Snohomish Basin 2060 Scenarios: Adapting to an Uncertain Future

Decision Support for Long Term Provision of Ecosystem Services in the Snohomish Basin, WA

March 2013

A project of the Urban Ecology Research Laboratory, University of Washington, Seattle with funding provided by the Bullitt Foundation

Citation: Alberti, M. Russo, M and K. Tenneson. March 2013. Snohomish Basin 2060 Scenarios. Adapting to an Uncertain Future. Decision Support for Long Term Provision of Ecosystem Services in the Snohomish Basin, WA. Urban Ecology Research Laboratory, University of Washington, Seattle.

FOREWARD

The Snohomish Basin Scenarios (SBS) aim to support critical decisions for maintaining ecosystem functions in the Snohomish Basin in the long term despite irreducible uncertainty. The Project, led by the Urban Ecology Research Lab in partnership with a team of regional experts, aimed to develop and assess hypotheses about the future trajectories of ecosystem service provision in the basin by characterizing the uncertainty associated with alternative future baseline conditions. The project culminated in four scenarios presenting unique and surprising sets of future conditions. Together the four scenarios are intended to provide decision-makers with essential information for testing, monitoring, innovating and prioritizing policies in light of potential opportunities and challenges that future conditions may present. Project lessons are translated into six areas of support for making decisions under uncertainty. Scenario planning provides a systematic approach to 1) focus on system resilience rather than controlling change, 2) redefine the decision context and framework, 3) challenge our assumptions about future conditions, 4) highlight risks and opportunities that prompt creative solutions, 5) monitor warning signals of regime shifts, and 6) identify robust decisions under uncertainty.

We hope this project and report will contribute to the transformation of institutional frameworks and long term decision making in the basin towards a more resilient and anticipatory approach to maintain natural capital in the long term. To everyone who has collaborated along the way, and to all of you who are inspired to collaborate to ensure the basin a healthy future, we thank you.

Urban Ecology Research Lab

How can the Snohomish Basin Scenarios help decision makers shift the attention towards resilience?

Resilience is the capacity of a system to tolerate disturbance without shifting into a qualitatively different state that is controlled by a different set of processes. Resilience theory leans on four assumptions about the nature of coupled social-ecological systems: complexity, change, diversity, and uncertainty. At times, maintaining or enhancing the resilience of one sub-system comes at the cost of the resilience of another. Planning decisions may involve important tradeoffs that cannot be eliminated, but rather explicitly addressed in a negotiation process by various basin stakeholders. The SBS Science Team developed a set of questions to guide planners and decision makers in the complex task of assessing alternative strategies towards maintaining system resilience.

How can the Snohomish Basin Scenarios help decision makers redefine the decision framework?

A key step of developing future scenarios is to define the problem and identify the diversity of basin actors and their views. Their unique lenses stem from the diversity of values, backgrounds, and experience. The scenario building process explores shifts in decision context and tradeoffs associated with shifts in power domains (actors), problem conceptualization (information), political attention (priorities) and innovations (substitutable actions) that divergent strategies may imply. An expanded decision context helps explore strategies that are generally more 1) equitable, 2) flexible, 3) proactive, and 4) anticipatory in character.

How can the Snohomish Basin Scenarios help decision makers challenge assumptions about the future?

Scenarios focus on the 'irreducible uncertainty'- future changes that diverge from past observations. Based on the interactions of variable trajectories of multiple drivers, scenarios explore hypothetical boundary conditions beyond the scope of assumptions of predictive models. Scenarios are extremely powerful when combined with predictive modeling. Scenarios also require linking multiple social and ecological models in an integrated framework. Using the expanded boundary conditions set by the divergent scenarios, integrated models can help 1) test hypothesized trajectories and interactions; 2) refine potential relationships and feedback among variables; and 3) assess potential impacts of hypothesized futures on ecosystem services and human wellbeing. Scenarios are not an alternative to models but rather a complement to them, expanding the boundary conditions of predictive models and providing a systematic approach to deal with i uncertainties in assessing alternative strategic actions.

How can the Snohomish Basin Scenarios help decision makers highlight risks and opportunities?

One of the fundamental objectives of scenario planning is to explore the interactions between multiple critical uncertainties supporting otherwise overlooked future conditions. Scenarios attempt to highlight risks and opportunities of plausible future conditions by looking at divergent trajectories. The four Snohomish Basin scenarios describe futures where economic, social and ecological drivers vary greatly; testing regional worldviews about what is appropriate and certain. Our hypothesis is that exposing multiple divergent scenarios to planners and decision makers supports a more creative process for imagining solutions. For example, to one decision maker the growth in recreational activity in the basin may pose new pressures through the spread of invasive species, the higher market value of wildland homes and increased carbon emissions through day-trips. However, another decision maker may see this trend as a new revenue source and a source of increased public attention and volunteering efforts.

How can the Snohomish Basin Scenarios help decision makers anticipate potential system shifts?

Scenarios help illuminate warning signals that could allow decision makers to anticipate potential regime shifts and change their strategies in a timely and effective manner. Robust strategies are effective under divergent futures, but adaptive strategies support effective action under specific conditions – depending on how the future changes. Critical sensitivities refer to potential thresholds or irreversible conditions with significant implications for multiple ecosystem services and diverse stakeholders. The most pervasive sensitivities in the basin include snowmelt, lowland productivity, and economic diversity. Multiple strategies can facilitate reduced impacts from earlier snowmelt - from upland snowpack reservoirs to lowland wider riparian and estuary buffers. The management of the basin's lowlands, including floodways, agricultural valleys, urban corridors and salmon habitat represents significant overlap and divergence of stakeholder values. Decisions over the management of these lands over the next decade will likely determine the course of the basin over the next half century. Lastly, the future of the basin highly depends on the future of aerospace engineering for its role in its economic stability. While several diverse economic sectors including the medical industry, outdoor recreation and service sectors are at play, conditions in the basin would shift dramatically depending on the actions of few key players.

How can the Snohomish Basin Scenarios help decision makers identify robust decisions?

Scenario planning aims to support decision making under uncertainty by providing a systematic approach to assess the robustness of alternative strategies under a set of plausible future conditions. The SBS explore divergent future conditions that can emerge from the interaction of uncertain trajectories characterizing a major vs. a minor potential climate change (magnitude and variability) and diverse trajectories of change in social values that characterize the relationship of society with nature (mastery vs. harmony). Climate change and social values are the two driving forces selected by the project Science Team to represent the critical uncertainties influencing the future of the Snohomish Basin. In our research we have found that investments in natural capital, including upland intact forests, corridors of riparian habitat, and both above and below ground reservoirs represent strategies that are most robust under uncertain futures providing co-benefits and wider buffers for increased pressures and variability of key driving forces.










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EXECUTIVE SUMMARY

The Snohomish Basin

The Snohomish Basin[1] is a vast forested landscape draining from the Cascade Range to the Puget Sound. The greater Seattle Metropolitan Area relies heavily on the ecosystem services provided by these natural lands, from drinking water and biodiversity, to carbon storage and recreation. In fact, it is estimated that the Snohomish Basin provides more drinking water than any other Basin in the State [1], is one of the primary producers of salmon in the Puget Sound region [2], and supports more carbon stock per acre than any other basin in the Puget Sound[2] [3]. With over 600,000 acres of protected lands, it is one of the greatest recreation destinations within thirty minutes of a metropolitan area in the state.

Figure ES.1: Map of the Basin

Past Trends

The Snohomish Basin is also one of the fastest growing areas in the state. With major employers including Boeing, Providence Regional Medical Center and Microsoft nearby, the basin attracts employees and corresponding development growth. Over the last fifty years, the basin has shifted from supporting a largely rural population to an urban population, and along with this change it has seen dramatic transitions in landscape character, resource consumption and governance. Urban growth and ecosystem service provision don't have to be at odds with one another, but they certainly pose important challenges and tradeoffs.

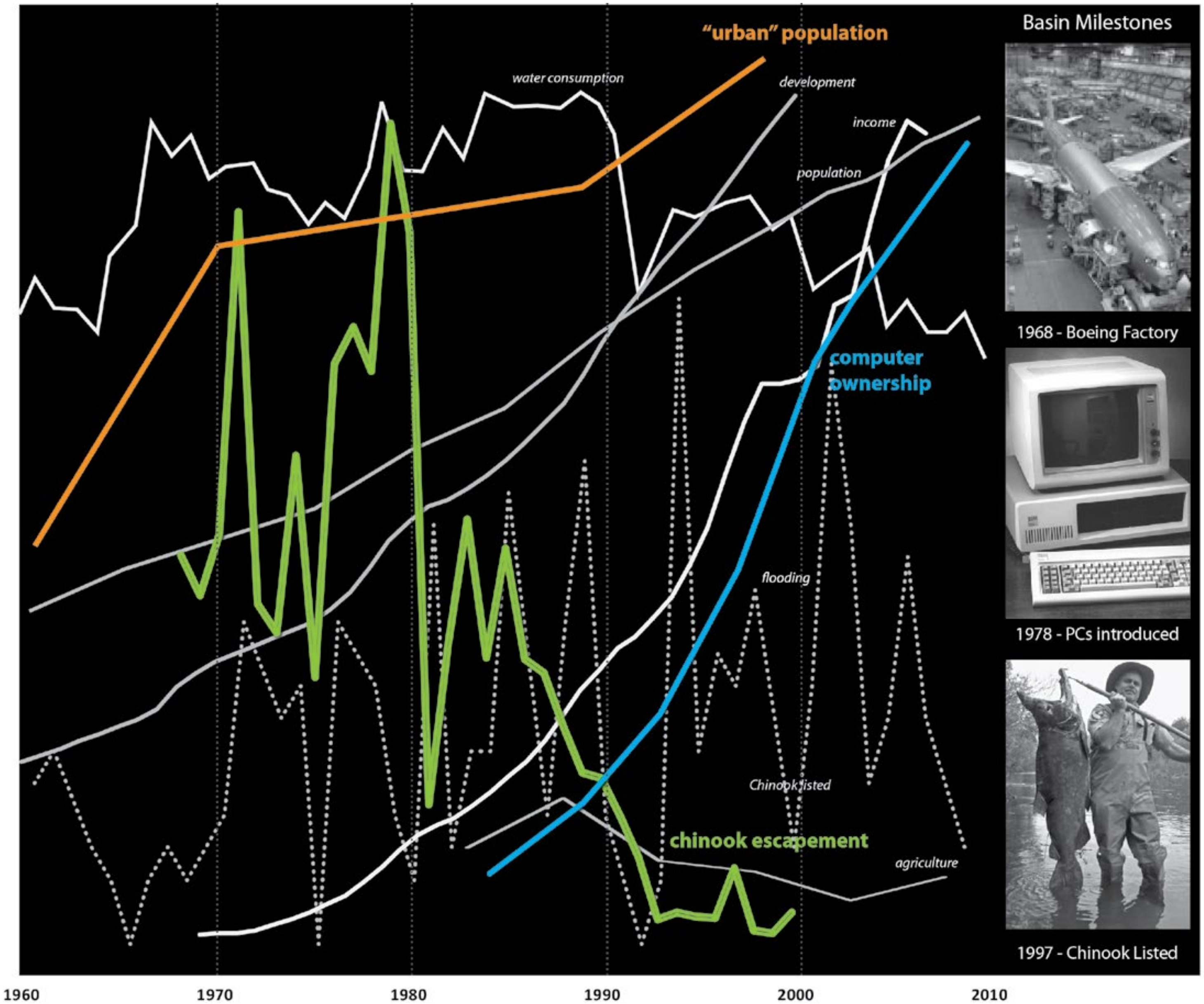

Figure ES.2: Past Trends

Future Trends

Looking out to the next fifty years, the Snohomish Basin faces many critical challenges in balancing social, economic and ecological health. Strategies that decision-makers and land managers employ today will influence the basin's ability to continue to provide the very ecosystem services that are needed to successfully support the growing population. Future conditions in the basin, controlled largely by external drivers, will change how effective regional strategies are at maintaining ecosystem service provision. The direction of technological innovation, the pace of climate change, the transformation of social values, the regulatory strength of government, global economic markets are all parts of the complex socio-ecological system governing ecosystem service provision in the basin. However, there is great uncertainty in predicting future conditions due to the complex interactions between multiple drivers at various scales.

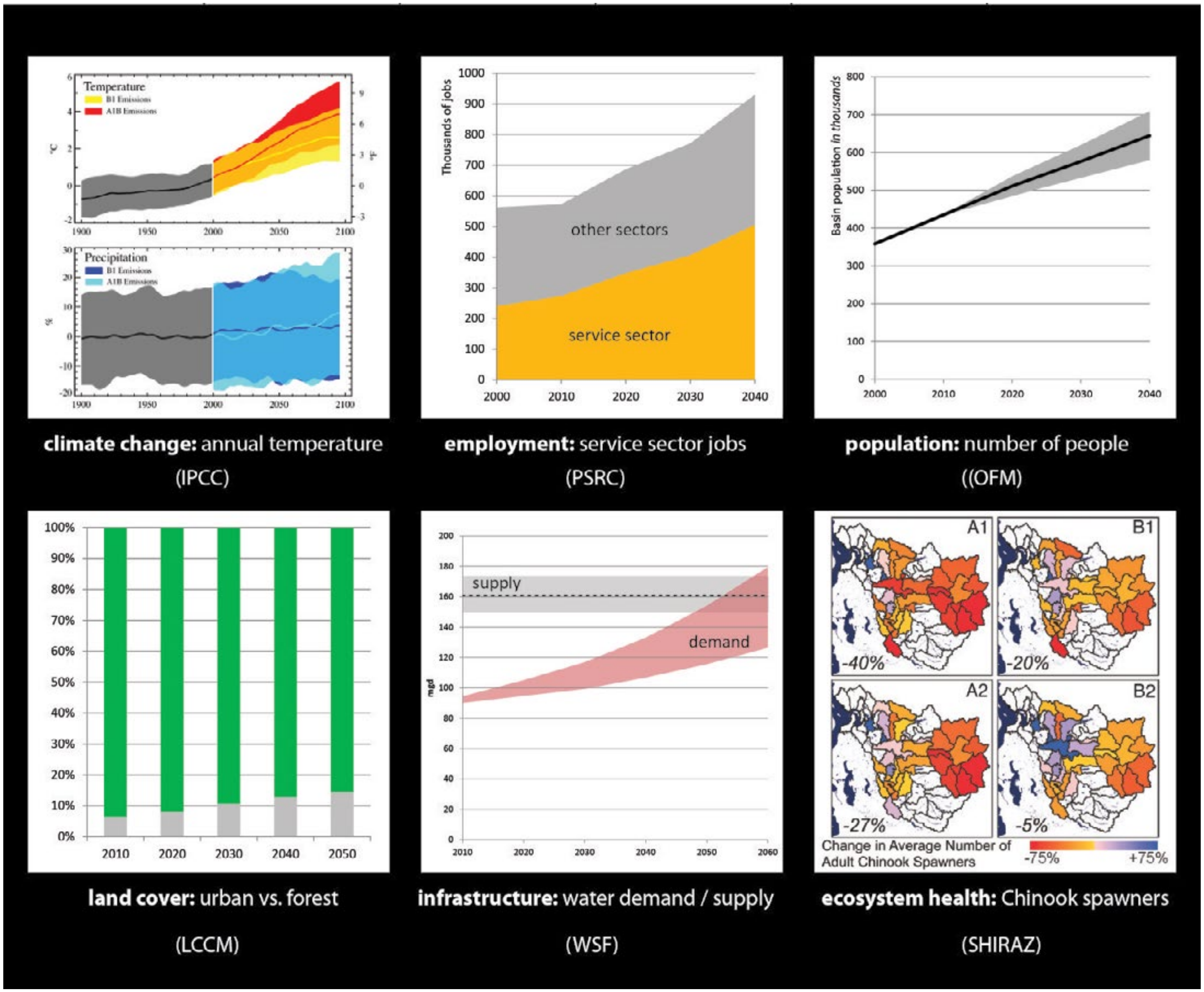

Figure ES.3 Future Trends

Project Approach

The Snohomish Basin Scenarios project characterizes the future uncertainty of the basin through four alternative future scenarios for the Snohomish Basin. The project was initiated in the summer of 2010 by the Urban Ecology Research Lab (hereafter referred to as UERL), housed at the University of Washington and under funding from the Bullitt Foundation. The primary approach of the Snohomish Basin Scenarios project was 'scenario planning'. This approach is intended to support robust decision making by characterizing alternative futures that influence the efficacy of strategic solutions. For example, what might happen if major climate change is coupled with an economic recession?

