41	82.3	0.14	0.86	0.58	TRUE	0.41	82.9	0.14	0.86	0.57	TRUE
2005	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	93.2	1.00	1.00	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	98.6	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.7	1.00	1.00	1.00	FALSE	1.00	97.2	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.9	1.00	1.00	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	96.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE
Chinook														
2000	0.33	TRUE	0.31	43.8	0.08	0.93	0.42	TRUE	0.35	57.3	0.11	0.89	0.45	TRUE
2001	0.35	TRUE	0.34	46.1	0.08	0.93	0.58	TRUE	0.36	59.0	0.09	0.91	0.59	TRUE
2002	1.00	FALSE	1.00	92.0	1.00	1.00	1.00	FALSE	1.00	94.0	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE
2004	0.71	TRUE	1.00	71.8	1.00	1.00	1.00	FALSE	0.41	71.6	0.14	0.86	0.57	TRUE
2005	1.00	FALSE	1.00	89.2	1.00	1.00	1.00	FALSE	1.00	92.2	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	88.9	1.00	1.00	1.00	FALSE	1.00	91.7	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	84.6	1.00	1.00	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	91.9	1.00	1.00	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	97.7	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE	1.00	94.5	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.25	TRUE	0.21	43.6	0.03	0.97	0.27	TRUE	0.30	55.2	0.07	0.93	0.39	TRUE
2001	0.16	TRUE	0.00	49.8	0.00	1.00	0.51	TRUE	0.32	56.5	0.07	0.93	0.48	TRUE
2002	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	87.7	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE	1.00	94.0	1.00	1.00	1.00	FALSE
2004	0.71	TRUE	1.00	90.2	1.00	1.00	1.00	FALSE	0.41	77.2	0.14	0.86	0.58	TRUE
2005	1.00	FALSE	1.00	96.1	1.00	1.00	1.00	FALSE	1.00	91.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE	1.00	93.9	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE	1.00	90.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	95.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	96.9	1.00	1.00	1.00	FALSE	1.00	96.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	98.0	1.00	1.00	1.00	FALSE	1.00	94.4	1.00	1.00	1.00	FALSE

Upper Lemhi River, Site 2

Table B.34. Percent weighted usable area (% WUA) for a given discharge for Upper Lemhi River, Site 2.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
16.5	35.60	33.30		35.60	33.30		30.50	19.70	
22.5	46.80	44.90		46.80	44.90		42.20	31.50	
28.5	58.20	58.00		58.20	58.00		53.00	47.60	
34.5	68.40	68.70		68.40	68.70		62.30	64.00	
40.5	76.10	75.40		76.10	75.40		71.30	75.00	
41.1	76.90	76.10		76.90	76.10		72.20	76.40	
46.5	81.90	82.70		81.90	82.70		76.80	86.70	
50.1	84.00	87.90		84.00	87.90		71.20	93.40	
52.5	87.40	89.10		87.40	89.10		80.90	95.50	
58.5	92.40	94.40		92.40	94.40		91.90	99.40	
60.3	93.70	95.60		93.70	95.60		94.00	99.60	
64.5	96.30	97.80		96.30	97.80		96.80	100.00	
70.5	100.00	100.00		100.00	100.00		100.00	99.60	

Table B.35. Site summary results for Upper Lemhi River, Site 2.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.72	TRUE	0.73	TRUE	0.71	TRUE	0.73	TRUE	0.73	FALSE	0.73	TRUE
Chinook	0.72	TRUE	0.79	TRUE	0.73	TRUE	0.79	TRUE	0.72	TRUE	0.79	TRUE
Bull Trout	0.67	TRUE	0.65	TRUE	0.74	TRUE	0.72	TRUE	0.61	TRUE	0.57	TRUE