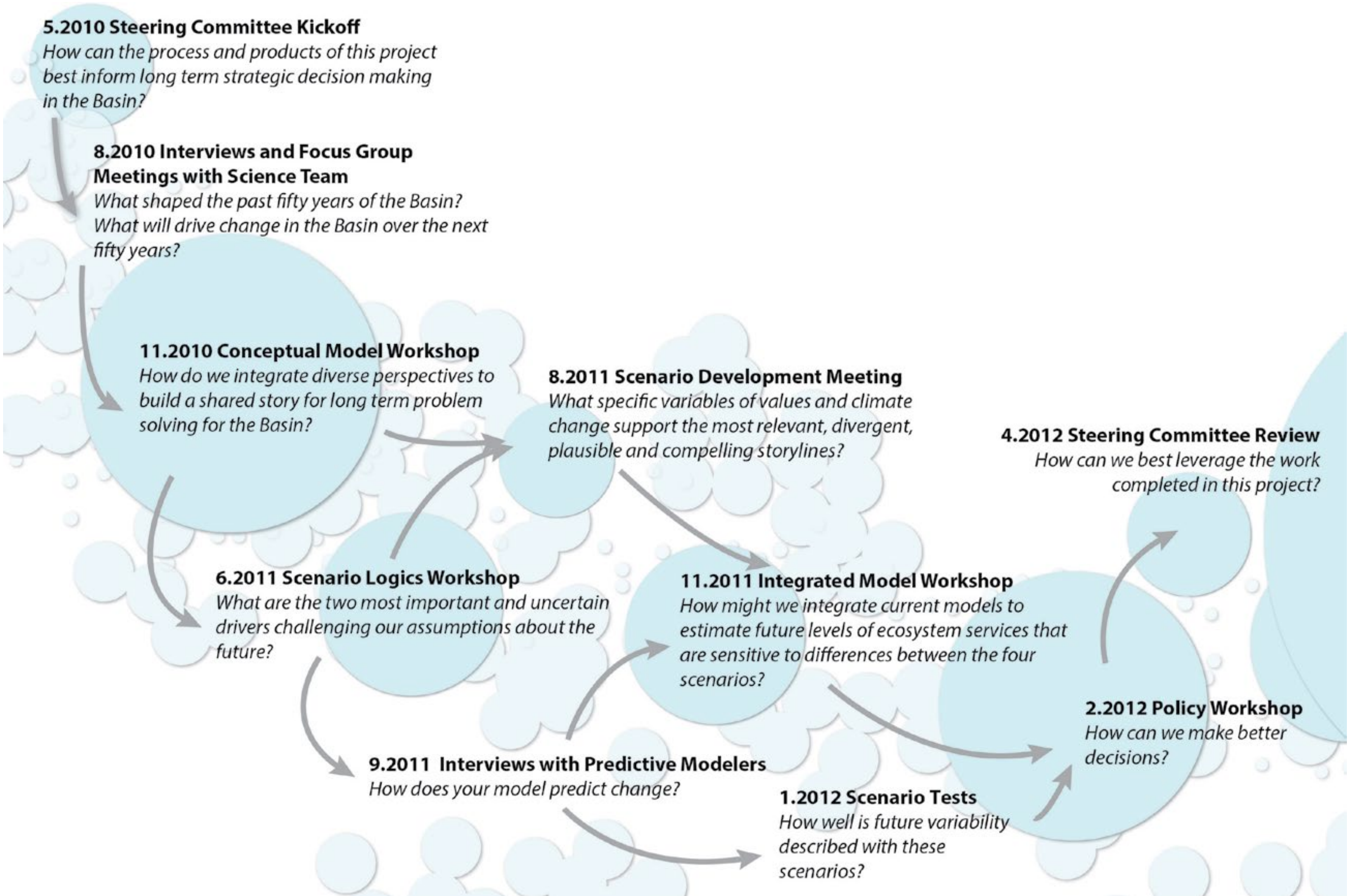

Figure ES.4 Project Approach

Project Partnerships

Scenario planning is a collaborative process grounded on the experience of diverse expertise and perspective of multiple stakeholders. The Snohomish Basin Scenarios is the result of a 2-year process involving over one hundred regional experts, representing over fifty agencies, and collectively volunteering over a thousand hours of their time. The project direction was informed by a steering committee of a dozen regional decision makers. The content of the scenarios were developed and tested with a science team of hydrologists, ecologists, economics, developers, utility analysts, naturalists, demographers, among several other disciplines. The final scenarios were interpreted in terms of their salience for regional decision makers with a team of stakeholders.

Norm Abbott
Jackie Aitchison
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William Beyers
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Jim Franzel
John Gamon
Simon Geerlofs
Bonnie Geers
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Jonathen Guzzo
Andy Haas
Troy Hall
Alan Hamlet
Chris Harvey
Kelly Heintz
Ryan Hembree
Jan Henderson
Judy Herring
Kollin Higgins
Abby Hook
Peter Jackson
Jennifer Jerabek
Janne Kaje
Alice Kelly
Kristin Kelly
Michael Kern
Karen Kinney
Jacque Klug
Deborah Knutson
Bill Knutson
Dave Kosciuk
Sarah Krueger
Brent Lackey
Sim Larkin
Joan Lee
Tom Leschine
Dennis Lettenmaier
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Sandra Mallory
Mike March
Stewart Matthiesen
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Mark Maureen
Heike Mayer
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Marcia Meyers
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Anna Miles
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John Moore
Tom Niemann
Tom O'Keefe
Deborah Oaks
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Mike Pattison
Thomas Payant
Dave Peterson
Chris Picard
Patrick Pierce
Philip Popoff
John Postema
Scott Powell
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Dave Redman
David Remlinger
Casey Rice
Luke Rogers
Mary Rucklehaus
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Eric Salathe
Rowan Schmidt
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Mark Simonson
Amy Snover
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Cindy Spiry
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Stephen Stanley
Andrew Stout
Don Stuart
Jeannie Sumnmer-hays
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Brett Swift
Debbie Terwilleger
Jim Teverbaugh
Dan Tonnes
Joe Tovar
Mike Town
Stacy Trussler
John Ufford
Anne Vernez Moudon
Elizabeth Walker
Tim Walls
Elizabeth Weldin
Richard White
Jan Whittington
Matt Wiley
Daryl Williams
Terry Williams
Clark Williams-Derry
Kathy Wolf
Hendrik Wolff
Ken Yocom
Yi Zhao
Ken Zweig

Figure ES.5 Partner list

The Four Scenarios

The Science Team identified climate change (magnitude and variability) and social values (relationship between society and nature) as the two most important and uncertain drivers influencing future conditions in the Snohomish Basin by 2060. These two drivers shaped the final four scenarios, or stories, which describe alternative trajectories, challenges, and opportunities for maintaining ecosystem service provision.

minor

mastery ← → harmony

major

ACCELERATION

This is the story of how our **ingenuity and ambition supports unprecedented prosperity at a great price to our environment**. The major force shaping the Snohomish Basin over the last 50 years is an accelerating economic boom. The rapidly urbanizing region is home to an expanding population of citizens who appreciates outdoor recreational opportunities, but are more concerned with maintaining human quality of life than the integrity of natural environments in their own right. The impacts of climate change are relatively minor, but farming and forestry decline as resource lands are claimed or degraded by urbanization.

SMALL

This is the story of how a **local environmental ethic adapts to a long-term economic recession**. Over time, as investment capital is drained from the basin, the reins of power shift, from industry leaders to new actors characterized by community-scale sustainability ethics. In 2060, rates of job growth and development are low but stable, shifting away from decades of environmental pressures towards modest improvements in biodiversity and ecosystem health. Leaders are drawn to small farms and reduced consumption, but challenged with past legacies of environmental damage, tight budgets and an inability to coalesce around larger regional issues.

RESISTANCE

This is the story of how **extreme climate challenges is countered by powerful human actions**. Initially, a series of disastrous floods result in major public investments into stronger armaments, redevelopment and economic renewal. A goal-centric approach focuses on immediate human security inadvertently leading to ecological and economic instability and social disparities. In 2060, the basin's landscape is characterized by highly degraded resource lands and increasingly expensive technological infrastructure to maintain service provision. The basin supports two distinct communities, the rich and the poor, with radically divergent neighborhoods, access to resources, and overall welfare

METAMORPHOSIS

This is the story of how we **embrace change through experimentation and upfront investments.** While climate changes break records and urbanization continues to pressure natural systems, society responds with greater flexibility, diversity, and integration. Each new challenge is transformed into a learning opportunity, using long-term accountability and a historical context to guide decision-making. Mandated individual sacrifices are significant, with greater investments of time, money and knowledge needed to invest and variable successes. However, when zooming out from the household or business to the Region and from the now to future generations, the benefits are evident.

Figure ES.6 The Four Scenarios

Project Lessons

This report is oriented towards policy makers and planners. Project lessons are translated to reflect policy implications and future research arenas. Project lessons are broadly grouped into six areas of support that: 1) shift the focus to **Resilience** to consider the irreducible complexity and uncertainty of the system; 2) Redefine the **Decision Context** to expose multiple perspectives and shifting power domains; 3) support a blueprint for an **Integrated Predictive Model** to test the sensitivity of system components to expanded boundary conditions; 4) **Highlight Risks and Opportunities** that support a more creative and inclusive policy formation; 5) **Illuminate Warning Signals** to increase our anticipatory capacity and flexibility and 6) **Identify Robust Strategies** that are effective across divergent yet plausible future conditions.

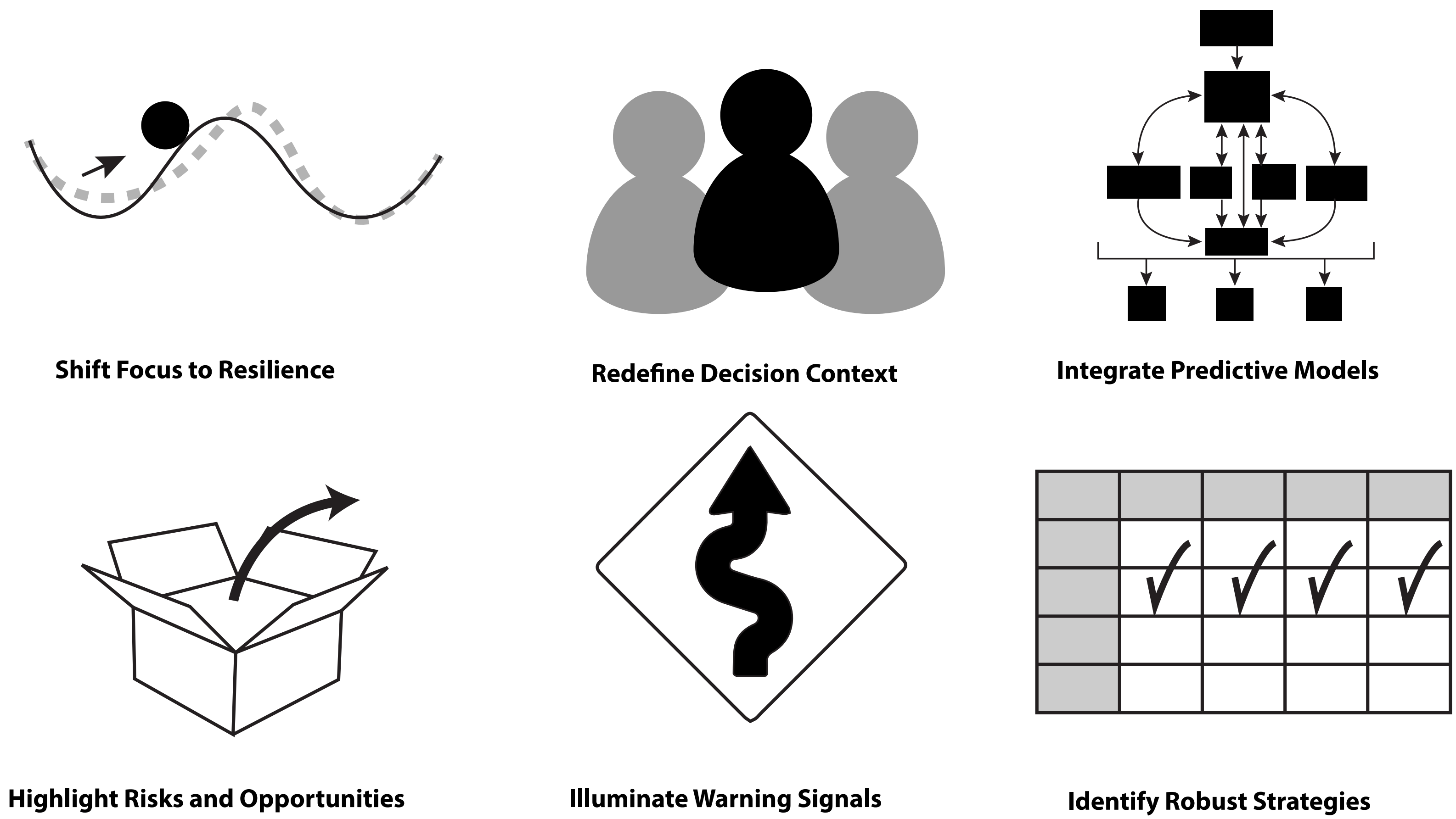


Figure ES.7: Project Lessons

CHAPTER 1 INTRODUCTION

1.1 Problem Definition

Ecosystem services reflect the multitude of benefits that are supplied by natural ecosystems. Examples include provisioning services (food, water, fiber); regulatory functions such as water and carbon cycling; cultural benefits including aesthetics, and recreational and spiritual values; and supporting services such as nutrient cycling and soil formation[4]. The Snohomish Basin provides many ecosystem services. According to a recent Earth Economics report the basin currently provides between $383.1 million and $5.2 billion in benefits every year including flood protection, water supply, climate regulation, fisheries, food production, critical habitat and waste treatment [5]. In this report we focus specifically on 6 broad groups of ecosystem services: water quality, water quantity, carbon stocks, carbon fluxes, habitat provision and species diversity. While current decisions about job growth, transportation infrastructure, new schools, agricultural production and trailhead protection do not have ecosystem service provision as their focus, the long-term health of the basin is inseparable from these investment decisions. Decision makers need to be able to assess the implications of alternative actions on these shared resources in order to protect them effectively. However, the Snohomish Basin is characteristic of a coupled human natural system in which changes by one set of agents, whether a developer (human system) or a stand of trees (natural system), influence the benefits of the other. Predicting the future condition of ecosystem services in this type of system is very difficult due to the complexity of network interactions.

Over the next decade, public decisions by basin actors will become increasingly encumbered by the number of affected parties, the information available and required to support decision-making, and both the complexity and uncertainty of interactions among important variables shaping the future. An example is today's critical decision facing the basin known as the 'Farm-Fish debate', a struggle to find ways to simultaneously support productive farms and maintain salmon viability in the basin's lowlands [6]. The challenge is to incorporate the needs and knowledge of the Tulalip Tribes, the farming community, ecologists, planners, businesses and residents. To address this challenge, decision-makers need to take into account the future implications of upland development, food security, climate change, and loss of cultural heritage associated with the interaction between multiple drivers of change [6]. This decision is emblematic of the types of complex multi-actor resource decisions that will challenge the basin's decision-makers in the future.

Decision-makers are faced with allocating limited resources while resolving conflicting interests and coordinating with jurisdictions that increasingly overlap over resource management [7]. Critical decisions are delayed in the effort to support extensive and controversial cost-benefit analyses, and due to disagreements regarding the assessment criteria. Meanwhile, critical decisions are suspended, incur paralyzing additional costs, and exhaust the time and interest of assigned committees. The Snohomish Basin Scenarios[3] provide an alternative approach for decision-makers to move forward despite irreducible uncertainty, and to make more informed decisions by integrating the uncertainty into the decision-making process.

1.2 Project goal + critical decisions

The objective of the Snohomish Basin Scenarios project is to support critical decision-making. Critical decisions are actions with pervasive long-term implications. In the context of this project, these decisions specifically focus on the investment of time, resource and money by actors with implications for the basin's ability to maintain *ecosystem service provision*. Three objectives frame the project's approach and products:

- Identify critical **factors** driving the future urban growth and associated environmental change in the basin.

- Systematically assess the impacts of future scenarios on essential **ecosystem services** focusing on *biodiversity*, *water*, and *carbon*.

- Collaborate between a diversity of **experts** and stakeholders to identify opportunities and develop a set of robust strategies to maintain human and ecosystem wellbeing under alternative futures.

CHAPTER 2: SCENARIOS FOR THE SNOHOMISH BASIN

2.1 What has driven change in the Snohomish Basin over the last fifty years?

The last fifty years in the Snohomish Basin were marked by unprecedented urban growth; 550,000 [8] additional people, living in 210,000 [9] households, developing an estimated 40,000[4] [10] acres of urban land and over 20 [11] times the total income of a half century earlier. Global socio-political, technological and ecological events have shaped the world around the basin during the last fifty years. From the end of Apartheid to the end of the Cold War, civil rights and international relationships have evolved in transformative ways. From the first man on the moon to Web 2.0, access to information has infiltrated every corner of the world. From Silent Spring to Chernobyl, to the tsunami of 2011, the environmental movement has altered how society perceives the natural environment. Through these global events, the basin has held a front seat, from the revolution of computers to the establishment of Microsoft headquarters, from the environmental movement to the listing of the spotted owl and the Chinook salmon. The first step in the scenario process involved closely examining the historical factors that have shaped the current basin conditions through interviews with the Science Team. While several variables have shaped the basin today, three recurrent stories emerged.

The Computer Age: How innovation influenced industry and everything around it.

Over the past fifty years, industry jobs have shifted from factories, farms, and construction to desk jobs. The basin lost acres of dairy farms and active timber to aerospace manufacturing and Microsoft. Today, basin residents are six times more likely to be working in the service industry than in resource extraction (e.g. farming, forestry, and manufacturing) [12]. As the service sector grew, factories, mills – and the infrastructure to support industries – were replaced with office buildings and stores [13]. The City of Smokestacks became the all American City [14], and the demographics of the basin changed alongside it. Computers altered the approach for conducting businesses, from picking lettuce to accessing health records [13,15], As computers entered every business and household, people's access to information changed. Today's opportunities and challenges, from technological security threats to networking and social media, were inconceivable for the average basin resident in 1960.

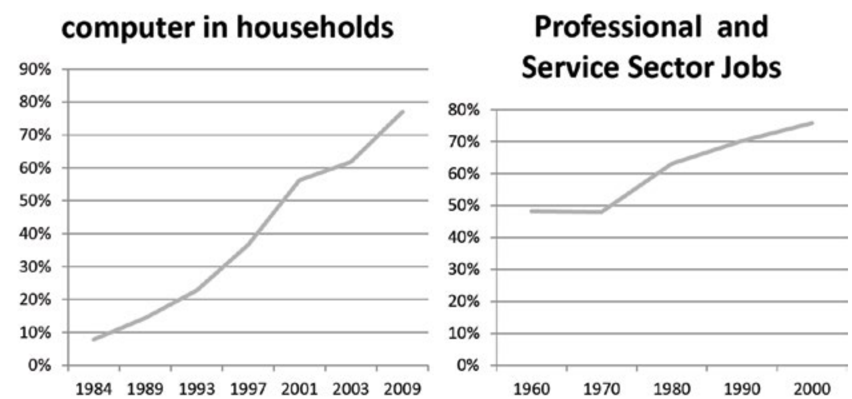


Figure 2.1 The Computer Age Trends

Social and Environmental Equity: How human impact on society and the environment changed the role of government.

Silent Spring and the establishment of the U.S. Environmental Protection Agency marked a new era of assessing human impacts on the environment, and of greater awareness about the limitations of our natural resources, once perceived as inexhaustible [16]. The basin is home to unique and sensitive species such as the spotted owl and Chinook salmon, which have significantly influenced the region's[5] economic base and development regulations over the past few decades [17]. Simultaneously, national and global social values have emerged: civil rights have expanded, more women have moved into the workforce, and Native Americans have received greater protection [18,19]. As a greater percentage of the population became endowed with rights, their participation in, and access to public decision-making grew too, significantly expanding the complexity of the decision-making process.