Table B.36. Baseline Scenario results from Upper Lemhi River, Site 2.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.17	TRUE	0.17	69.9	0.06	0.94	0.09	TRUE	0.17	58.2	0.02	0.98	0.21	TRUE
2001	0.09	TRUE	0.00	70.8	0.00	1.00	0.10	TRUE	0.17	58.5	0.02	0.98	0.22	TRUE
2002	1.00	FALSE	1.00	91.0	1.00	1.00	1.00	FALSE	1.00	81.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	91.3	1.00	1.00	1.00	FALSE
2004	0.07	TRUE	0.00	61.7	0.00	1.00	0.09	TRUE	0.15	68.7	0.03	0.97	0.11	TRUE
2005	1.00	FALSE	1.00	91.6	1.00	1.00	1.00	FALSE	1.00	90.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE	1.00	89.7	1.00	1.00	1.00	FALSE
2007	0.00	TRUE	0.00	65.2	0.00	1.00	0.14	TRUE	0.00	73.3	0.00	1.00	0.13	TRUE
2008	1.00	FALSE	1.00	91.1	1.00	1.00	1.00	FALSE	1.00	83.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	93.6	1.00	1.00	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE
Chinook														
2000	0.19	TRUE	0.21	16.9	0.03	0.97	0.36	TRUE	0.17	33.0	0.01	0.99	0.32	TRUE
2001	0.19	TRUE	0.23	21.7	0.03	0.97	0.47	TRUE	0.15	36.1	0.01	0.99	0.41	TRUE
2002	1.00	FALSE	1.00	80.7	1.00	1.00	1.00	FALSE	1.00	84.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	92.0	1.00	1.00	1.00	FALSE	1.00	94.9	1.00	1.00	1.00	FALSE
2004	0.24	TRUE	0.23	42.9	0.03	0.97	0.40	TRUE	0.25	41.9	0.05	0.95	0.35	TRUE
2005	0.59	FALSE	0.60	72.7	0.40	0.60	0.89	FALSE	0.59	78.8	0.40	0.60	0.84	FALSE
2006	1.00	FALSE	1.00	85.8	1.00	1.00	1.00	FALSE	1.00	91.0	1.00	1.00	1.00	FALSE
2007	0.18	TRUE	0.18	44.6	0.02	0.98	0.40	TRUE	0.18	44.9	0.02	0.98	0.30	TRUE
2008	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE	1.00	94.2	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	90.4	1.00	1.00	1.00	FALSE	1.00	94.3	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	97.7	1.00	1.00	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	83.3	1.00	1.00	1.00	FALSE	1.00	85.8	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.20	TRUE	0.26	21.3	0.03	0.97	0.51	TRUE	0.14	32.6	0.01	0.99	0.22	TRUE
2001	0.21	TRUE	0.29	29.9	0.04	0.96	0.73	TRUE	0.12	34.2	0.01	0.99	0.28	TRUE
2002	0.28	FALSE	0.00	85.2	1.00	0.00	0.98	FALSE	0.56	79.4	0.26	0.74	0.92	FALSE
2003	1.00	FALSE	1.00	95.6	1.00	1.00	1.00	FALSE	1.00	94.1	1.00	1.00	1.00	FALSE
2004	0.25	TRUE	0.50	69.2	0.16	0.84	0.92	FALSE	0.00	51.9	0.00	1.00	0.30	TRUE
2005	0.77	TRUE	1.00	80.0	1.00	1.00	1.00	FALSE	0.53	80.6	0.29	0.71	0.75	TRUE
2006	1.00	FALSE	1.00	87.6	1.00	1.00	1.00	FALSE	1.00	88.4	1.00	1.00	1.00	FALSE
2007	0.35	TRUE	0.56	72.0	0.25	0.75	0.92	FALSE	0.14	55.0	0.01	0.99	0.30	TRUE
2008	0.71	FALSE	1.00	95.7	1.00	1.00	1.00	FALSE	0.42	87.3	0.10	0.90	0.84	FALSE
2009	1.00	FALSE	1.00	89.9	1.00	1.00	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	85.4	1.00	1.00	1.00	FALSE	1.00	89.4	1.00	1.00	1.00	FALSE