Timeline of Social and Environmental Equity Events

1962 Carson publishes Silent Spring
1964 Civil Rights Act passed
1964 Wilderness Act enacted
1970 EPA established / Earth day celebrated
1972 DDT is banned
1973 Endangered Species Act
1973 Abortion legalized in US
1974 Boldt decision reaffirmed
1976 No-tilage Agriculture popularized
1978 The American Indian Religious Freedom Act passed
1979 Tulalip revives First Salmon ceremony
1985 Ozone Hole discovered
1988 IPCC established
1990 Native American Graves Protection and Repartriation Act passed
1991 Apartheid Laws repealed in South Africa
1992 Official end of Cold War
1993 'Don't ask don't tell' policy implemented
2012 WA legalizes same sex marriange

Figure 2.2 Social and Environmental Equity Trends

Urban Neighbors: How changing demographics changed living standards and expectations.

The average basin resident today has an income more than ten times that of his 1969 counterpart [11]. He is 20% more likely to be African American, Hispanic or Asian and 50% more likely to have a college education [20]. Higher household income, ethnic diversity and educational attainment is characteristic of urbanization patterns. Urbanization changes happened very quickly, with urban populations nearly doubling between 1980 and 1990 [21]. According to the US Census, 86% of the basin's population was living in urban areas in 2000, compared with only 40% in 1960 [21]. These households are more likely to commute more than 10 miles to work outside the basin [22], to live in a house larger than 2,000 [23] square feet, and to spend over $5,000 a year on entertainment [24]. These new urban neighbors have grown to expect urban amenities from their small towns, dramatically shifting municipality budgets. These expectations extend across fence lines to their rural neighbors, imposing restrictions on working lands, from access to open space to the ways operations are conducted (e.g. delivery times, clearcuts, and pesticide applications) [17,25].

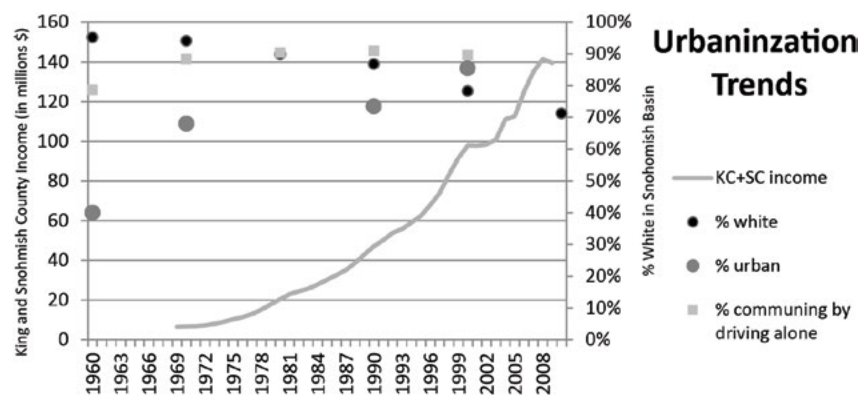


Figure 2.3 Urban Neighbor Trends

2.2 What drivers will be influential in shaping the next 50 years in the basin?

The rich legacy of the basin's past will, in many ways, influence its future. The Puget Sound will continue to attract in-migration for its myriad growth opportunities, supporting additional urbanization with more jobs, more development, and increased demand on supporting infrastructure [26]. In parallel, the population will continue to age and become more ethnically diverse, especially in its Hispanic and Asian communities [27]. Globally, technological innovation will accelerate, making technology ever more accessible and dominant in our lives [28]. Ecological challenges will also accelerate, as more people depend on increasingly stressed natural resources. Also certain will be the increasingly important role of climate change, as global temperature rise and extreme events threaten global communities.

Despite our knowledge of current trends, the trajectories of future change are largely unknown. The future will plausibly be shaped by surprise events, perhaps a volcanic eruption or massive forest fire. Perhaps an innovation will eliminate carbon emissions, or a new major employer will replace aerospace as the leading industry in the basin. However, much of the future's uncertainty will be shaped by the timing, magnitude and novel interactions of the trajectories of drivers influencing the basin today.

Global **climate change** impacts have already been observed in the region through recent fluctuations in several biophysical variables. Average temperatures have risen by 1°C per decade, snowpack has been melting earlier in the year, and indexes of extreme events have shown greater variability than historical trends [29].Over the next fifty years, the uncertainty of climate impacts, both globally and locally, includes the degree of warming, the variability of seasonal precipitation, the magnitude of sea level rise, and the pace of change overall. Further complicating model predictions are the complex relationships and feedback both between climatic variables and between those variables and the contextual landscape [30]. In the basin, critical uncertainties include the rate and extent of change in snowmelt and seasonal streamflow [30], groundwater recharge [31], and the resilience of forest [30] and salmon to additional stressors [32].

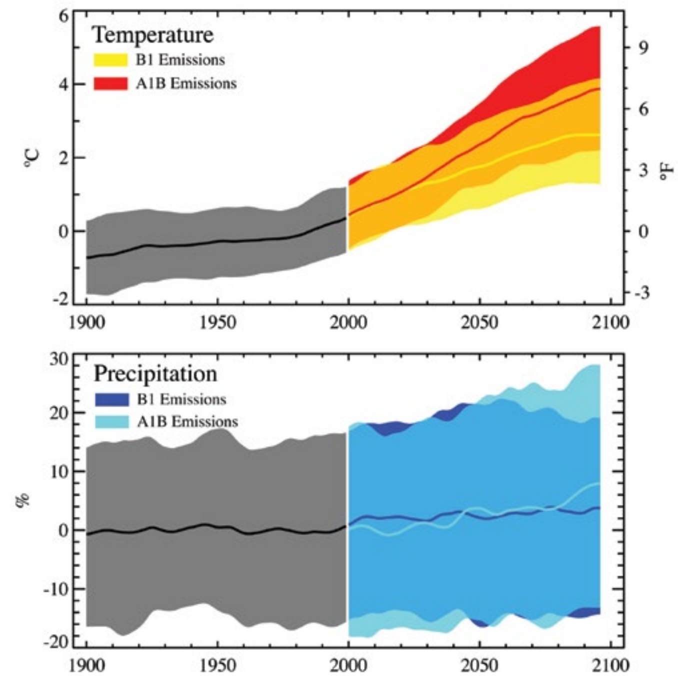


Figure 2.4 Regional Climate Forecasts

Simulated temperature change and percent precipitation change for the 20th and 21st century global climate model simulations for the Pacic Northwest. The black curve for each panel is the weighted average of all models during the 20th century. The colored curves are the weighted average of all models in that emissions scenario ("low" or B1, and "medium" or A1B) for the 21st century. The colored areas indicate the range (5th to 95th percentile) for each year in the 21st century. All changes are relative to 1970-1999 averages [30].

Economic forecasters [33,34,35] agree that service-sector jobs (from gas station attendants to software developers) will continue to dominate job growth. Meanwhile manufacturing and resource-based jobs (timber and farming) are forecasted to decline in the basin [36]. These trends are consistent with urbanization patterns seen across the globe. However, job trends are highly uncertain when we look out fifty years [37]. Future growth sectors are tied to fluxes in global markets (e.g. competition with China), governance (e.g. the strength and size of government and the cost of environmental regulations), innovations (e.g. the next 'Dreamliner' or 'Amazon'), and worldviews dictating social relationships to the natural environment (e.g. an organic Snoqualmie Valley or energy pellets as upland forestry practices). The variability of long term shifts is greater when we focus on regional and local scales. Economic sectors will shape demographic composition (age, education, diversity, values), changes in the built environment (location and type of development and resource lands), and implications for ecosystem health (e.g. forest conversion, pollution).

Future **population growth** is forecast based on rates of natural change (i.e. fertility and death) and migrations [37]. The basin's population is predicted to increase by an additional 210,000 [36] people by 2040; over 80% of them will reside in its western half [36]. How will that population choose to live, in terms of the footprint

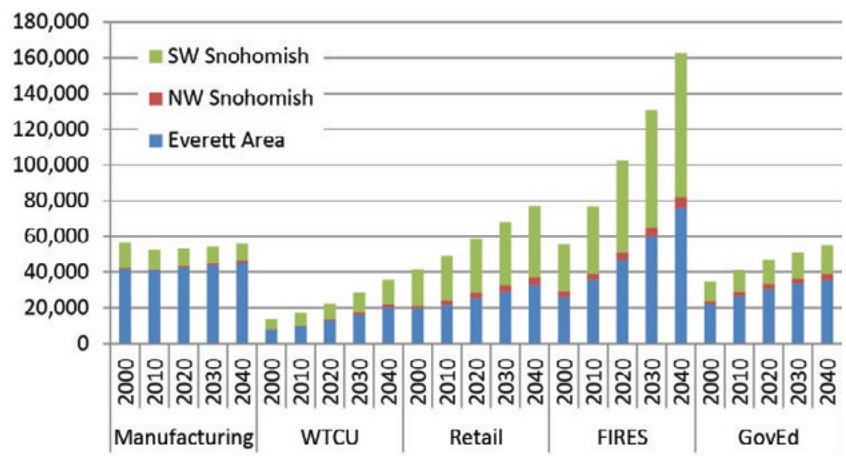


Figure 2.5 Job Forecasts by Sector

Between 2010 and 2040 the King and Snohomish Counties are forecasted to grow by an additional 520,000 jobs and 160,000 jobs, respectively. The majority of these jobs will be within the financial, professional, business and educational services sectors (FIRES). The Basin is forecasted to increase by an additional 150,000 jobs between 2010 and 2040, 57% of these additional jobs are forecasted for the FIRES sector. Manufacturing is modestly forecasted to grow by 2%. King and Snohomish Counties overall are forecasted to lose over 17,000 jobs [36].

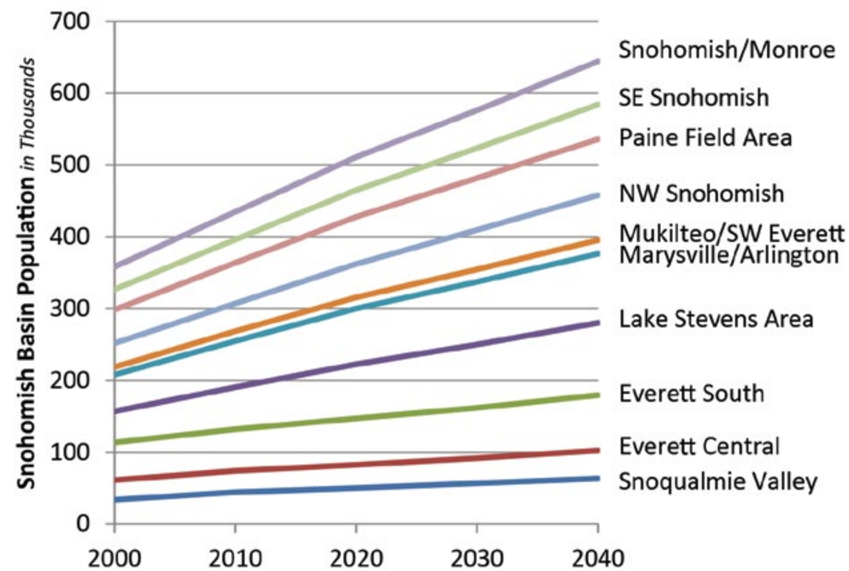


Figure 2.6 Demographic Forecasts

PSRC 2006 trends are based on declining rates of growth in both King and Snohomish Counties. While the growth rate was 9% in King and 21% in Snohomish County between 2000-2010, the rate is forecasted to decrease to 7.5% and 12%, respectively, between 2030-2040. If 2000-2040 trends were extended linearly to 2060, the Basin could be forecasted for an additional 350,000 people in the Basin (2010-2060) [36].

of their houses, the number of cars and commuting distances, the consumption of resources from water and energy to exports, and the types of policies they approve? All these changes will lead to cascading shifts in development patterns, infrastructure demands, resource management and governance structure.

Currently, over 66% of the basin is forested [38], and 25 percent of that forested land is protected from **development** as wilderness areas [39], conservation easements, parks [40], etc. The magnitude of population growth and of restrictions on development on undeveloped lands will largely determine the future land cover pattern in the basin. Based on past trajectories and land availability, urbanized areas are forecast to more than double by 2050, while agricultural lands, grasslands and lower elevation deciduous and mixed forests will be drastically reduced [38]. If growth pressures have been over-estimated and mechanisms for land protection (zoning, conservation, household preferences for higher densities) are under-estimated, urban development and the conversion of natural lands will be minimal. Alternatively, higher development pressures and looser protections may culminate in sprawling development, eliminating nearly all the unprotected natural lands over the next fifty years[6] [41].

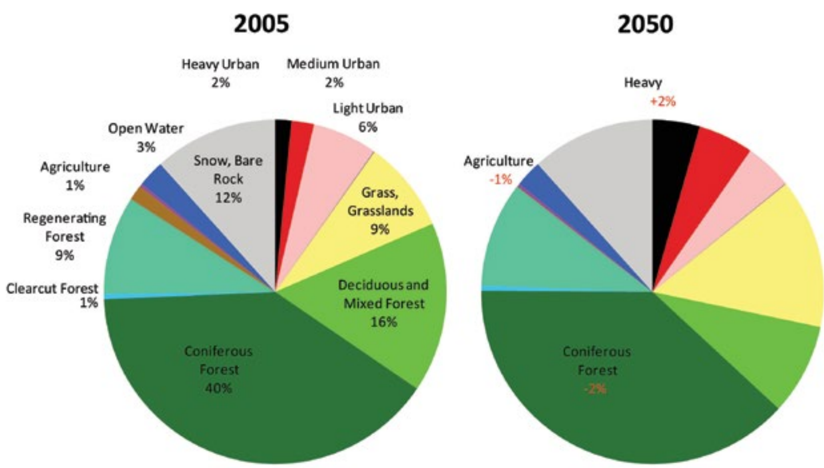


Figure 2.7 Land Cover Forecasts [38]

Future estimations for **energy and water provision** currently predict sufficient resources to support future urban growth, at least to 2050 [52]. Forecasts are based on assumptions about future demand

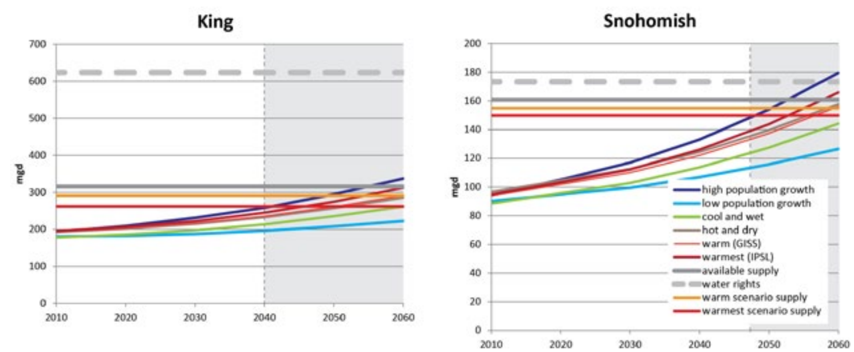


Figure 2.8 Water and Energy Provision Forecasts

Three sets of alternative demand scenarios were run by the Water Supply Forum. Population growth was forecasted using low population and high growth. The forecast also included a 2.5% below baseline and 3.5% above baseline employment growth. Weather Forecast utilized historic temperature and precipitation data to forecast alternative future weather parameters. The projected impacts of climate change utilized the A2 and B1 SRES emissions scenario. In addition to demand, supply was explored. The total amount of supply is dictated by water rights. Surface water supply is forecasted to change as a result from the expected seasonal shift in streamflow, with less runoff in late spring and early summer months, which have traditionally marked the reservoir refill period of the region's supply reservoirs. The above graphic does not represent new planned or proposed projects which will increase water supply in each County [1].

(population, industry growth), efficiencies (conservation and innovative technology, and supplies (current stocks and portfolio of new sources) [1]. Climate impacts will inevitably influence service provision in the basin; uncertain, however, are the magnitude of impact and the ability of utility providers to continue reliable service despite these challenges [1].

Over the next fifty years, the **health of ecosystem services** in the Snohomish Basin is predicted to deteriorate with increased urbanization, consumption, and climate changes. Salmon populations have been the center of attention for several decades, but their future fate is largely unknown [43]. Even if we manage to protect and restore estuaries and riparian habitat, reduce upland impervious development to slow down runoff, and improve fish passage through numerous culverts and dams, the future fate of salmon is highly uncertain [44]. Changes in the future viability of salmon have already been put into play by past legacies that we cannot reverse, from climate change to the clearing of old-growth forests and contamination of groundwater. Salmon are just one example of the many future challenges to protecting the basin's ecosystem services. Urbanization and climatic changes will influence the health of upland forests [1,17], of stream habitats and the nearshore environment, cascading implications to all of the basin's functions and species [45,18]. While highly dependent on shifts in social values and environmental regulations, great uncertainty lies in the resilience of our ecosystems, critical thresholds, and the role of system feedbacks.

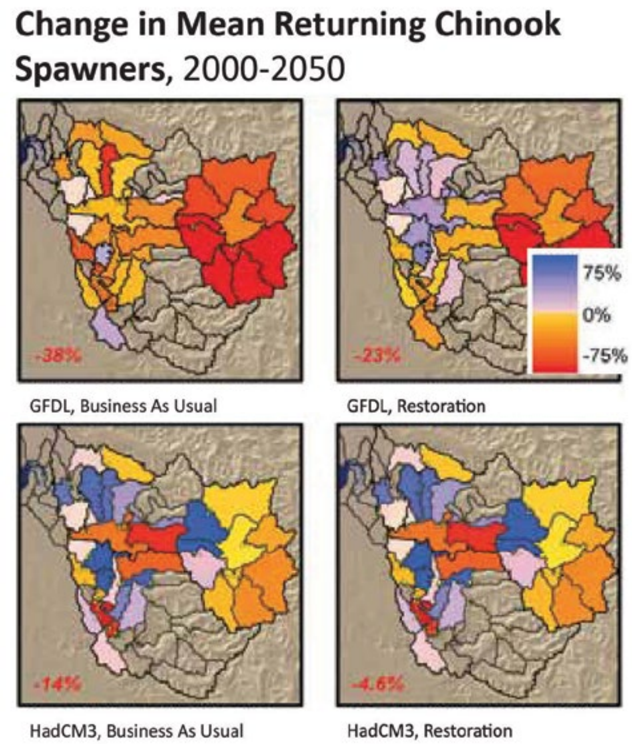


Figure 2.9 Salmon Viability Forecasts [44]

2.3 Scenario Comparison

The four scenarios look at the intersection of climate change and social values. In **acceleration**, minor climate changes and a mastery approach result in fast economic growth and urbanization, in **small**, minor climate change and a harmony approach succumb to an economic recession, a focus on conservation and a lack of regional coordination. In **resistance**, the basin experiences major hydrological shifts associated with climate change and reactions with engineered solutions and restricted viewpoints leading to social disparities and degraded ecosystem. Lastly, in **metamorphosis**, the region transforms itself responding to new challenges with flexible and accountable strategies.