Table B.37. Optimized Irrigation Scenario results from Upper Lemhi River, Site 2.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.36	TRUE	0.48	84.4	0.25	0.75	0.61	TRUE	0.23	68.9	0.04	0.96	0.34	TRUE
2001	0.11	TRUE	0.00	85.3	0.00	1.00	0.81	FALSE	0.23	69.0	0.04	0.96	0.34	TRUE
2002	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE	1.00	84.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE	1.00	92.3	1.00	1.00	1.00	FALSE
2004	0.00	TRUE	0.00	84.1	0.00	1.00	0.62	TRUE	0.00	85.2	0.00	1.00	0.61	TRUE
2005	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE
2007	0.00	TRUE	0.00	85.3	0.00	1.00	0.71	TRUE	0.00	88.0	0.00	1.00	0.66	TRUE
2008	1.00	FALSE	1.00	91.2	1.00	1.00	1.00	FALSE	1.00	83.6	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Chinook														
2000	0.28	TRUE	0.25	25.3	0.03	0.97	0.57	TRUE	0.30	45.3	0.05	0.95	0.55	TRUE
2001	0.28	TRUE	0.26	27.6	0.03	0.97	0.63	TRUE	0.29	46.8	0.04	0.96	0.61	TRUE
2002	1.00	FALSE	1.00	87.7	1.00	1.00	1.00	FALSE	1.00	92.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE
2004	0.39	TRUE	0.40	53.8	0.09	0.91	0.77	TRUE	0.38	59.9	0.08	0.92	0.71	TRUE
2005	1.00	FALSE	1.00	81.7	1.00	1.00	1.00	FALSE	1.00	88.1	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	91.6	1.00	1.00	1.00	FALSE	1.00	95.0	1.00	1.00	1.00	FALSE
2007	0.39	TRUE	0.42	56.3	0.10	0.90	0.78	TRUE	0.36	62.3	0.07	0.93	0.73	TRUE
2008	1.00	FALSE	1.00	95.6	1.00	1.00	1.00	FALSE	1.00	97.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	92.3	1.00	1.00	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.18	TRUE	0.20	20.7	0.02	0.98	0.52	TRUE	0.16	40.0	0.01	0.99	0.34	TRUE
2001	0.07	TRUE	0.00	25.1	0.00	1.00	0.63	TRUE	0.13	40.7	0.01	0.99	0.37	TRUE
2002	0.24	FALSE	0.00	84.0	1.00	0.00	0.94	FALSE	0.48	85.8	0.14	0.86	0.92	FALSE
2003	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE
2004	0.30	TRUE	0.60	69.9	0.36	0.64	0.95	FALSE	0.00	63.3	0.00	1.00	0.58	TRUE
2005	0.50	FALSE	1.00	78.0	1.00	1.00	1.00	FALSE	0.00	88.9	1.00	0.00	0.81	FALSE
2006	1.00	FALSE	1.00	88.7	1.00	1.00	1.00	FALSE	1.00	91.2	1.00	1.00	1.00	FALSE
2007	0.44	TRUE	0.61	73.5	0.50	0.50	0.90	FALSE	0.27	66.3	0.03	0.97	0.59	TRUE
2008	0.71	FALSE	1.00	95.9	1.00	1.00	1.00	FALSE	0.42	89.4	0.10	0.90	0.83	FALSE
2009	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	88.7	1.00	1.00	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE

Upper Lemhi River, Site 3

Table B.38. Percent weighted usable area (% WUA) for a given discharge for Upper Lemhi River, Site 3.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	
9.5	43.10	28.30		43.10	28.30		56.70	30.90	
13.5	54.30	41.10		54.30	41.10		67.60	43.50	
17.5	65.80	59.00		65.80	59.00		79.10	59.50	
21.5	72.40	66.80		72.40	66.80		85.40	68.80	
24.4	76.40	70.40		76.40	70.40		89.00	74.70	
25.5	77.40	71.40		77.40	71.40		89.30	76.40	
29.5	82.10	75.20		82.10	75.20		92.00	82.50	
33.5	86.10	78.80		86.10	78.80		94.30	88.40	
37.3	88.30	81.80		88.30	81.80		94.90	92.60	
37.5	89.50	82.90		89.50	82.90		96.20	94.00	
41.5	92.60	86.20		92.60	86.20		98.40	98.10	
44.4	94.50	88.20		94.50	88.20		99.40	100.00	
45.5	94.80	88.80		94.80	88.80		99.00	99.80	
49.5	96.40	91.20		96.40	91.20		99.50	99.80	
53.5	97.70	93.30		97.70	93.30		100.00	98.40	
57.5	98.70	95.30		98.70	95.30		99.50	95.90	
61.5	99.50	97.10		99.50	97.10		98.50	93.00	
65.5	99.80	98.50		99.80	98.50		97.50	89.60	
69.5	100.00	99.40		100.00	99.40		96.00	86.30	
73.5	99.90	99.90		99.90	99.90		94.90	83.00	
77.5	99.70	100.00		99.70	100.00		93.90	79.90	
81.5	98.80	99.60		98.80	99.60		93.60	76.30	
85.5	98.10	98.60		98.10	98.60		92.40	73.00	
89.5	97.10	97.00		97.10	97.00		90.90	70.20	
93.5	96.20	95.90		96.20	95.90		90.50	67.40	
97.5	94.40	93.30		94.40	93.30		89.50	64.20	
101.5	92.80	90.40		92.80	90.40		88.80	61.50	

Table B.39. Site summary results for Upper Lemhi River, Site 3.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.87	TRUE	0.81	TRUE	0.92	TRUE	0.90	TRUE	0.82	FALSE	0.72	TRUE
Chinook	0.89	TRUE	0.77	TRUE	0.95	TRUE	0.79	TRUE	0.83	TRUE	0.75	TRUE
Bull Trout	0.92	TRUE	0.81	TRUE	0.95	TRUE	0.92	TRUE	0.90	TRUE	0.70	TRUE