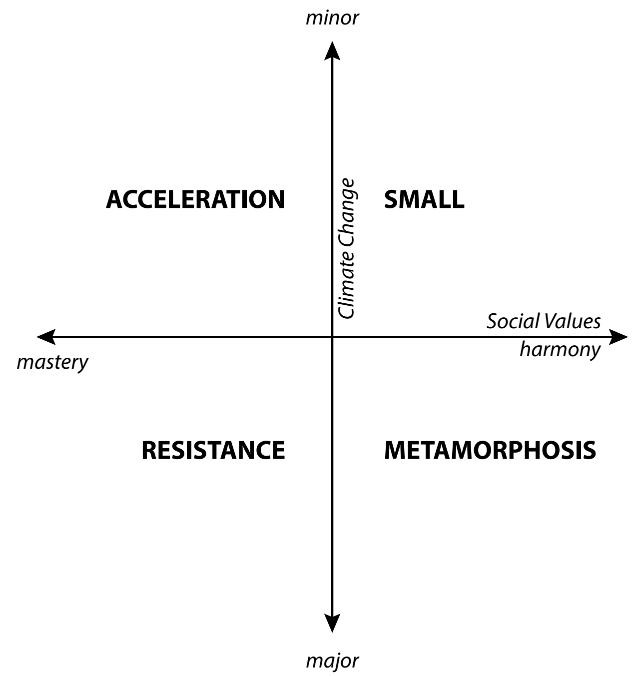


Table 2.1: Comparison of the Four Scenarios.

TREND	accelerate	small	resistance	metamorphosis
climate change	minor	minor	major	major
IPCC emissions scenarios	B1	B1	A1B	A1b
temperature magnitude	less than 1degC	less than 1degC	more than 3degC	more than 3degC
precipitation variability	historic seasonal	historic seasonal	major, extreme events	major, extreme events
snowpack and streamflow	historical variability	historical variability	early and fast	early and fast
values	mastery	harmony	mastery	harmony
Society and Nature	Nature serves society.	Society is part of nature. Nature is fragile.	Society controls nature to reduce uncertainty.	Nature and society are inseparable, mutually interdependent.
worldviews [1]	Nature Flat	Nature Anarchic	Nature Balanced	Nature Evolving
social relationships[2]	ambition, competition	equity, responsibility	security, control	accepting, informed
governance	Increased privatization	More decision makers	Government for security	Proactive, integrated, flexibility
employment (rate; sector)	Fast; High Tech	Slow; Resource Industry	Unstable; Government and Services	Stable; Diverse
population (rate; characteristic)	Fast; Diverse	Slow; Aging	Unstable; Divergent	Moderate; Diverse
wealth (income; disparity gap)	High; Wide Gap	Low; Narrow Gap	Moderate; Widest Gap	Moderate; Narrower Gap
investments	high; infrastructure	minimal; social	high; reactive	high; ecosystem
development	extensive	rural, clustered	sprawled	urban, planned
infrastructure	innovative, regional	retrofit, site-level, sharing	engineered, traditional	prioritizing natural processes, flexible
resource management	high intensity, high commodity, hobby	sustainable; family; working; volunteer	largely gone; flooded and sold	low-yields (reduced rotations), conserved
ecosystem pressures	intense use; extraction	death of a thousand cuts	cc; fragmentation	cc; novel
strategic approach	high yield, high control; innovative; market-based	site-level; risk-averse; low-tech; ecofriendly	quantitative; blunt; short-term benefits	accountability; resilience; coordination
ecosystem condition	heavily degraded. substituted	local successes, regionally degraded	past or approaching thresholds	highly variable but functioning
actors	few, wealthy, private	many, advocacy groups	federal government; opposing	linked; public
opportunities	investment capital, innovation	low pressure, ethic	crises focus	integration; flexibility
challenges	growth pressure; impervious; market-focus	no money; lack of coordination	climate pressures; social disparity; rigid approach	climate pressures; process paralysis; high cost of living

[1] Based on Gunderson and Holling. 2002. Panarchy. Myths of Nature.

[2] Based on Schwartz.Schwartz, S.H. 1999. A Theory of Cultural Values and Some Implications for Work. Applied Psychology: An International Review. 48(1). p23-47

Hypotheses of Future Ecosystem Service Conditions

The Snohomish Basin supports a multitude of resources and services that are supplied by natural ecosystems for example clean drinking water, beautiful landscapes, fuel and fiber. These 'ecosystem services' are controlled by ecosystem functions for example water filtration or carbon sequestration. In general, 6 ecosystem service groups are explored within this project including water quality and quantity, habitat and species diversity and carbon fluxes and stocks. 'Appendix 4: Ecosystem Services: Hypotheses' describes each of the systems and their relationships to key driving forces. For example, the future condition of water quantity, as measured by in-stream flows (specifically the recurrence of critical low flows) is influenced by changed in the trajectories of withdrawals (controlled by demand and technology) climate change (timing of snowmelt) and urbanization patterns (both the extent and configuration of impervious surfaces). In conjunction with the Science Team we developed hypotheses for the future trajectories of the six ecosystem services under the 4 alternative scenarios. The following hypotheses are intended to reflect potential uncertainty around future conditions and important relationships to consider when exploring the use of integrated predictive model to forecast future changes.

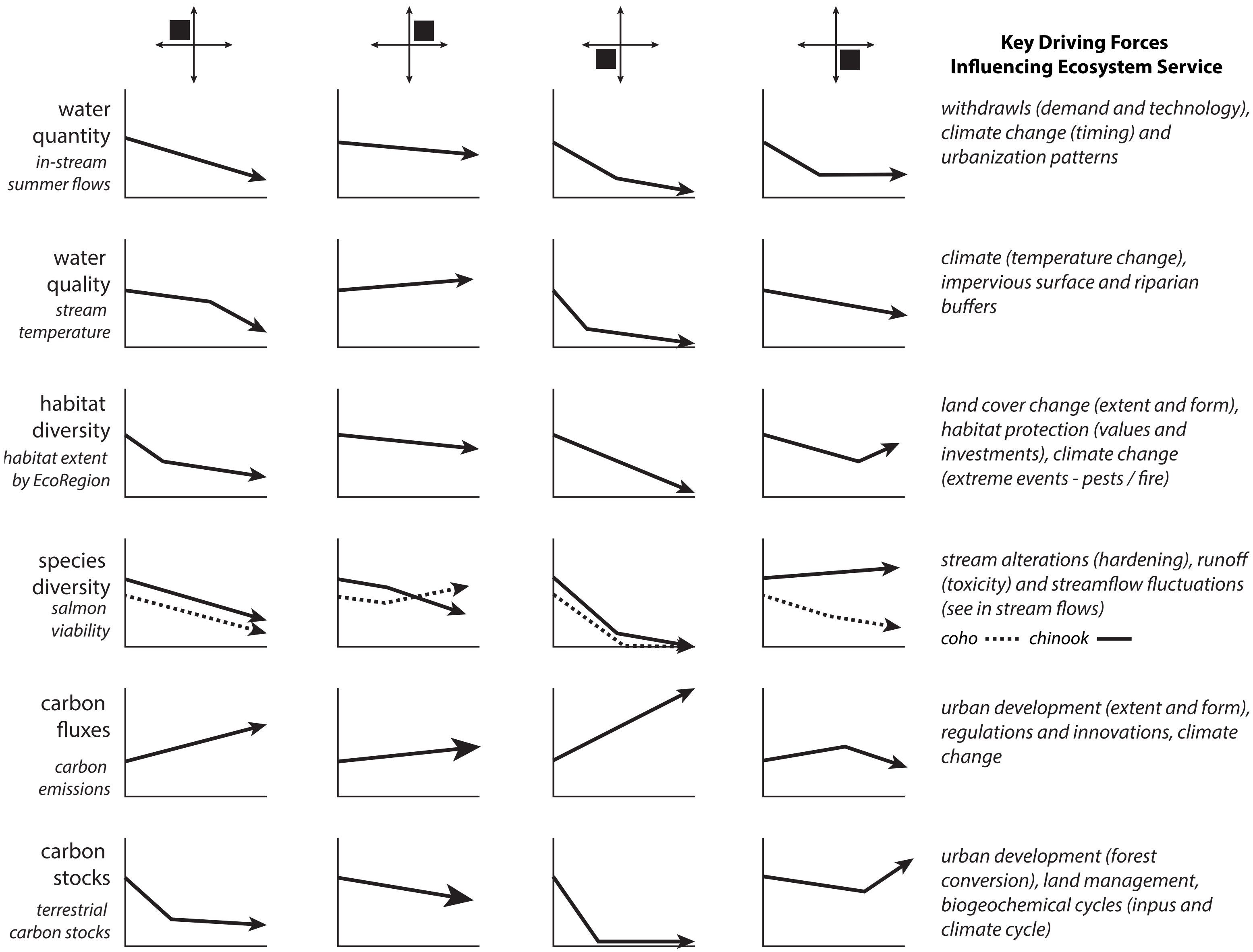


Figure 2.10 Hypotheses for Future Ecosystem Service Conditions

2.4 Acceleration

This is the story of how our ingenuity and ambition supports unprecedented prosperity at a great price to our environment.

Figure 2.11 Aerial of Accelerate, 2060

The major force shaping the Snohomish Basin over the last 50 years is an accelerating economic boom. The rapidly urbanizing region is home to an expanding population of citizens who appreciate outdoor recreational opportunities, but are more concerned with maintaining human quality of life than the integrity of natural environments in their own right. The impacts of climate change are relatively minor, but farming and forestry decline as resource lands are claimed or degraded by urbanization.

Despite nearly a decade of recession in the early 21st century, the Snohomish Basin rebounds quickly and strongly. Biotech and health services located along the I-5 corridor bring thousands of new jobs. The Providence Regional Medical Center breaks ground on a major expansion in 2035 to support the growing population of generation-Xers retiring to the basin. The Port of Everett surpasses both Seattle and Tacoma in cargo volume. Just outside North Bend, a new outdoor outfitter opened its headquarters and purchases five hundred acres as a private outdoor playground, with fee hunting, mountain biking, and ATV trails.

This economic growth makes the basin the most quickly urbanizing area in the state of Washington. Growth in housing and commercial development is accelerating both within and outside of urban centers. Cities like North Bend, Marysville, and Lake Stevens are increasing their growth boundaries to accommodate new development. Meanwhile, smaller communities like Gold Bar, Sultan, and Skykomish struggle to keep pace with the demand for increased government services. Households and businesses advocate for maintaining a high urban quality of life, characterized by reliable utilities, services for a growing aging population, better schools, and improved traffic conditions.

The region's increased wealth provides the opportunity to carry out several large-scale infrastructure projects. Tolls along I-5 and I-90 fund a wide breadth of transportation investments outlined in the Puget Sound Regional Council's 2040 plan. Increased water demands are met with additional aquifer withdrawals from the Getchell Plateau. New and restructured levees protect over 5,000 acres of lowland communities from flooding, while also providing space for a new 1000-acre recreation corridor with sports fields, bike trails, and wildlife viewing habitat.

Basin cities are bigger while the county government has been largely eliminated, as surrounding lands are annexed. Private services support new urban development as small public agencies are poorly equipped to handle additional growth. Industry leaders are the key lobbyists in the political arena, pursuing streamlined permitting processes and scaling back redundant environmental oversight. These changes are in line with national political trends, which have resulted in the restructuring and elimination of many federal agencies including the EPA, FEMA, and BLM.

Agriculture and forestry are still present in the basin as hobby farms. International resource production is better suited to meet growing demands, as land prices and degraded environmental conditions do not support profits in the basin. Upland development results in more frequent winter flooding that carries heavily polluted water and sediments onto farm fields. However, while less land is in agricultural production, some farmers have successfully transitioned to greenhouse crops and vertical production methods, or migrated to fields at higher elevations.

Moderate climate change has occurred in the basin over the last half century. Temperatures have risen modestly, and snowmelt comes earlier, altering streamflow patterns. However, the majority of environmental change in the basin stems from urbanization. Global climate change is an engine of economic growth in the region, as basin leaders reach out to support rebuilding after natural disasters in Third World nations.

Rapid urbanization disrupted the ecological integrity of the Snohomish Basin, yet many important natural features are conserved for the health and enjoyment of the region's population. Residential communities along rivers and lakes support recovery efforts to treat and reclaim waters with innovative biotechnologies. While five out of the region's 12 wild salmon stocks have declined beyond hope of recovery, new sustainable hatcheries support the continued survival of pink salmon, steelheads, and cutthroat trout in the basin.

2.5 Small

This is the story of how a local environmental ethic adapts to a long-term economic recession.

Figure 2.12 Aerial of Small, 2060

Over time, as investment capital is drained from the basin, the reins of power shift, from industry leaders to new actors characterized by community-scale sustainability ethics. Rates of job growth and development are low but stable, shifting away from decades of environmental pressures towards modest improvements in biodiversity and ecosystem health. Leaders are drawn to small farms and reduced consumption, but challenged with past legacies of environmental damage, tight budgets and an inability to coalesce around larger regional issues.

The economy of the Puget Sound region is a shadow of the booming industry before the Great Recession. Boeing has shut its Paine Field operations and global competition has resulted in out-sourcing and relocation of many high-skilled and manufacturing jobs. The rate of new business formation is high, especially in the non-profit and human service sector, but few businesses are expanding and surviving over the long term. Over 15% of the basin is retired, but the younger generations face unemployment rates around 10%.

A young, highly educated, but underemployed population is seated at the decision-making table. This diverse group, brought up on progressive social values and highly accessible technology, has transformed the basin's social and political landscape. Grassroots organizations support new informal communities oriented around neighborhoods and shared interests. Though their approaches are varied, these organizations tend to focus on protecting a fragile natural environment and on risk aversion. The values of competition and personal advancement that were prevalent around the turn of the 21st century are replaced by equity, responsibility, public and environmental health, family values, and leisure.

There is little recent development in the Snohomish Basin. Most of the new buildings are multiple-family structures within the urban center. Average household size is stable after over fifty years of continuous decline, as lower household incomes force young adults to move in with extended family and friends. A renewed "back to the land" movement and the rising cost of urban living fuel migrations into the basin's resource lands. However, despite the popularity of small rural farms, only a small percentage of the basin's population can afford this lifestyle.

The basin's population is adapted to make do with greatly reduced local government and household budgets. Approaches promote utilization of natural capital, efficiencies from greater accountability, and repairs rather than new purchases. Low-impact and low-investment development techniques that support 'off-grid' resources are popular, like cisterns for water and run-of-the-river shallow dams for community energy. Utilities and infrastructure agencies retrofit structures and abandon failing projects. For example, washed-out forest roads are removed and several aging levees are eliminated. Further, government incentive programs support small-scale local industry, alternative transportation modes and sustainable farming practices.

The effects of climate change, while minor, are highly apparent to a tenured population that lives close to the landscape. Higher average temperatures mean an expanded growing season, benefiting both agriculture and forestry. Conversely, earlier snowmelt translates into higher winter flows and lower summer flows in several watersheds, challenging resource management to handle more frequent seasonal floods and drought. However, in-stream flows are strictly regulated and managed, supporting adequate supplies for salmon and efficient irrigation technologies.

There is great enthusiasm over restoration projects, as moderate climate impacts and reduced development pressures relieve stressors on natural systems. Successful restoration efforts are benchmarked by miles of recovered streams, people volunteering, and hours of outreach. New farms are small and inspired by a humble deep ecology ethic. New foresters implement sustainable practices within their lands. Organizations such as the Washington Trails Association, Mountains to Sound Greenway, and the Mountaineers contribute thousands of volunteer hours to trail maintenance and noxious weed removal. The American Rivers and Wild Fish Conservancy support dozens of miles of restored creeks. The Tulalip tribes have expanded far beyond the reservation, collaborating on upland forest conservation easements, snowpack detention reservoirs, and estuary mitigation.

The Snohomish Basin's greatest environmental challenges are coordination and funding. Mounting criticism suggests that projects fail to scale up into a bigger picture. Restoration benefits to Chinook viability, for example, reflect the challenges of large regional investment, coordinating across thousands of adjacent parcels and diverse interest groups. The bottom-up approach characteristic of the basin's current culture is energetic, but lacks strong leadership and is overwhelmed by a sea of accessible information. Increasingly stressed agency budgets and great effort spent on 'the process' raises tensions between various interest groups, delaying critical decisions.

2.6 Resistance

This is the story of how extreme climate challenges are countered by powerful human actions.

Figure 2.13 Aerial of Resistance 2060

In 2020, a series of disastrous floods result in major public investments into stronger armaments, redevelopment and economic renewal. A goal-centric approach that is focused on immediate human security inadvertently leads to ecological and economic instability and social disparities. In 2060, the basin's landscape is characterized by highly degraded resource lands and increasingly expensive technological infrastructure to maintain service provision. The basin supports two distinct communities, the rich and the poor, with radical divergence in the quality of their neighborhoods, access to resources, and overall welfare.

In January 2018, the City of North Bend declared a Presidential Flood Disaster after an unprecedented 500-year flood covered 90% of the city and over 800 homes were inundated. Five more floods of similar severity occurred in the basin over the following decade. After each event, rebuilding of flood walls, homes, businesses, and damaged infrastructure provided economic stimulus. But with public funds diverted towards flood protection measures and emergency response programs, other priorities, from education to environmental services, suffered.