Table B.40. Baseline Scenario results from Upper Lemhi River, Site 3.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.40	TRUE	0.48	65.8	0.29	0.71	0.54	TRUE	0.31	49.4	0.08	0.92	0.42	TRUE
2001	0.41	TRUE	0.47	66.8	0.23	0.77	0.59	TRUE	0.34	49.9	0.10	0.90	0.42	TRUE
2002	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	80.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE	1.00	87.6	1.00	1.00	1.00	FALSE
2004	0.50	FALSE	1.00	81.4	1.00	1.00	1.00	FALSE	0.00	78.7	1.00	0.00	0.96	FALSE
2005	1.00	FALSE	1.00	88.9	1.00	1.00	1.00	FALSE	1.00	80.1	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	84.0	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	85.1	1.00	1.00	1.00	FALSE	1.00	83.6	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	92.6	1.00	1.00	1.00	FALSE	1.00	84.4	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE	1.00	94.8	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	95.6	1.00	1.00	1.00	FALSE	1.00	92.6	1.00	1.00	1.00	FALSE
Chinook														
2000	0.33	TRUE	0.31	50.5	0.08	0.92	0.41	TRUE	0.35	44.4	0.08	0.92	0.55	TRUE
2001	0.71	TRUE	1.00	58.6	1.00	1.00	1.00	FALSE	0.42	49.2	0.11	0.89	0.77	TRUE
2002	1.00	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE	1.00	85.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.6	1.00	1.00	1.00	FALSE	1.00	92.5	1.00	1.00	1.00	FALSE
2004	0.50	FALSE	1.00	76.4	1.00	1.00	1.00	FALSE	0.00	70.6	1.00	0.00	0.96	FALSE
2005	1.00	FALSE	1.00	86.2	1.00	1.00	1.00	FALSE	1.00	80.9	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.6	1.00	1.00	1.00	FALSE	1.00	86.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	77.8	1.00	1.00	1.00	FALSE	1.00	72.6	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE	1.00	91.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.0	1.00	1.00	1.00	FALSE	1.00	93.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	96.1	1.00	1.00	1.00	FALSE	1.00	94.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE	1.00	86.1	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.31	TRUE	0.30	52.2	0.10	0.90	0.31	TRUE	0.32	46.9	0.08	0.92	0.48	TRUE
2001	0.69	TRUE	1.00	73.1	1.00	1.00	1.00	FALSE	0.37	50.9	0.09	0.91	0.63	TRUE
2002	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE	1.00	88.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	86.4	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	88.6	1.00	1.00	1.00	FALSE	1.00	69.7	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE	1.00	88.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE	1.00	85.8	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	74.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE	1.00	86.2	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE	1.00	86.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE	1.00	81.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE	1.00	69.9	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	90.8	1.00	1.00	1.00	FALSE	1.00	80.0	1.00	1.00	1.00	FALSE

Table B.41. Optimized Irrigation Scenario results from Upper Lemhi River, Site 3.