The combination of restricted waterways and rising temperatures has shifted hydrological systems beyond repair. In 2060, winter snowpack in both the Tolt and Sultan watersheds is 80% below 2010 levels. The South and North Forks of the Skykomish routinely suffer near-drought summer conditions, and higher winter flows that scour edge habitat. At low elevations, the combination of high water temperatures and pollution creates toxic conditions along urbanized stretches of rivers including the Pilchuck, Raging, and Tolt. Regional utility providers struggle to supply water and power to the Snohomish Basin's population. The Tolt and Spada Reservoirs are depleted by the summer of 2045 and 2048, respectively. Frequent power outages result from downed power lines during severe storms in the winter and hydroelectric shortages from low flows in the summer. Political turmoil over these failures leads to fast-tracking several projects with minimal environmental oversight. As the basin's ability to support energy and water through natural functions declines, the cost of service provision grows exponentially. Costs are passed on to utility customers, leading to growth outside service areas (wells, septics, wood fuel) and greater hardships for low-income households.

Given the intensity of the 'farm-fish debate' a half-century ago, it's hard to believe that now in 2060 both farm and fish are largely gone from the basin. Repeated cycles of flooding leave lowland fields contaminated, and the financial benefits of agriculture dwindle in the shadow of levee costs. As for fish, both Chinook salmon and bull trout are officially extinct in the basin. The flurry of flooding, redevelopment, and deregulation over recent decades leave little funding for restoration projects, and many streams are so degraded that little is left to save in any case. Some other wild fish stocks, while still present and monitored, are struggling to survive.

Each new tide of disasters and reconstruction ushers in a flow of jobs, followed by an inevitable out-migration. Jobs created in levee construction, housing development, road and wastewater repairs, and emergency services are often underpaid and unstable. Local governments respond to the demand for economic growth and employment stability with loosened regulations and streamlined permitting processes. Boeing remains a major employer, though it too follows a boom-and-bust cycle of job growth and massive layoffs. The Port of Everett shut its doors after over 135 years of business, unable to absorb the cost of constant repairs due to climate impacts and competition from global facilities.

Unstable economic and resource conditions drives a dividing wedge between the 'haves' and the 'have-nots.' Wealthy upland households are not afflicted by floods and shortages as their higher-elevation suburban homes are supported by private global services and elastic incomes. But members of lower-income groups, especially elderly households and migrant families concentrated in low-lying areas, are much more vulnerable. For these households, flood insurance payouts have fail to cover the cost of damages, especially as federal and regional funding is depleted after multiple disasters. Further, these groups are squeezed by unemployment and the rising cost of gas, food, health services, and utilities. The Tulalip tribes, after decades of struggling to implement proactive restoration and mitigation policies, succumb to a loss of clean reliable water and fish stocks. While they receive financial compensation, the tribes lost their tribal heritage and experienced strained relationships with their basin neighbors.

2.7 Metamorphosis

This is the story of how we embrace change through experimentation and upfront investments.

Figure 2.14 Aerial of Metamorphosis 2060

While climate changes break records and urbanization continues to pressure natural systems, society responds with greater flexibility, diversity, and integration. Each new challenge is transformed into a learning opportunity, using long-term accountability and a historical context to guide decision-making. Mandated individual sacrifices are significant, with greater investments of time, money and knowledge needed to invest and variable successes. However, when we zoom out from the household or business to the region and from the now to future generations, the benefits become evident.

Irrefutable ecological pressures support a new era of accountability. Climate change brings year after year of record-breaking events to the Snohomish Basin, from floods to heat waves to strong winds. Higher elevations lose the majority of their snowpack by early spring, leading to more frequent winter floods and declining summer flows. Stream temperatures rise, as do the levels of toxins and pollutants carried by urban streams. Salmon stocks decline and many fear the populations of these iconic fish will not rebound. Regional partnerships collaborate with academic institutions and private industries to establish a response network that can track and guide action.

Leadership and financial support empower public agencies to see new challenges as an opportunity to correct past errors. Land managers use the basin's historical geomorphology and land cover patterns as a guide to relocate and redesign patterns of development. In 2018, when a 500-year flood on the Snohomish River destroyed aging levees, new 'softer' levees were rebuilt, set back farther from the river channel with re-vegetated riparian buffers. This reduced the impacts of severe floods in subsequent decades. Meanwhile, agricultural incentive districts subsidize farms that promote sustainable practices by insuring harvests from flood damage (i.e. pay for flooded crops). Likewise, upland, private timber companies are paid to not harvest and are financially encouraged to seek alternative environmentally sustainable forest initiatives.

Expensive public investments are supported by stable economic prosperity and coupled with unprecedented political will. The Snohomish Basin is globally known as a great place to work and live, attracting additional growth. With its easy access to both healthy natural lands and thriving metropolitan centers, development pressure is intense, outpacing both Pierce and King Counties in job and population growth. As private industries prosper, their willingness to invest in regional infrastructure grows. As household wealth and quality of life increases, so too does the public's approval of costly long-term social and ecological investments.

Urbanization and technological innovation are paired to facilitate greater diversity and efficiencies. The Growth Management Act tightly funnels development into existing urban corridors, and cities like North Bend, Monroe, and Snohomish double in size. Increased density creates diverse neighborhoods with unique cultural, business, and natural amenities, and facilitates investments in public transit and efficient utility provision. In keeping with the Pacific Northwest's reputation as a high-tech hub, local governments in the basin collaborate on numerous highly successful innovations from green energy and intuitive water conservation measures, to purchasing local products. Several leading global innovation companies are headquartered right in the basin, from biotech to information technology.

Paradoxically, the basin's proactive investments and economic prosperity are one of its toughest challenges. The high cost of investments, from agricultural subsidies to the purchase of conservation lands, from cumbersome regulatory oversight to innovative regional infrastructure, from public provision of health to leading educational institutions, take a significant toll on industry and household budgets. Further, rising real estate costs and oil prices threaten to price out lower income groups and start-ups from the basin. Instead of reducing costs, municipalities respond with new development regulations, from minimum quotas for affordable housing to subsidies for incubator businesses, with the hope of supporting diversity. Over the years, social norms lead the public to embrace more equitable long-term investments, expanding the decision-making framework.

While novel conditions continue to challenge the basin, a flexible and integrated institutional framework supports a long-term resiliency. Despite inter-agency monitoring, alternative energy, and investments in social and natural capital - unprecedented changes continue. Politically, decision-makers are often paralyzed by complex factors, conflicting interests, a lack of certainty, and constricting tradeoffs. Both the size of government and the number and types of relationships with private industries, academia and advocacy group grow to support transparency and trust. Over time, economic burdens are boasted as redistributive and egalitarian. With each new hazard, the duration and intensity of emergencies is dampened by the flexibility, diversity and accountability of the basin's social and ecological institutions.

CHAPTER 3 METHODOLOGY

3.1 The Process

This scenarios report is the culmination of a 2-year research collaboration including several workshops and dozens of meetings and interviews. The timeline outlined in Table 3.1 describes the overall flow of the process. Each step is characterized by a specific meeting, a key organizing question or objective, the role of participating experts, and a specific product delivered. The process was not linear, but rather involved several iterations as we refined central questions and project deliverables. The process has been the collaborative effort of the Urban Ecology Research Lab at the University of Washington and over a hundred regional expert members. From this process four preliminary products were synthesized: driving forces, a shared conceptual model, scenario logics and an integrated model blueprint. These products were pulled together to create the final scenarios describing how the history of the basin may influence plausible alternative futures.

3.2 Project Committees

The project involved the input of many regional experts, including professionals from private industry, public agencies, the non-profit sectors and academia. Three committees were formed to support different aspects of the project. The full list of project members and their current affiliations and expertise can be found in Appendix 1.

The Snohomish Basin **Steering Committee** consists of fourteen representatives of basin municipalities and tribes, regional land holders and managers, agencies for economic growth and capital improvements, and environmental policy and advocacy groups. These partners were selected because they have direct influence over the strategic implementation of future actions in the basin. The Steering Committee met twice, once in the beginning of the project to identify project directives and once at the end of the project to provide feedback on the final report and directions for future integration of the work.

The **Science Team** included over a hundred representatives of various disciplines and backgrounds to direct research on driving forces and important relationships, as well as to ensure that the final scenarios were scientifically valid. Experts were selected based on a snow-ball technique, in order to incorporate a wide variety of perspectives. Representative fields included biological and physical science, economic forecasting, demographic and policy analysis, education and social services, real estate and development, infrastructure management, government at various scales, planning and design, innovation, restoration ecology, forestry, outdoor recreation, farming, hazard mitigation, and tribal leadership.

Science Team members supported the process at multiple levels, from participating in an online interview to attending multiple workshops and providing written feedback. Over the two-year timeline, three major workshops, two meetings, and dozens of focus groups and interviews provided opportunities for Science Team members to be involved in the process. Two subgroups of the Science Team, a Scenario Development Team and a Predictive Modeler Team, were formed to respond to two specific questions: What specific variables of values and climate change support the most relevant, divergent, plausible and compelling storylines? And How might we integrate current models to estimate future levels of ecosystem services that are sensitive to differences between the four scenarios?

The **Stakeholder Team** included representatives of twenty basin stakeholders that characterize major actors and various interests in the basin including the Tulalip tribes, aerospace industry, salmon conservation, farming, forestry, ecosystem assessment, recreation, county planning, and the non-profit stewardship and advocacy arena. At the end of the process, this group was invited to discuss the potential role of the Snohomish Basin Scenarios project in

Table 3.1: The Snohomish Basin 2-year research process

5.2010 Steering Committee Kickoff: *How can the process and products of this project best inform long-term strategic decision-making in the Basin?*

Fourteen regional decision makers representing municipalities, tribes, business interests, utilities, land managers and environmental organizations provided eight project directives.

8.2010 Interviews and Focus Group Meetings: *What shaped the past fifty years of the Basin? What will drive change in the Basin over the next fifty years?*

Seventy eight individual and focus group interviews with diverse academic and professional regional experts helped formulate the focal issue and identification of critical drivers.

11.2010 Conceptual Model Workshop: *How do we integrate diverse perspectives to build a shared story for long-term problem-solving for the Basin?*

Twenty nine science team members collaborated on a common language for a conceptual model relating drivers, actors, assessments and actions.

6.2011 Scenario Logics Workshop: *What are the two most important and uncertain drivers challenging our assumptions about the future?*

Science team members formulated alternative hypotheses for the Basin's future by exploring the trajectories of climate change and human values.

8.2011 Scenario Development Meeting: *What specific variables of values and climate change support the most relevant, divergent, plausible and compelling storylines?*

Ten science team members with disciplinary foci on climatology and social sciences refined the scenario logics to explore the magnitude and variability in future regional climate changes and the shift in social relationships to people and nature through mastery versus harmony values.

9.2011 Interviews with Predictive Modelers: *How does your model predict change?*

Eight regional predictive models were assessed in terms of their objective, approach, input and output and limitations.

11.2011 Integrated Model Workshop: *How might we integrate current models to estimate future levels of ecosystem services that are sensitive to differences between the four scenarios?*

Modelers developed a draft blueprint to explicitly link the inputs and outputs of eight predictive models forecasting future conditions in the Snohomish Basin.

1.2012 Scenario Tests: *How well is future variability described with these scenarios?*

Sixteen science team members provided detailed feedback on the draft scenarios, with specific recommendations on how to better represent the potential variability across the four scenarios with respect to their area of expertise.

2.2012 Policy Workshop: *How can we make better decisions?*

Representatives of eighteen Basin stakeholders identified ten questions to support more informed long-term critical decisions facing the Basin's uncertain future.

7.2012 Steering Committee Review: *How can we best leverage the work completed in this project?*

Feedback from Steering Committee on how to best represent project outcomes to decision makers and the public.

supporting more informed long-term critical decisions facing the basin's uncertain future. At the Policy workshop, the Stakeholder Team developed a set of questions that support a resilience framework through additional criteria for consideration by decision makers (see Section 4.1 Resilience Framework).

3.3 Preliminary Products

Four preliminary products were created to develop the final four scenarios. Each product was developed over several meetings, integrating feedback and revisions to better reflect the current state of knowledge and diverse perspectives. These four products are: the selection of driving forces shaping the basin's future, a shared conceptual model describing the relationships among driving forces, the scenario logics and storylines outlining key hypotheses about driver interactions, and a blueprint for integrating predictive models to forecast and assess the impact of the four scenarios on the basin's ecosystem services over the long term.

The final scenarios weave together these four products, bringing together the contextual stories from the initial expert narratives to the analytical frameworks of models and assessments.

Driving Forces

Driving forces are factors or phenomena that alter the future trajectory in significant ways. For example, population growth is a driving force that affects resource consumption and water quality. Driving forces are the main ingredients in scenario planning, helping planners bring together various trends to tell a coherent story of future change. Lingren and Bandhold described the important role of driving forces in 2003: "when we scan our environment we see events and can make general assumptions about what is happening. But events are just the visible tip of the iceberg. If we look below we will see what is driving those events, and only then can we understand how to change our behavior accordingly."[46]

In the summer of 2010 the project team identified an initial group of Science Team members and met with them to understand the various perspectives of regional experts on how the basin changed over the last fifty years, and thus how it might change over the next fifty years. Interviews and focus group meetings were conducted with seventy eight Science Team experts, representing over one hundred[7] agencies, departments and tribes. Over sixty hours of interviews were recorded and transcribed. Transcribed interviews notes were coded to identify major themes and potential driving forces. Fourteen drivers were synthesized, vetted and refined with the Science Team at the Conceptual Model Workshop (Figure 3.1). The driving forces were organized under four overarching categories of humans, institutions, built environments, and natural environments. Each driver takes into consideration multiple disciplines, the theoretical foundations, published literature and input on uncertainty with substantial implications for influencing future change. However, not everyone would agree with this selection of drivers, their definition or grouping. The final set of driving forces is a compromise, expanding beyond traditional criteria but not completely including all perspectives.

Shared Conceptual Model

The shared conceptual model[8] illustrates the relationships between the driving forces influencing the future of the Snohomish Basin. The objective of the shared conceptual model is to link the various conceptual models supported by different disciplines and perspectives to support a more inclusive view of the system. Further, the model highlights potential relationships between drivers and areas of agreement and disagreement.

The model is the product of both the individual and group interviews held during the summer of 2010 (see details under Driving Forces) and the Conceptual Model Workshop, held in November 2010. During interviews, Science Team members were asked to articulate a conceptual model that depicts how they see the Snohomish Basin's future (Figure 3.2). Interview notes were synthesized and shared as

HUMAN

Demography is the study of human populations including the size, structure and distribution of the population, and changes associated with birth, migration, aging and death.
Themes: Growth, characteristics, health

Behavior represents individual action including physical alterations, interactions (with people and the environment) and where we put our money (consumption and investment).
Themes: Adaptation, Consumption, Human-nature interaction, investments

Values are beliefs. They refer to the desirable goals guiding the selection or evaluation of actions, policies, people and events.
Themes: Belief, preference, perception

INSTITUTIONS

Economy refers to the production, distribution and consumption of goods and services. Economic growth is equated with profits, quantified by dollars earned.
Themes: Funding, industry, labor, market and wealth

Governance is the rules and rulers, and the various processes by which they are selected, defined and linked together.
Themes: Politics, planning and regulation and service provision

Knowledge represents the sum body of information (or facts) acquired by a population. For the purposes of this project knowledge is described in terms of the passage of knowledge through teaching or outreach, gaining new knowledge through research, science, or exploration, and innovation as the physical culmination of new ideas.
Themes: Innovation, science and outreach

Social institutions represent groups that share some mental concept of right and wrong. Institutions, by definition, are resistant to change and are there to support the current status.
Themes: Community, culture, tribes, the world, public engagement, organizations

BUILT ENVIRONMENT

Development describes the settlement pattern on the landscape and changes in land use and in land cover.
Themes: Character, form, land use, municipalities and real estate

Infrastructure refers to the technical structures that support a society, such as roads, water supply, sewers, electrical grids, and telecommunications lines.
Themes: Energy, flood mitigation, transportation, water provision and waste stream

Resource management refers to the management of materials or substances such as minerals, forests, water, and fertile land that occur in nature.
Themes: Agriculture, forestry, recreation

NATURAL ENVIRONMENT

Hydrology is the study of water, including the movement, distribution and quality of water (or water bodies).
Themes: Flooding, groundwater, streamflow, morphology, stormwater, water quality and water quantity

Climate change a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years.
Themes: Air quality, carbon, natural cycles, global change, ocean acidification, precipitation, sea level rise, snow pack, temperature

Ecosystems support life, encapsulating both organisms and their habitat.
Themes: Biodiversity, estuaries, fire, forest habitat, invasives and salmon and stream habitat

Biophysical Template focuses on the partitioning and cycling of chemical elements and compounds between the living and nonliving parts of an ecosystem.
Themes: Chemicals and nutrients, landscape movement, seismic, soils and minerals

Figure 3.1: Driving Forces

three alternative conceptual models, which were then elaborated on at the Conceptual Model Workshop (Figure 3.3). The final shared conceptual model (Figure 3.4) was then shared with the Science Team and refined through multiple follow-up conversations with the Science Team.