	Overall		Spawn						Adult					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.27	TRUE	0.36	56.1	0.11	0.89	0.46	TRUE	0.17	42.9	0.02	0.98	0.34	TRUE
2001	0.25	TRUE	0.34	56.8	0.09	0.91	0.48	TRUE	0.17	43.0	0.02	0.98	0.34	TRUE
2002	1.00	FALSE	1.00	91.4	1.00	1.00	1.00	FALSE	1.00	78.4	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE
2004	0.50	FALSE	1.00	77.8	1.00	1.00	1.00	FALSE	0.00	75.1	1.00	0.00	0.81	FALSE
2005	1.00	FALSE	1.00	86.7	1.00	1.00	1.00	FALSE	1.00	78.3	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.9	1.00	1.00	1.00	FALSE	1.00	82.1	1.00	1.00	1.00	FALSE
2007	0.50	FALSE	1.00	82.9	1.00	1.00	1.00	FALSE	0.00	81.7	1.00	0.00	0.99	FALSE
2008	1.00	FALSE	1.00	92.1	1.00	1.00	1.00	FALSE	1.00	83.6	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE	1.00	96.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	96.3	1.00	1.00	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	94.7	1.00	1.00	1.00	FALSE	1.00	94.8	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE	1.00	91.6	1.00	1.00	1.00	FALSE
Chinook														
2000	0.22	TRUE	0.25	18.4	0.05	0.95	0.35	TRUE	0.20	20.8	0.02	0.98	0.31	TRUE
2001	0.22	TRUE	0.25	22.9	0.04	0.96	0.40	TRUE	0.19	22.9	0.02	0.98	0.36	TRUE
2002	1.00	FALSE	1.00	79.9	1.00	1.00	1.00	FALSE	1.00	77.5	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	91.7	1.00	1.00	1.00	FALSE	1.00	89.3	1.00	1.00	1.00	FALSE
2004	0.34	TRUE	0.36	57.7	0.06	0.94	0.81	FALSE	0.33	52.7	0.05	0.95	0.70	TRUE
2005	0.78	FALSE	1.00	72.4	1.00	1.00	1.00	FALSE	0.57	69.7	0.25	0.75	0.97	FALSE
2006	1.00	FALSE	1.00	80.8	1.00	1.00	1.00	FALSE	1.00	78.8	1.00	1.00	1.00	FALSE
2007	0.41	FALSE	0.41	62.1	0.09	0.91	0.89	FALSE	0.41	57.9	0.11	0.89	0.74	FALSE
2008	1.00	FALSE	1.00	90.0	1.00	1.00	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	93.2	1.00	1.00	1.00	FALSE	1.00	91.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE	1.00	95.2	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	96.3	1.00	1.00	1.00	FALSE	1.00	94.2	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	85.7	1.00	1.00	1.00	FALSE	1.00	83.8	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.29	TRUE	0.38	37.5	0.15	0.85	0.44	TRUE	0.19	29.0	0.02	0.98	0.32	TRUE
2001	0.35	TRUE	0.53	49.6	0.23	0.77	0.83	TRUE	0.18	30.8	0.02	0.98	0.36	TRUE
2002	1.00	FALSE	1.00	93.9	1.00	1.00	1.00	FALSE	1.00	80.5	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.7	1.00	1.00	1.00	FALSE	1.00	85.2	1.00	1.00	1.00	FALSE
2004	0.67	TRUE	1.00	79.9	1.00	1.00	1.00	FALSE	0.34	56.8	0.06	0.94	0.74	TRUE
2005	0.50	FALSE	1.00	90.2	1.00	1.00	1.00	FALSE	0.00	77.8	1.00	0.00	1.00	FALSE
2006	1.00	FALSE	1.00	95.4	1.00	1.00	1.00	FALSE	1.00	78.0	1.00	1.00	1.00	FALSE
2007	0.71	FALSE	1.00	87.2	1.00	1.00	1.00	FALSE	0.41	63.8	0.11	0.89	0.75	FALSE
2008	1.00	FALSE	1.00	98.3	1.00	1.00	1.00	FALSE	1.00	84.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE	1.00	84.6	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	95.2	1.00	1.00	1.00	FALSE	1.00	82.9	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE	1.00	70.2	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	90.9	1.00	1.00	1.00	FALSE	1.00	78.4	1.00	1.00	1.00	FALSE

Upper Lemhi River, Site 4

Table B.42. Percent weighted usable area (% WUA) for a given discharge for the Upper Lemhi River, Site 4.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	
6	53.30	23.00		53.30	23.00		52.00	27.50	
9	62.60	37.80		62.60	37.80		63.50	41.50	
12	69.20	49.60		69.20	49.60		71.30	51.10	
15	75.00	59.20		75.00	59.20		76.50	60.50	
15.5	75.80	60.60		75.80	60.60		77.10	61.60	
18	79.60	64.70		79.60	64.70		82.30	68.70	
21	83.50	69.60		83.50	69.60		86.80	75.00	
24	87.50	74.40		87.50	74.40		90.60	81.90	
27	90.50	83.20		90.50	83.20		93.90	88.30	
30	93.00	90.60		93.00	90.60		96.00	93.90	
31	93.50	92.10		93.50	92.10		96.10	95.70	
32.5	95.00	93.80		95.00	93.80		97.70	96.70	
33	95.20	94.30		95.20	94.30		97.80	97.00	
36	97.00	96.50		97.00	96.50		98.90	98.30	
39	98.60	98.40		98.60	98.40		99.60	99.50	
42	100.00	100.00		100.00	100.00		100.00	100.00	

Table B.43. Site summary results for Upper Lemhi River, Site 4.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.92	TRUE	0.91	TRUE	0.93	TRUE	0.93	TRUE	0.90	FALSE	0.89	TRUE
Chinook	0.93	TRUE	0.84	TRUE	0.94	TRUE	0.89	TRUE	0.91	TRUE	0.78	TRUE
Bull Trout	0.92	TRUE	0.83	TRUE	0.95	TRUE	0.87	TRUE	0.90	TRUE	0.80	TRUE

Table B.44. Baseline Scenario results from Upper Lemhi River, Site 4.