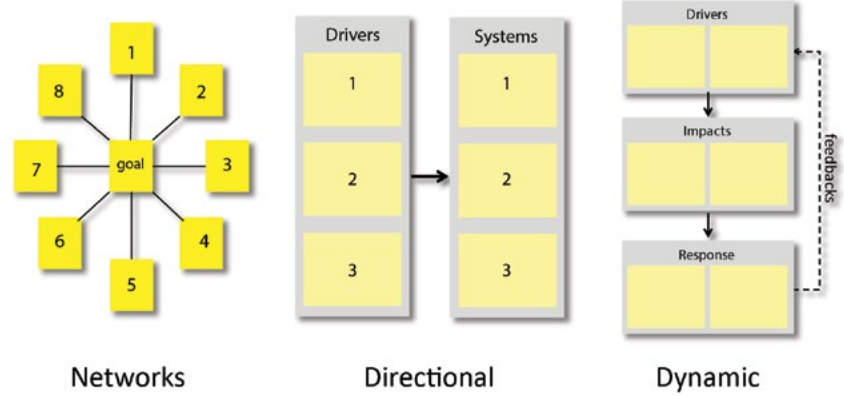


Figure 3.3 Overarching Conceptual Models

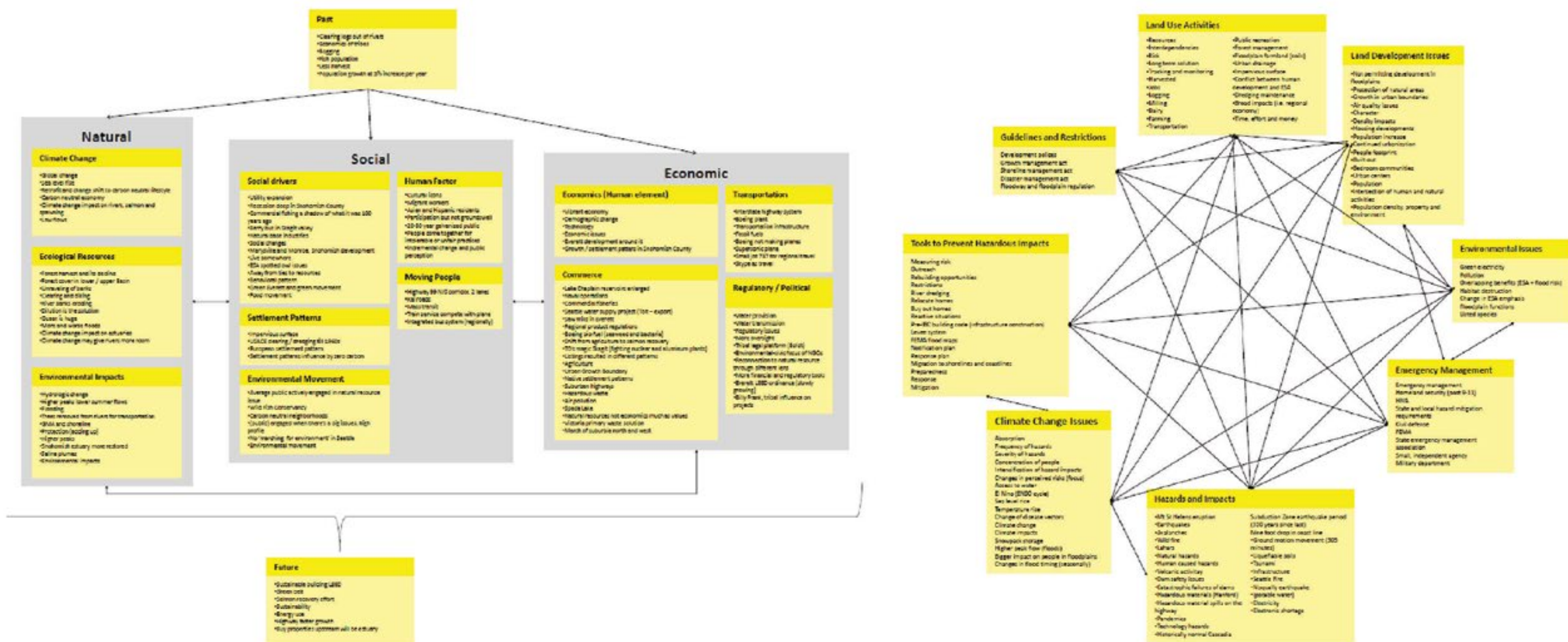


Figure 3.2 Example of Individual and Focus Team Conceptual Models

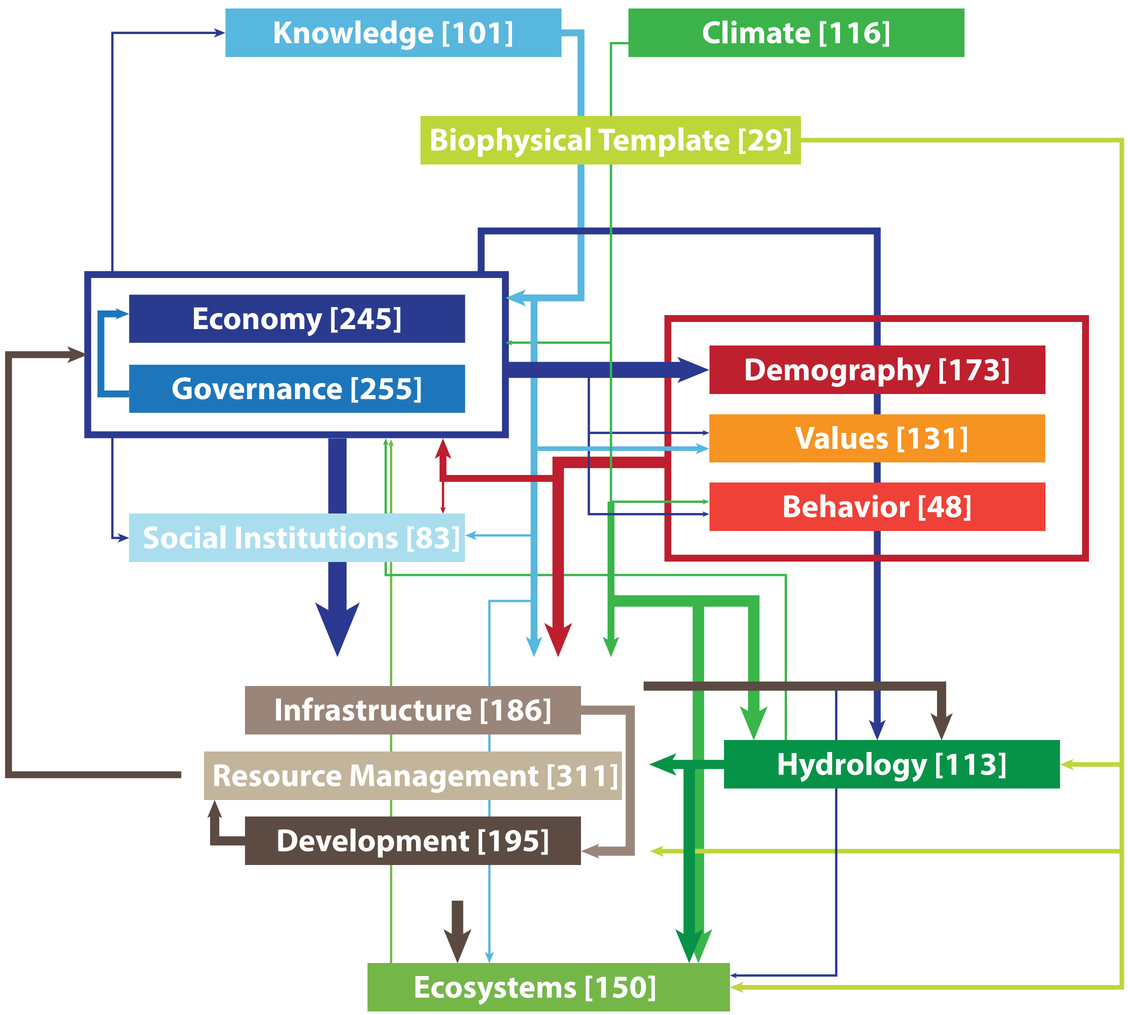


Figure 3.4 Shared Conceptual Model

The shared conceptual model illustrates a network map of described relationships between the 14 driving forces. In brackets is the number of comments made on each driver. The drivers are organized from top to bottom based on the ratio of comments about what they drive to how they are driven. For example, climate change was described as a driver of change, while ecosystems were largely described in terms of how they are influenced by other drivers. Arrow width and direction represents the relationships and feedbacks described between drivers based on the relative frequency of discussed relationships. Drivers with overlapping influences are grouped together in frames. For example, there is a tight feedback between demography, values and behavior that challenges the delineation of what is driving what.

Scenario Logics

The purpose of scenario logics is to select the two most important and uncertain drivers alongside their divergent trajectories in order to characterize the critical dimensions of the bounds of future reality. The resulting logics support a set of plausible and divergent future conditions against which decision makers can test the robustness of their strategies. There are infinite permutations of future conditions to potentially consider. Scenario logics suggest that drivers that are important and certain reflect the 'rules of the game', shaping the future in predictable ways. Meanwhile uncertain but less important drivers reflect distractions, changes that will surprise us but inevitably not shift future conditions. However, the interaction between the polar endpoints of the two most important and uncertain drivers direct decision-makers' "attention towards a handful of plausible alternative directions that contain the most relevant uncertainty dimensions."[46]

The Snohomish Basin scenario logics represent the interactions among alternative trajectories of climate change and social values, creating four alternative frames, translating into the four scenarios (Figure 3.5). The Scenario Development Team, a subgroup of the Science Team, subsequently refined the trajectories of each driver and described hypotheses for the interactions between each of the two endpoints. For climate change, the team selected the *magnitude of climate change and the variability of extreme events*. For social values, the team selected a *harmony versus mastery social disposition* regarding the relationship to society and nature. An initial hypothesis arose from each pairing. In terms of climate change, we looked at IPCC's A1B and B1 scenarios, as downscaled for the region. In terms of harmony vs. mastery we looked at Schwartz's definitions where mastery reflects an emphasis on controlling change or exploiting further interests, while harmony focuses on accepting the world as it is, trying to fit in rather than change it [47].

The Scenario Logics were developed over a series of meetings incorporating material from the Conceptual Model Workshop. At that workshop, Science Team members reviewed the working papers synthesized by the Urban Ecology Team describing definitions and past trends, and selected expert comments about the relevance and uncertainty of the set of fourteen driving forces. Workshop participants ranked the fourteen drivers in terms of their importance and uncertainty. Based on the two most highly ranked drivers, the participants, seated in teams, were asked to develop preliminary logics crossing two potential future trajectories for each axis. Participants had the opportunity to briefly 'play out' the hypothetical implications of their preliminary logics to assess if the outcomes were different enough from one another and relevant to exploring how to maintain ecosystem service provision. The great majority of workshop participants then voted on Climate Change and Social Values as the two critical uncertainties influencing the future of the basin.

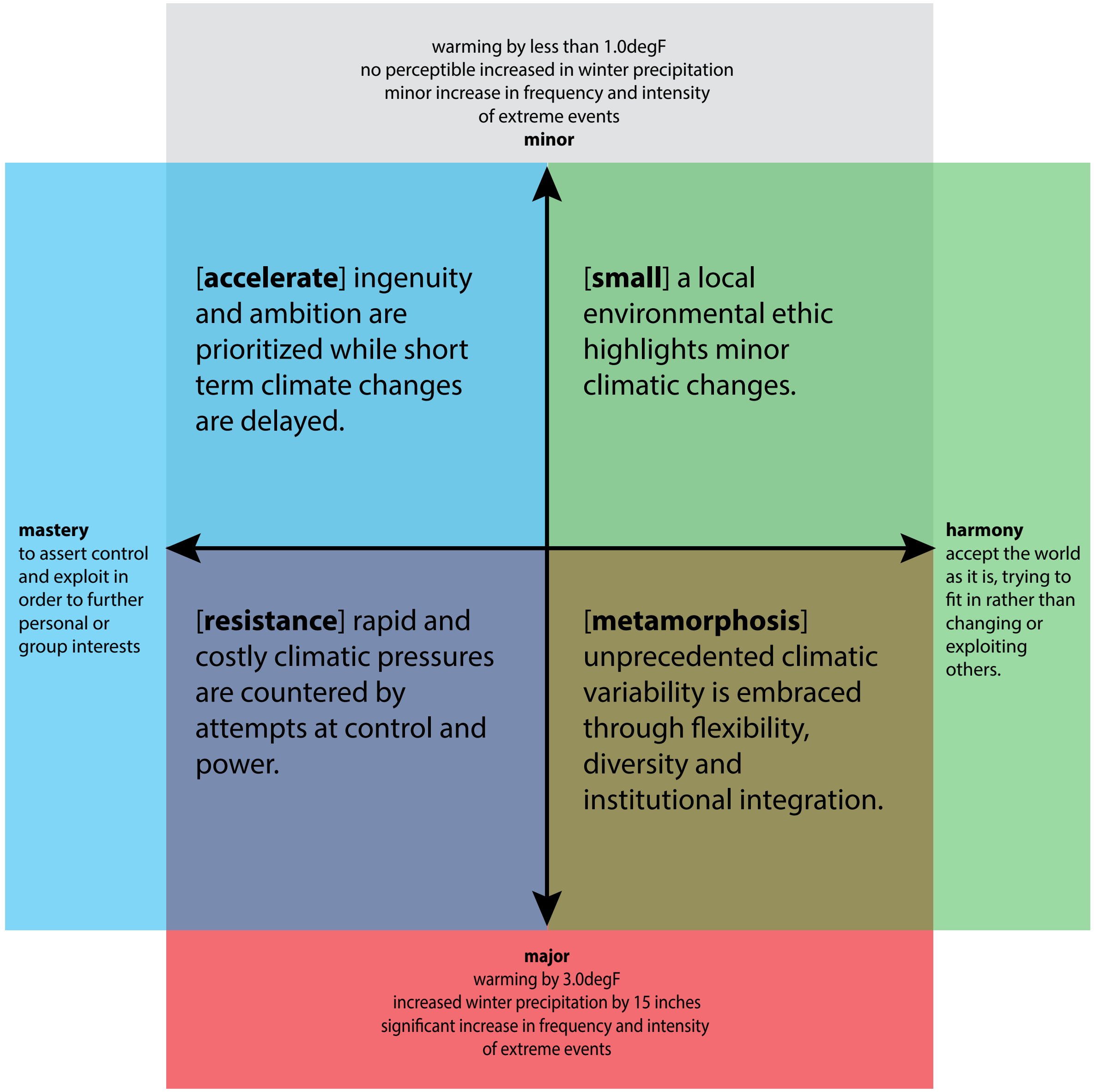


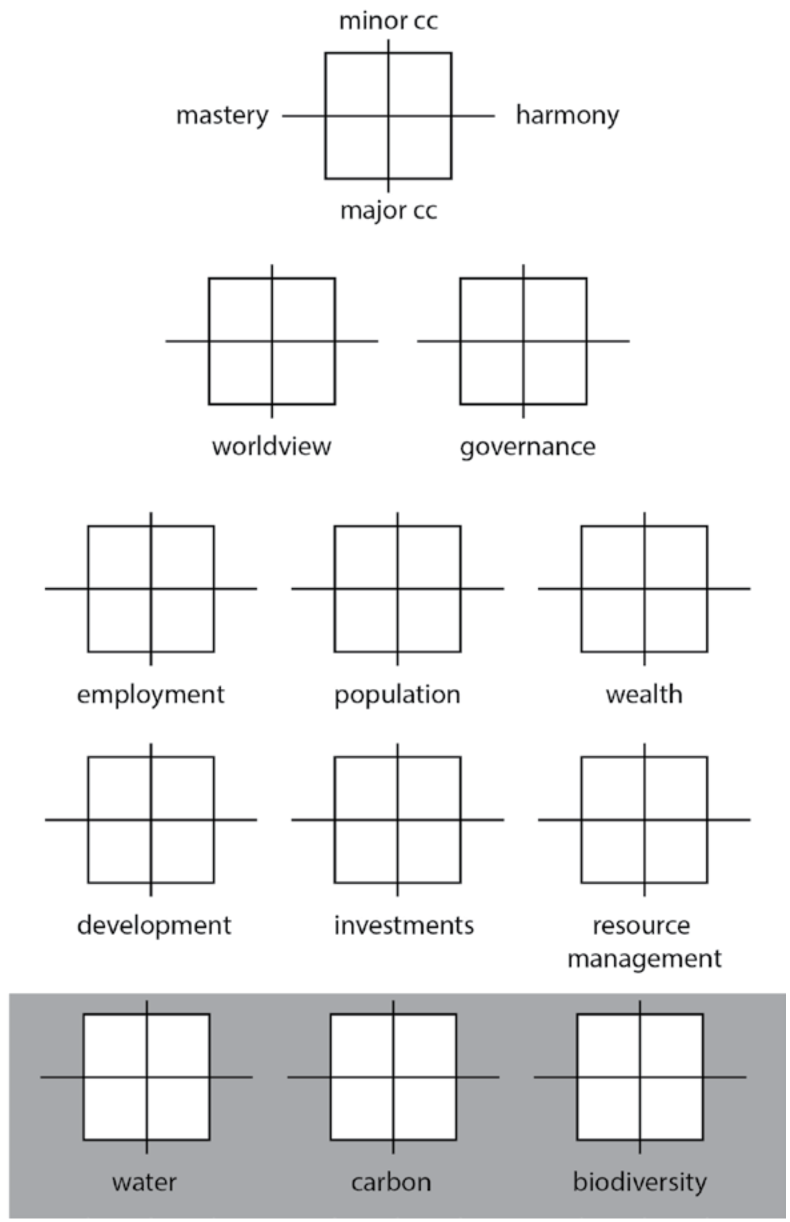
Figure 3.5 Scenario Logics

Storyline Comparison

A storyline refers to the narrative or plot described within each scenario. Once we had characterized the logics and divergent scenario hypotheses, we began to develop the scenario storylines. Each initial scenario hypothesis from the scenario logics was developed by incorporating alterative future trajectories of the remaining driving forces. The final scenarios and their respective storylines are the direct result of this integration. The process for identifying appropriate measures and logical trajectories for each driver involves several iterations of discussions with experts to identify important themes, collection of historical data to establish trends, and allocation of trajectories across the storylines to establish narratives that are internally consistent and compelling.

In order to elucidate the implications for the basin of the interactions between the two selected drivers and selected variables, we combined the divergent conceptualizations from the Science Team interviews, historical and forecast data on key trends of selected driving forces, and blueprints for integrating predictive models to assess ecosystem service conditions in the basin (see following section). The final storylines characterize the plot of each scenario by navigating the initial hypotheses through four overarching dimensions (Figure 3.6), including worldviews and governance, employment, demographics and wealth, changes to the built environment and changes toecosystem services. The four dimensions were arranged according to their correlated trajectories. Reflecting back to the Shared Conceptual Model, the dimensions were grouped together during the initial interviews.

The specific trajectories associated with each scenario can be found in Appendix 3 – Driving Forces Past and Future Trajectories. The forecasts are based on collected reports from regional agencies and conversation with Science Team members. Specific forecast products included OFM and PSRC's economic and demographic projections, land cover projections with LCCM, utility forecasts by PSE and Water Supply Forum, Climate Impact Groups State Assessment, downscaled hydrological modeling, slamm's and WashDOT sea level rise predictions and SHIRAZ's salmon model. Future baseline conditions for selected ecosystem services are hypothesized based on discussions with regional modelers exploring expanded boundary conditions of the scenarios with potential integrated predictive models. Initial ideas about future shifts are described in Appendix 4: Ecosystem Services: Hypotheses.



1. **Worldview and governance:** how values combine with climatic pressures to influence our interpretation of the world, the role of government, and the overall strategic approach.

2. **Employment, population and wealth:** the number and types of jobs, the growth and characteristic of the population, and the overall wealth and disparity in households.

3. Changes to the built environment: the shape and control over development, investment in infrastructure, and services and management of resource lands.

4. Changes to **ecosystem services**: implications for water quality and quantity, carbon stocks and fluxes, and the diversity of salmon and upland trees.

Figure 3.6 Storyline Comparison

Integrated Model Blueprint

The scenarios explore the uncertainty and relationships between critical driving forces that cannot be described by past events alone. The model integration phase of this project was pursued to complement the scenarios through two actions: 1) exploring potential relationships between systems represented by separate existent regional models, and 2) quantifying future baseline conditions associated with the alternative futures scenario hypotheses. Potential linkages between models can help us hypothesize a plausible range of future baseline conditions of ecosystem services. Based on each scenario's narrative, we can modify model assumptions and adjust model parameters. If the integrated model is sensitive to the differences between the scenarios, then the outcome (ecosystem service) will vary across the scenarios.

We conducted a series of personal interviews with regional model developers during the summer of 2011. We had three objectives for these interviews: 1) identify and summarize regional models in use (i.e. review their required input, spatial and temporal scale, assumptions and biases and results); 2) inventory the methods that have been used to address model uncertainty; and 3) explore suitability and methods for model integration.

Models were selected based on four criteria:

- They represent at least one of the 6 ecosystem service areas (species and habitat biodiversity, water quality and quantity and carbon storage and fluxes) or identified significant drivers of the outcome of interest (e.g.. land cover change).

- They have a high level of development (ideally have undergone a scientific peer review)

- They have been developed specifically for the study area (Snohomish Basin or Puget Sound lowland region).

- They have a flexible structure that can easily be (or already have been) integrated with output from others models. This was a high priority.

In November of 2011 we held an Integrated Model Workshop with 10 regional modelers to explore potential linkages between the selected models (Table 3.2). Modelers developed draft blueprints to integrate the models in order to assess future baseline ecosystem service conditions associated with the four alternative scenarios (Figure 3.7). The report of findings from the initial interviews (included as Appendix 2: Integrated Predictive Models) was intended as a reference for the modeling team to refer to as they explore model integration.

Major findings from that workshop represent both the importance of model linkages and critical gaps in current knowledge. Experts agreed that WRF (regional climate) and UrbanSim (urban development) represent overarching inputs (top level) while SHIRAZ and EcoPath represent overall outputs (bottom level). Hydrology models, LCCM (Landcover change) and Potential Vegetation Model had varied representation; however they generally incorporated the highest number of relationships, both as inputs into other models and as feedbacks. The Integrated Model would need to represent the differences across the four scenarios by varying the boundary conditions associated with dimensions of driving forces such as demography, economy, governance, and infrastructure. It was clear from the exercise outcomes that social dimensions including human values, behavior, governance and social institutions required substantially better proxies in three areas: 1) clearer definitions of what would be measured; 2) clearer representation of expected relationships to scenario logics; and 3) detailed information about what is quantitatively available.

Modelers were asked to hypothesize changes in future functioning of ecosystem services as represented by the outcome of an integrated model specified by indicators for water quality and quantity, carbon fluxes and storage and species and habitat diversity.

Table 3.2 Selected Predictive Models

Model	System Modeled	Related Driving Force or Ecosystem Service
UrbanSim	Land use	Development, economy, infrastructure
Land Cover Change Model (LCCM)	Land cover change	Habitat diversity, development
Weather Research Forecast Model (WRF)	Climate change	Climate change
Shiraz	Fish population model (Chinook)	Species diversity
Potential Vegetation Model	Vegetation	Habitat diversity
Hydrological Simulation Program – Fortran (HSPF)	Hydrology	Water quality and quantity
Distributed Hydrology-Soil-Vegetation Model (DHSVM)	Hydrology	Water quantity
Variable Infiltration Capacity Model (VIC)	Hydrology	Water quantity
Puget Sound Watershed Characterization Project	Hydrology	Water quantity
Ecopath with Ecosim	marine food web biomass dynamics	Species diversity, carbon
Atlantis	marine food web biomass dynamics	Species diversity, carbon

Modelers assessed selected variables in terms of their 1) availability, if they are 2) compelling, and 3) appropriate measures that have been 4) previously linked to predictive models. The response rate and agreement level (variance) between modelers reflects that the workshop included good representation of water quality and quantity expertise, but poor representation in the other measures, especially measurement of carbon fluxes and stocks (see Appendix 6: Workshop Materials and Syntheses).

While the actual development and testing of an integrated predictive model is far beyond the scope of this project, efforts are underway to implement this research venture.

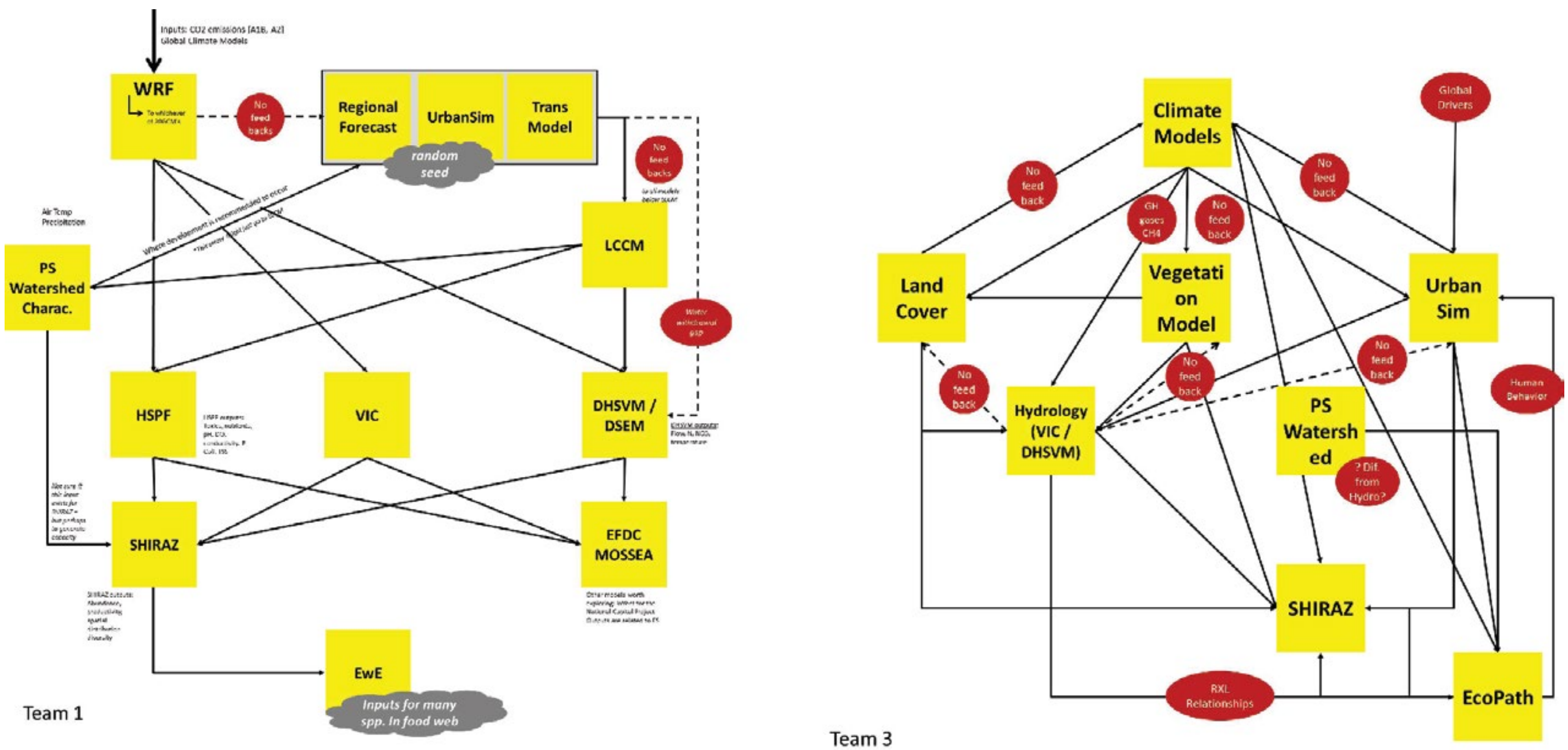


Figure 3.7 Examples of Draft Model Blueprints

CHAPTER 4: PROJECT LESSONS

In this chapter, we reflect on the lessons learned in the SBS project to articulate how scenarios can provide a systematic framework for making decisions under uncertainty. We explore six dimensions of decision support that: focus on resilience, redefine the decision framework, expand predictive models, highlight risks and opportunities, monitor early warning signals, and identify robust strategies.

4.1 A Resilience Focus

What is Resilience?

Resilience is defined as the capacity of a system to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes [48]. Disturbances are pressures, either natural or man-made, that influence the ability of the system to continue its functions. Fishing, development, heavy rainfall, sedimentation and pollution are all examples of disturbances. Resilience theory assumes that there are multiple alternative states; each state is governed by different interactions and feedback mechanisms that support system functions [48] Self-organizing mechanisms in different systems allow them to absorb internal and external disturbances, but if thresholds are exceeded, systems will be attracted to an alternative state which may lead to undesirable conditions and reduced function [49]. Further, reversing a state change may be very expensive or unattainable. The concept of resilience has been applied to both ecological [50] and human [51] systems separately. The concept has also been applied to socio-ecological systems (SES) coupling interactions and feedbacks between human and natural systems at multiple scales. These coupled systems are characteristic of urbanizing environments such as the Snohomish Basin.

What is the difference between resilience and traditional resource management?

Resilience shifts the attention of decision-makers from growth and efficiency to adaptation and flexibility [52]. The aim of resilience management and governance is to keep the system within a particular system regime (or state) that will continue to deliver desired ecosystem services. Resilience theory leans on four assumptions about the nature of SES: complexity, change, diversity and uncertainty. These are unique characteristics that may be overlooked in other frameworks.

Complexity: The assumption that human and natural systems cannot be studied in isolation, and that social and ecological variables are critical to understand system functions and their interactions and feedbacks at multiple time and spatial scales [51].

Change: Social ecological systems are dynamic at various scales. Ecological systems are characterized by natural variability, from water flow fluctuations to the sinusoidal relationship between predators and prey populations over time. Resilience theory is predicated on the assumption that change is an essential element of these coupled systems, and when we try to reduce or eliminate change we actually reduce the systems' resilience (ability to withstand new or additional pressure).

Diversity: The key to resilience is diversity, or heterogeneity. How diversity is classified depends on the system of interest and interacting variables. Diversity can refer to genetic or habitat diversity, to economic sector diversity, to the diversity of urban developments or institutional partnerships. Resilience theory assumes that no one species, form, strategy or condition is 'optimal.'

Rather, due to the systems' complexity and dynamic nature, redundancy and diversity provide opportunities for adaptation to change [52].

Uncertainty: While we may be able to reduce the uncertainty around future events and conditions of complex systems by expanding empirical studies and improving predictive models, we will never have complete knowledge. We therefore need approaches to decision making that are effective across multiple future conditions (i.e. robust strategies) and that improve our adaptive capacity and opportunities for self-organization.

Maintaining the resilience of the Snohomish Basin

In answering the question of how to maintain ecosystem services in the Snohomish Basin out to 2060, the concept of resilience was a major contender. However, while publications on the theoretical concept are widely available, specific guidelines to improve the resilience of the basin are lacking and often controversial. For example: would protecting floodplains for salmon habitat improve the basin's resilience? What if we consider the implications for lowland agricultural practices and their social and ecological functions? It is important to note the critical relationships between the resilience of the basin as a whole (a coupled dynamic system) and the resilience of specific basin subsystems, for example, the resilience of Tribal culture, or upland forest systems. At times, maintaining or enhancing the resilience of one sub-system comes at the cost of the resilience of another [53]. These constitute important tradeoffs that we may not be able to eliminate, but rather introduce as components of a needed negotiation between various basin stakeholders.

Developing the four scenarios was instrumental in understanding the sensitivity of the Snohomish Basin to a diversity of future changes.

The scenario planning process deliberately sought to understand the ***complexity*** of the Snohomish Basin by exploring interdisciplinary publications and the perspective of multiple and diverse regional experts. Specific activities included 1) developing multiple conceptual models that integrate social ecological system drivers at various scales; and 2) integrating multiple predictive models to specify important mechanisms and gaps in linkages between various system components (e.g. hydrology, land cover).

Past and plausible future ***change*** in the basin was described by tracking over 67 environmental and social variables historically and through predictive and conceptual (Appendix 3: Driving Forces Past and Future Trajectories). The Scenario narrative specifically explored change as associated with extreme climatic events and increased variability and magnitude as well as how change is perceived and managed through shifting social values.

Diversity within the Snohomish Basin was explored via three different approaches. The first is the diversity of knowledge domains, specifically developing the storylines not from the consensus or common perspectives between experts, but rather at the divergent endpoints of understandings. The second is the diversity of patterns; in addition to tracking growth rates we looked at the diversity of several variables including demography, economic sectors, land cover, development typologies, infrastructure approaches and species. The third is the assumption of reduced resilience and function; when hypothesizing the implications that each scenario had for ecosystem services we assumed that scenarios in which the diversity of landscapes, actors and approaches are reduced will see declining resilience.

Finally, we explored ***uncertainties*** as they stemmed from gaps in knowledge (e.g. markets for biofuels), statistical or modeling uncertainty (e.g. temperature increase will be between 1 and 4deg C), expert disagreement (e.g. the GMA is effective at curbing sprawl) and surprises – what we don't even know that we don't know. We investigated these gaps in knowledge through expert interviews and a review of published literature. We explored the statistical or modeling uncertainty through interviews with regional modelers and a review of model documents (Appendix 2: Predictive Models and Integration). We examined expert disagreement through interviews, development of multiple conceptual models, and collaborative workshops. Lastly, surprises were examined through the narrative development of the four scenarios and the exploration of national and global precedents for similar changes.

How can we apply a resilience framework to decision making in the Snohomish Basin?

Rather than creating a list of specific strategies that may enhance the resilience of specific subsystems, the Stakeholder Committee developed a set of questions for planners and decision makers to investigate whether an action or strategy may improve the resilience of the system as a whole (Figure 4.1). The set of questions is intended to serve as a starting point for regional agencies to develop protocols to ensure that the strategies they implement do not unintentionally reduce the system's resilience by attempting to eliminate or ignore its complexity, dynamic character, diversity or uncertainty.

Consider the National Environmental Policy Act (NEPA), an act established in 1970 requiring federal officials to consider environmental values alongside the technical and economic considerations that are inherent factors in federal decision making. Or at the state level, the SEPA (State Environmental Policy Act) which utilizes a "systematic, interdisciplinary approach to insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment;"[54] With over forty years of proposals and oversight, NEPA and SEPA standards have become the vernacular in environmental protection. However, there are no local, state or federal standards that *regulate* the potential of a decision to decrease the resilience of a system, or standards

Criteria for Resilience Framework

1. How does this strategy take into account the complexity of the system?
    a. Are both human and natural dynamics taken into consideration?
    b. Are variables and their interactions considered across multiple temporal and spatial scales?
2. Does this strategy attempt to limit change or variability in the system?
    a. What are the distributional effects of this reduction?
    b. How does this strategy improve our adaptive capacity, or ability to change?
3. How does the strategy improve on the current diversity of approaches?
    a. How does the strategy overlap existing actions and networks?
    b. How does this strategy reduce risks through redundancy and modularity?
4. How does this strategy take into account future uncertainty of key variables?
    a. How does this strategy create buffers for unanticipated changes or errors?
    b. How does this strategy incorporate diverse knowledge domains?

Figure 4.1 Criteria for Resilience Framework that provide *incentives* to make decisions that are more robust, or enhance an institution's capacity for learning. The criteria for Resilience Framework could amend regulatory programs to expand their efficacy in supporting a more resilient system.

4.2 Redefine the Decision Framework

What is a redefined decision framework?

A decision framework represents the intersection between values and the system condition that influences the selection of appropriate decisions in a given place and time. Over time, this framework changes, as actors with different values gain or lose power, as new conditions emerge reprioritizing our attention, as new knowledge expands our understanding of system conditions and functions, and innovations expose new opportunities. When assessing tradeoffs between alternative strategies, in complex and uncertain systems, decision makers should further consider potential shifts in decision frameworks over the lifespan of the strategy. Decisions that are more effective under a shifting decision framework are generally more *1) equitable, 2) flexible, 3) proactive, and 4) anticipatory.*

The removal of the Elwha Dam in 2011 is a regional example of a shifting decision framework. In 1910, Thomas Aldwell and the Olympic Power Company built a dam in the narrow gorge of the Elwha River valley on the Olympic Peninsula. While there was opposition at the time from the Elwha Tribe, as well as regulations restricting river alterations that prevent fish migration, those voices were largely overshadowed by a growing demand to bring industrial and economic growth to the area [65]. A century later, the power domain of both the tribes (in accordance with the Boldt Decision) and environmental advocates has grown significantly. We now have greater understanding of system dynamics and the cascading implications of preventing river flow, and that understanding extends to a broader segment of the population. Further, as urbanization trends regionally and globally have depressed salmon runs, watershed health and tribal culture, society is placing a significantly higher priority on protecting natural river systems. Lastly, innovations over the last century have created several more efficient alternatives for energy provision, making it easy to find substitutes elsewhere for the hydroelectric capacity of the Elwha dams. However, one of the most important elements that has not changed over the century is the extent of development in the basin lowlands. If the lowlands had been significantly urbanized, it would not have been politically feasible to release the upland lakes. After nearly two decades of debating and analyzing the watershed, the two dams were removed and salmon have already been observed returning to the headwaters [66].

While the Elwha example shows a decision that was overturned over a century later, there is a significant risk of current strategies being ineffective, or worse, harmful, within a much shorter time span given the accelerated rates of change pervasive in the current urbanizing culture. Might shifting demographics associated with an aging population or migrant workers shift service provision? Might our understanding of regional climate impacts lead to us to invest more heavily in hydroelectric technologies? Might frequent floods destroying property and infrastructure direct political pressure towards immediate and reactive policy?