	Overall		Spawn						Adult					
Year	SI	SS	SI	Ave	Res.	Rel.	Vul.	SS	SI	Ave	Res.	Rel.	Vul.	SS
Steelhead														
2000	0.47	TRUE	0.56	78.4	0.38	0.63	0.77	TRUE	0.38	56.1	0.15	0.85	0.43	TRUE
2001	0.43	TRUE	0.49	79.5	0.17	0.83	0.86	FALSE	0.36	56.6	0.13	0.87	0.43	TRUE
2002	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	88.0	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	94.4	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	90.4	1.00	1.00	1.00	FALSE	1.00	85.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	92.6	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE	1.00	91.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE	1.00	88.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
Chinook														
2000	0.31	TRUE	0.25	65.6	0.07	0.93	0.23	TRUE	0.38	52.4	0.13	0.87	0.50	TRUE
2001	0.74	TRUE	1.00	74.6	1.00	1.00	1.00	FALSE	0.48	58.3	0.27	0.73	0.58	TRUE
2002	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE	1.00	97.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	86.3	1.00	1.00	1.00	FALSE	1.00	74.9	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE	1.00	93.8	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	87.4	1.00	1.00	1.00	FALSE	1.00	78.3	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.32	TRUE	0.29	57.2	0.13	0.87	0.21	TRUE	0.34	55.3	0.11	0.89	0.40	TRUE
2001	0.68	TRUE	1.00	77.6	1.00	1.00	1.00	FALSE	0.36	60.0	0.11	0.89	0.45	TRUE
2002	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	93.6	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE	1.00	83.8	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	95.8	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	95.0	1.00	1.00	1.00	FALSE	1.00	86.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	94.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE

Table B.45. Optimized Irrigation Scenario results from Upper Lemhi River, Site 4.

	Overall		**Spawn**						**Adult**					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.41	TRUE	0.52	68.5	0.50	0.50	0.57	TRUE	0.29	48.5	0.07	0.93	0.38	TRUE
2001	0.41	TRUE	0.53	69.3	0.50	0.50	0.58	TRUE	0.29	48.6	0.07	0.93	0.38	TRUE
2002	1.00	FALSE	1.00	97.3	1.00	1.00	1.00	FALSE	1.00	87.3	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	94.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE	1.00	83.6	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE	1.00	90.9	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	91.0	1.00	1.00	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE
Chinook														
2000	0.25	TRUE	0.27	31.0	0.07	0.93	0.29	TRUE	0.23	25.5	0.03	0.97	0.36	TRUE
2001	0.26	TRUE	0.27	37.4	0.07	0.93	0.31	TRUE	0.24	28.4	0.03	0.97	0.42	TRUE
2002	1.00	FALSE	1.00	90.3	1.00	1.00	1.00	FALSE	1.00	88.1	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2004	0.67	FALSE	1.00	73.5	1.00	1.00	1.00	FALSE	0.34	60.6	0.05	0.95	0.74	FALSE
2005	1.00	FALSE	1.00	84.8	1.00	1.00	1.00	FALSE	1.00	80.2	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	90.2	1.00	1.00	1.00	FALSE	1.00	87.5	1.00	1.00	1.00	FALSE
2007	0.69	FALSE	1.00	76.7	1.00	1.00	1.00	FALSE	0.38	66.4	0.07	0.93	0.83	FALSE
2008	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE	1.00	97.5	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	94.9	1.00	1.00	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.30	TRUE	0.32	46.5	0.19	0.81	0.22	TRUE	0.28	35.0	0.06	0.94	0.37	TRUE
2001	0.14	TRUE	0.00	60.4	1.00	0.00	0.40	TRUE	0.27	37.3	0.05	0.95	0.41	TRUE
2002	1.00	FALSE	1.00	96.6	1.00	1.00	1.00	FALSE	1.00	87.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	96.7	1.00	1.00	1.00	FALSE
2004	0.68	FALSE	1.00	86.0	1.00	1.00	1.00	FALSE	0.36	71.9	0.06	0.94	0.82	FALSE
2005	1.00	FALSE	1.00	92.9	1.00	1.00	1.00	FALSE	1.00	85.5	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.6	1.00	1.00	1.00	FALSE	1.00	89.4	1.00	1.00	1.00	FALSE
2007	0.74	FALSE	1.00	89.6	1.00	1.00	1.00	FALSE	0.47	76.5	0.14	0.86	0.89	FALSE
2008	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	93.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE

Upper Lemhi River, Site 5

Table B.46. Percent weighted usable area (% WUA) for a given discharge for the Upper Lemhi River, Site 5.

Discharge [cfs]	Steelhead			Chinook			Bull Trout		
	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile	Spawn	Adult	Juvenile
0	0.00	0.00		0.00	0.00		0.00	0.00	
6	54.50	35.60		54.50	35.60		57.00	39.00	
8	61.60	49.60		61.60	49.60		67.00	52.00	
10	67.40	60.00		67.40	60.00		74.00	62.00	
10.4	68.40	61.60		68.40	61.60		75.00	64.00	
12	72.40	67.00		72.40	67.00		81.00	73.00	
14	76.40	72.40		76.40	72.40		86.00	81.00	
16	79.20	76.00		79.20	76.00		91.00	87.00	
18	82.10	80.40		82.10	80.40		94.00	92.00	
19	83.40	82.30		83.40	82.30		95.00	93.00	
20	84.50	83.90		84.50	83.90		96.00	94.00	
22	86.60	86.70		86.60	86.70		97.00	97.00	
22.9	87.60	87.70		87.60	87.70		98.00	97.00	
24	88.80	88.80		88.80	88.80		99.00	98.00	
26	90.50	90.60		90.50	90.60		99.00	99.00	
28	92.00	92.30		92.00	92.30		100.00	100.00	
30	93.20	93.90		93.20	93.90		100.00	100.00	
32	94.60	95.40		94.60	95.40		100.00	100.00	
34	95.80	96.60		95.80	96.60		100.00	99.00	
36	96.70	97.50		96.70	97.50		100.00	99.00	
38	97.30	98.10		97.30	98.10		100.00	98.00	
40	98.00	98.90		98.00	98.90		100.00	97.00	
42	98.50	99.50		98.50	99.50		99.00	95.00	
44	99.00	99.80		99.00	99.80		99.00	94.00	
46	99.40	100.00		99.40	100.00		99.00	92.00	
48	99.50	99.70		99.50	99.70		99.00	91.00	
50	99.70	99.70		99.70	99.70		99.00	89.00	
52	99.70	99.40		99.70	99.40		99.00	87.00	
54	99.90	99.40		99.90	99.40		99.00	86.00	
56	100.00	99.30		100.00	99.30		99.00	84.00	

Table B.47. Site summary results for Upper Lemhi River, Site 5.

	Site Overview				Spawning				Adult			
	Base		Optimized		Base		Optimized		Base		Optimized	
Steelhead	0.91	TRUE	0.91	TRUE	0.93	TRUE	0.93	TRUE	0.90	FALSE	0.89	TRUE
Chinook	0.92	TRUE	0.83	TRUE	0.92	TRUE	0.86	TRUE	0.91	TRUE	0.79	TRUE
Bull Trout	0.92	TRUE	0.84	TRUE	0.95	TRUE	0.87	TRUE	0.90	TRUE	0.80	TRUE

Table B.48. Baseline Scenario results from Upper Lemhi River, Site 5.

	Overall		Spawn						Adult					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.44	TRUE	0.54	74.2	0.29	0.71	0.75	TRUE	0.34	58.3	0.12	0.88	0.38	TRUE
2001	0.42	TRUE	0.50	75.3	0.17	0.83	0.88	FALSE	0.35	59.1	0.12	0.88	0.42	TRUE
2002	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE	1.00	87.3	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE	1.00	93.2	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	88.6	1.00	1.00	1.00	FALSE	1.00	88.2	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	88.4	1.00	1.00	1.00	FALSE	1.00	86.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE	1.00	91.5	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	90.9	1.00	1.00	1.00	FALSE	1.00	90.8	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	93.9	1.00	1.00	1.00	FALSE	1.00	86.5	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE
Chinook														
2000	0.15	TRUE	0.00	64.1	0.00	1.00	0.47	TRUE	0.30	62.1	0.08	0.93	0.39	TRUE
2001	0.76	TRUE	1.00	76.0	1.00	1.00	1.00	FALSE	0.52	70.2	0.30	0.70	0.67	TRUE
2002	1.00	FALSE	1.00	95.1	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	97.9	1.00	1.00	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	86.1	1.00	1.00	1.00	FALSE	1.00	83.5	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE	1.00	92.3	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	95.7	1.00	1.00	1.00	FALSE	1.00	97.0	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	86.4	1.00	1.00	1.00	FALSE	1.00	85.5	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	95.7	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	98.1	1.00	1.00	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	93.5	1.00	1.00	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.33	TRUE	0.34	56.3	0.12	0.88	0.40	TRUE	0.31	66.0	0.10	0.90	0.36	TRUE
2001	0.69	TRUE	1.00	84.6	1.00	1.00	1.00	FALSE	0.38	72.8	0.15	0.85	0.44	TRUE
2002	1.00	FALSE	1.00	99.9	1.00	1.00	1.00	FALSE	1.00	93.3	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE	1.00	91.7	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	96.2	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	99.6	1.00	1.00	1.00	FALSE	1.00	93.6	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	98.4	1.00	1.00	1.00	FALSE	1.00	92.4	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	99.7	1.00	1.00	1.00	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	90.0	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	85.9	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	84.0	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	91.5	1.00	1.00	1.00	FALSE

Table B.49. Optimized Irrigation Scenario results from Upper Lemhi River, Site 5.

	Overall		Spawn						Adult					
Year	**SI**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**	**SI**	**Ave**	**Res.**	**Rel.**	**Vul.**	**SS**
Steelhead														
2000	0.41	TRUE	0.51	64.0	0.50	0.50	0.53	TRUE	0.31	49.5	0.07	0.93	0.42	TRUE
2001	0.41	TRUE	0.52	64.7	0.47	0.53	0.57	TRUE	0.31	49.5	0.07	0.93	0.43	TRUE
2002	1.00	FALSE	1.00	94.1	1.00	1.00	1.00	FALSE	1.00	86.2	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	98.2	1.00	1.00	1.00	FALSE	1.00	93.0	1.00	1.00	1.00	FALSE
2004	1.00	FALSE	1.00	85.9	1.00	1.00	1.00	FALSE	1.00	85.2	1.00	1.00	1.00	FALSE
2005	1.00	FALSE	1.00	86.8	1.00	1.00	1.00	FALSE	1.00	85.2	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	95.6	1.00	1.00	1.00	FALSE	1.00	90.1	1.00	1.00	1.00	FALSE
2007	1.00	FALSE	1.00	89.1	1.00	1.00	1.00	FALSE	1.00	88.9	1.00	1.00	1.00	FALSE
2008	1.00	FALSE	1.00	93.5	1.00	1.00	1.00	FALSE	1.00	86.1	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.8	1.00	1.00	1.00	FALSE	1.00	99.4	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	96.8	1.00	1.00	1.00	FALSE	1.00	97.4	1.00	1.00	1.00	FALSE
Chinook														
2000	0.25	TRUE	0.25	28.1	0.05	0.95	0.36	TRUE	0.25	30.1	0.05	0.95	0.37	TRUE
2001	0.28	TRUE	0.30	35.7	0.09	0.91	0.32	TRUE	0.26	34.2	0.04	0.96	0.45	TRUE
2002	1.00	FALSE	1.00	87.3	1.00	1.00	1.00	FALSE	1.00	89.7	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	93.4	1.00	1.00	1.00	FALSE	1.00	95.5	1.00	1.00	1.00	FALSE
2004	0.49	FALSE	0.62	69.8	0.50	0.50	0.96	FALSE	0.35	66.1	0.06	0.94	0.78	FALSE
2005	1.00	FALSE	1.00	81.9	1.00	1.00	1.00	FALSE	1.00	82.4	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	87.6	1.00	1.00	1.00	FALSE	1.00	89.8	1.00	1.00	1.00	FALSE
2007	0.73	FALSE	1.00	73.1	1.00	1.00	1.00	FALSE	0.47	71.3	0.14	0.86	0.86	FALSE
2008	1.00	FALSE	1.00	89.5	1.00	1.00	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	94.6	1.00	1.00	1.00	FALSE	1.00	96.4	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	100.0	1.00	1.00	1.00	FALSE	1.00	99.3	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	86.6	1.00	1.00	1.00	FALSE	1.00	88.5	1.00	1.00	1.00	FALSE
Bull Trout														
2000	0.32	TRUE	0.37	43.5	0.15	0.85	0.40	TRUE	0.26	38.5	0.05	0.95	0.36	TRUE
2001	0.14	TRUE	0.00	60.6	1.00	0.00	0.43	TRUE	0.27	41.8	0.05	0.95	0.44	TRUE
2002	1.00	FALSE	1.00	98.5	1.00	1.00	1.00	FALSE	1.00	91.8	1.00	1.00	1.00	FALSE
2003	1.00	FALSE	1.00	99.5	1.00	1.00	1.00	FALSE	1.00	92.7	1.00	1.00	1.00	FALSE
2004	0.69	FALSE	1.00	87.9	1.00	1.00	1.00	FALSE	0.37	73.6	0.07	0.93	0.83	FALSE
2005	1.00	FALSE	1.00	96.5	1.00	1.00	1.00	FALSE	1.00	90.7	1.00	1.00	1.00	FALSE
2006	1.00	FALSE	1.00	98.8	1.00	1.00	1.00	FALSE	1.00	91.5	1.00	1.00	1.00	FALSE
2007	0.77	FALSE	1.00	92.8	1.00	1.00	1.00	FALSE	0.53	80.1	0.21	0.79	0.89	FALSE
2008	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	90.0	1.00	1.00	1.00	FALSE
2009	1.00	FALSE	1.00	99.2	1.00	1.00	1.00	FALSE	1.00	91.2	1.00	1.00	1.00	FALSE
2010	1.00	FALSE	1.00	99.1	1.00	1.00	1.00	FALSE	1.00	88.2	1.00	1.00	1.00	FALSE
2011	1.00	FALSE	1.00	99.0	1.00	1.00	1.00	FALSE	1.00	84.1	1.00	1.00	1.00	FALSE
2012	1.00	FALSE	1.00	95.3	1.00	1.00	1.00	FALSE	1.00	89.2	1.00	1.00	1.00	FALSE