A redefined decision framework in the Snohomish Basin

In November 2011, the Science Team met to discuss how to integrate alternative perspectives for conceptualizing ways to address long-term problem-solving in the basin. While each team came up with an alternative conceptual model to tell its story, every team shared one element of the story: the need to represent the decision framework linking between the 'system' and 'actors' through both 'actions' and 'assessments' (Figure 4.2). What came across as a very important piece of the puzzle was the need to articulate the diversity of basin actors and the unique lens through which they interpret the system (including both its current state and future trajectory) as well as what they deem to be appropriate actions to improve the system condition. These unique lenses stem from both the diversity of values and the team members' discipline backgrounds and experience.

Interviews with Science Team members helped identify the current diversity of basin actors and related actions and assessments; however the interviews further revealed how those relationships have changed over the basin's history, and how they may change in the future. For example, the ESA dramatically shifted the role and power dynamic of logging in the basin, and both the Boldt decision and the casinos have changed the role and power dynamic of the tribes in the basin. Today, Boeing is a major actor in the basin. However, if Boeing leaves who would take its seat at the table? Historically there have been tensions between farmers and salmon advocates, but innovative landscape practices might provide strategies that support both goals leading to new alliances.

In supporting decision making under irreducible future uncertainty, decision makers must incorporate tradeoffs associated with shifts in power domains (actors), problem conceptualization (information), political attention (priorities) and innovations (substitutable actions). In the Policy Workshop, held in June 2012, decision makers from around the basin described how potential shifts in the decision framework can be supported by more equitable, flexible, proactive and anticipatory strategies (Table 4.1).

Redefining the decision framework under four scenarios

The four scenarios intentionally explore divergent decision framework shifts under each of the four elements (actors, assessment, prioritization, actions; Table 4.2). For example, **Accelerate** tests a shifted power domain characterized by an unfair representation of a few industry leaders. **Metamorphosis** tests the potential implications of society adopting the concept of adaptive capacity. And **Resistance** tests the potential implications of reprioritizing restrictive flood control in response to frequent and severe flooding in the basin.

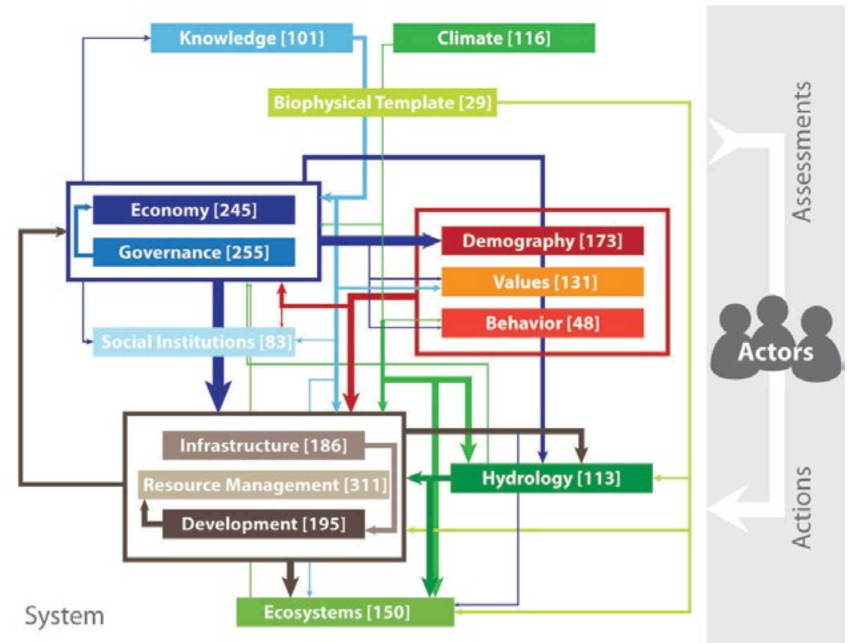


Figure 4.2 Decision Framework and Conceptual Model

Table 4.1 Questions, Goals and Strategic Evaluations for Redefined Decision Framework

Overarching Questions	Goal	Strategy Evaluations
1. How might the diversity and power domain of Basin **actors** change in the future?	**Equity**: reduce unfair burden / benefits to one group of actors over another	What are the distributional impacts of this strategy?
		How does this strategy interact with the diverse values and priorities of current Basin actors?
		If power domains shift in the Basin - would this strategy still be supported?
		Are any actors disproportionally harmed or benefiting from this action?
2. How might additional **information** change our understanding of the current problem?	**Flexible:** prioritize projects that can be redirected if our contemporary theories are wrong	How might the logic of this strategy be challenged under currently fringe theories?
		What are the major competing conceptual models for how the system works in relation to this strategy?
		what are the unintended consequences of this strategy?
		redirecting our efforts after implementing this strategy?
3. How might surprise critical events or conditions **reprioritize** our efforts?	**Proactive:** be weary of reactive strategies with long term impacts	Is this strategy concieved in response to or in anticipation of surprise events?
		What is the opportunity cost if in delaying the implementation of this strategy?
		What are the long term consequences of this strategy?
		How effective is this strategy against the full probability distribution of future events?
4. How might innovations change the suite and relative efficacy of potential **actions**?	**Anticipatory:** research potential substitutes and their comparitive long term costs	How does this strategy compare to current and future (potential) substitutes?
		How might the future conditions interact to raise the comparitive benefits of substitutes?
		What is the direction and rate of innovation in relation to this strategy and potential substitutes.

Table 4.2 Described Shifts in Future Actors, Actions and Assessments

	Accelerate	Small	Resistance	Metamorphosis
Actors	few, wealthy, private	federal government, opposing interests	many small advocacy groups	linked, public
Assessment	innovative, capacity, efficiency	personal, emergent, indeterminate	fixed goals	variability, complexity
Prioritization	Short term, individual benefits	precaution	safety, immediacy, status quo	flexibility, diversity
Actions	high yield, high control, innovative, market based.	site level, eco-friendly	quantitative, blunt methods	accountability, resilience, coordination

4.3 Integrated Predictive Models

The benefits and limitations of predictive models

A predictive model is a simplified representation of a phenomenon or process. Models usually take the form of a series of equations which represent the relationship between the model input and outcome variables reflecting the area of interest. Progress has been made in modeling the economic and social consequences of urbanization [55] and models representing natural systems (e.g., biogeochemical, ecological, hydrological, climate, etc.) are also becoming increasingly sophisticated [56,57]. However, the integration of socioeconomic and biophysical models is still at an early stage of development [58].

Predictive models that are designed to provide accurate assessments of future conditions can only account for some of the interactions between highly uncertain drivers of change and the surprising, but plausible, futures over the long term. Complexity and uncertainty emerge from scale mismatches (e.g. downscaling to model local processes), feedbacks between dynamic models, and potentially divergent future scenarios. Predictive models generate probabilities from observed dynamics and predict with a certain level of confidence the trajectory of each variable and mechanism taken individually, but we cannot predict unexpected interactions or tipping points, since the probability distribution of any interactions is unknown.

The integration of existent regional models allows us to represent the coupled human-natural system by exploring the interaction between urban dynamics and ecological processes. By linking operational models, we can expand the representation of relationships between subsystems and increase model realism.

Linking models and scenarios

In predictive modeling, the emphasis is on what we can predict using evidence from the past. Uncertainty is treated as 'lack of knowledge' to be reduced through sophisticated statistical approaches. Alternatively, scenarios focus on the 'untreatable uncertainty', future changes that diverge from past evidence. Based on the interactions of variable trajectories of multiple drivers, scenarios explore hypothetical boundary conditions that expand beyond the scope of predictive models. Scenarios therefore allow planners to assess how robust a set of strategies will be under alternative plausible futures.

Scenarios are extremely powerful when combined with predictive modeling. An integrated model can help in three ways: 1) test hypothesized trajectories and interactions; 2) refine potential relationships and feedback among variables; and 3) assess potential impacts of hypothesized futures on ecosystem services and human wellbeing. Scenarios are not an alternative to models but rather a complement to them, expanding the boundary conditions of predictive models and providing a systematic approach to deal with intractable uncertainties to assess alternative strategic actions. Based on scenarios, we can modify model assumptions. If the integrated model is sensitive to the differences among scenarios, then the assessment will provide information about tradeoffs. Scenarios can help model building by exploring gaps in variables and knowledge of mechanisms to assess future uncertain trajectories. While the scenarios tell the story of what the future could look like depending on the trajectories of important and uncertain driving forces, predictive models can use existing knowledge about known mechanisms to predict the future under the hypothesized conditions.

Building an integrated model for the region

There is increasing interest in integrating scenarios with new integrated models for the region to support a quantitative assessment of ecosystem services. A productive step in this direction would include linking operational models of urban development, climate, hydrology, land cover change, and ecological systems. The blueprint for an integrated model, created by the regional modelers in the Science Team for this project (see Chapter 3, Integrated Model Blueprint, pg 50), can effectively support a framework in this direction. Ten regional models simulating future ecosystem service conditions and driving force trends were selected for the integrated model. These are UrbanSim, Land Cover Change Model, WRF, DHSVM, VIC, HSPF, Shiraz, Ecosim with Ecopath, Pacific Northwest Vegetation Model and the Puget Sound Characterization Model. The integrated model blueprint illustrates how models can be joined in a way that is both sensitive to differences represented in the scenarios and capable of simulating future baseline ecosystem service conditions. While the actual development and testing of an integrated predictive model is far beyond the scope of this project, efforts are underway to implement this research venture.

Figure 4.3 represents a framework for linking urban development, climate, land cover, hydrological, and ecosystem dynamics developed at the UERL for the Central Puget Sound [59]. We model land use change through *UrbanSim*, which predicts the location behaviors of households, businesses, and developers, and consequent changes in land uses and physical development. UrbanSim interfaces with the *PSRC travel sub-model,* which predicts travel demand and forecasts. These are among the inputs required to predict the changes in land cover, hydrological and ecological impacts. *LCCM* allocates specific buildings and associated infrastructure to individual cells of high resolution (30m) to predict changes in hydrology and habitat conditions. *WRF* is a regional climate model (RCM) that uses global climate model output to downscale climate changes as input to the hydrological model (daily temperature and precipitation). The regional hydrology model *DHSVM* uses representations of surface characteristics (surface topography, soil characteristics, and vegetation and land cover) and predicted changes in regional climate data to simulate water and energy fluxes at and below the land surface and their impact on watershed conditions. Outputs from the *LCCM*, *DHSVM*, and *SHIRAZ* are proposed to assess impacts on watershed conditions measured through selected metrics of flow regime and fish productivity. Changes in watershed conditions would feed back on the choices of both households and business locations, and the availability of land and resources.

4.4 Highlighted Risks and Opportunities

The blindspots of traditional practices

We all have blind spots, not only when it comes to what we expect in the future, but also where we seek solutions. In many respects these blindspots are vital: they allow us to streamline our thinking and filter the complexity of our world towards a directed focus [61]. These blindspots get larger as we isolate ourselves within disciplinary silos and as we collaborate with like-minded individuals who reconfirm our biases. Researchers have shown that when reality returns conditions that are at odds with our biases or worldviews, we consider the conditions outliers [62] and modify our 'rules' to accommodate them. A classic example is the discovery of ozone depletion. The appearance of the hole was so unexpected that scientists didn't pay attention to what their instruments were telling them: They thought their instruments were malfunctioning. Exposing our blindspots can reveal both risks and opportunities in long-term planning. The scenario planning process is aimed at the 'aha moment' where potentially overlooked conditions are exposed [63].

How does scenario planning highlight risks and opportunities?

One of the fundamental objectives of scenario planning is to explore the interactions between multiple critical uncertainties supporting otherwise overlooked future conditions that expose our blindspots. Scenarios attempt to highlight risks and opportunities of plausible future conditions by doing three things: 1) integrating multiple disciplines; 2) looking at the divergent trajectories (as opposed to averages); and 3) weaving narratives that interplay between multiple driving forces to tell a compelling story. A common pitfall in developing scenarios is creating stories that are singularly 'bad' or 'good': a worst-case and a best-case scenario. Effective scenarios are messy, each entailing challenges that may be opportunities in disguise. Effective scenarios should reveal potential myths in current culture – about what is stable, what is a 'given' and where our values truly lie.

Investments and Stability in the Snohomish Basin

The four Snohomish Basin scenarios describe futures where economic, social and ecological drivers vary greatly, testing regional worldviews about what is appropriate and certain. While the scenarios show the interplay between dozens of specific expert perspectives, they largely manipulate four myths about future risks and opportunities:

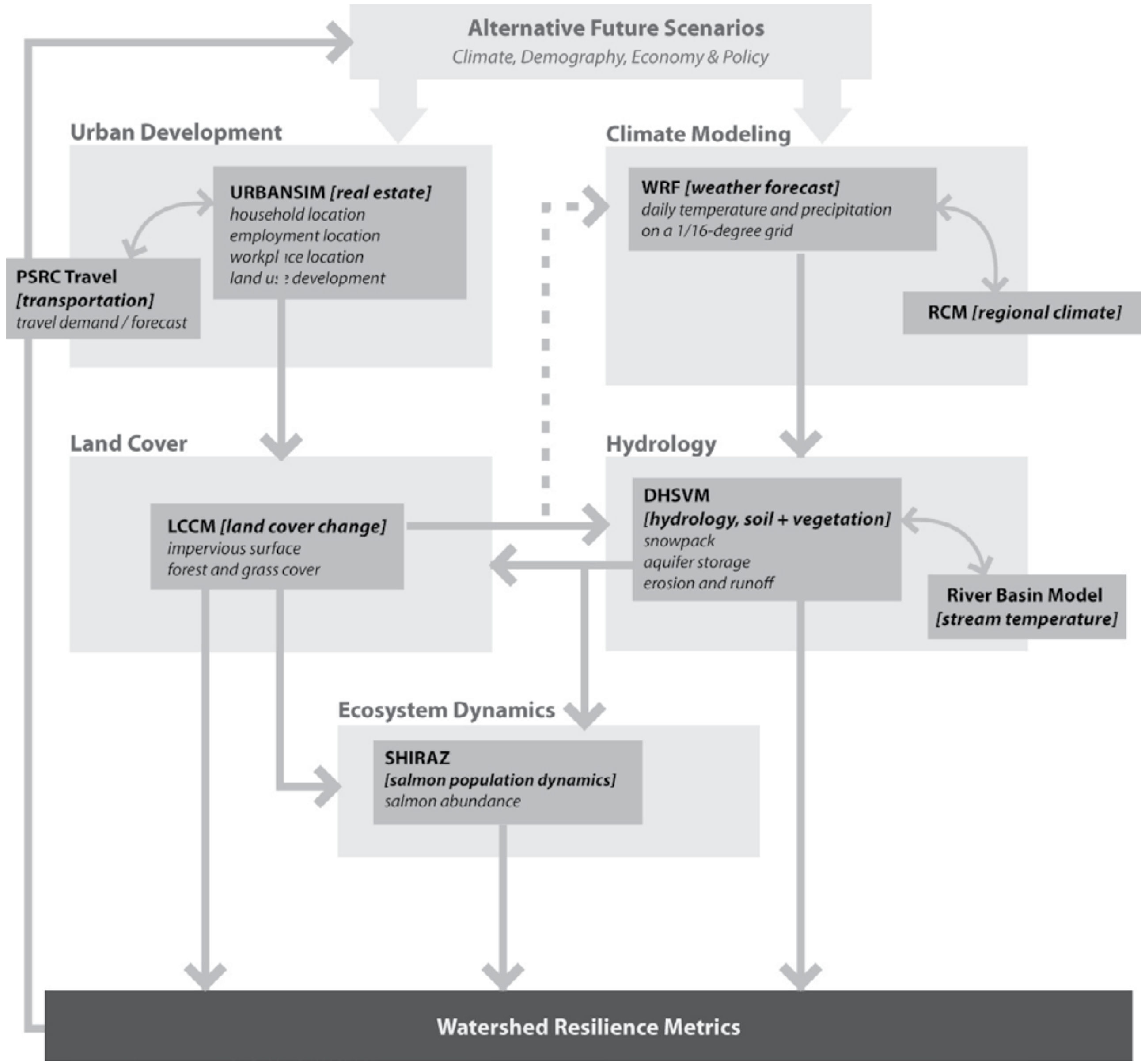


Figure 4.3 Regional Integrated Model Framework Example

- Economic growth will provide the investment dollars needed to support ecological protection.
- We can protect ourselves from future risks with stronger innovations.
- Diverse local and minimal interventions are necessary to understand and respond to environmental challenges.
- We need a dramatic event and strong leadership to fundamentally change our actions.

In some ways, these scenarios simply play the role of devil's advocate, testing the quality of alternative arguments about future conditions to identify weaknesses in their structure. Individuals hold contrasting views about the desirability of different paths towards sustainability; by considering the benefits and risks we can contribute to the dialogue among contrasting points of view [4]. Each of the myths noted above is only partially true and predicated on the linearity of other drivers – and this is of limited value in a complex coupled human natural system such as the Snohomish Basin. The four scenarios expose our assumptions about the basin's social, economic and environmental stability and the potential unintended cost of our investment strategies (Figure 4.4).

Accelerate initially shows some opportunities: significant investment in the basin from innovation and regional collaboration allow for long-term effective solutions. Meanwhile, climate impacts are minimal and the stability of the basin ecosystem appears intact. The risk in the Accelerate scenario is in our ability to counter growth pressure with larger and more effective innovations. Conversely, **Small** initially reflects how the lack of economic investment may support environmental protection. Here the surprise opportunity is in the way that economic depression may essentially 'force' us to care about the natural landscape. The risk in Small is that many environmental challenges require cross-boundary coordination and upfront investments that cannot be achieved without capital and on a site-level approach. In **Resistance** the risk is that optimizing protection at one scale (local) and towards a specific set of functions (e.g. flood protection) and actors (e.g. private and wealthy) can inadvertently reduce the overall resilience of the system. The opportunity in Resistance is perhaps the most hidden, and lies in what Holling terms 'release' or chance to start anew [64]. In **Metamorphosis** the support of experimentation and collaboration forms an obvious opportunity, but the risk that stems from abandoning the familiar looms heavily on the horizon.

Supporting a creative and inclusive policy formation

In developing the Snohomish Basin Scenarios hundreds of solutions were mentioned in early discussions with basin experts (Figure 4.5). However, we asked experts and decision-makers to suspend their judgments about how to solve the problem until the problem can be articulated fully. The scenarios redefine the problem to incorporate alternative perspectives and expose blind spots, with the assumption that diverse actors have different worldviews about what drives the system and what our priorities should be. Our untested hypothesis is that exposing designers and planners to multiple divergent scenarios supports a more creative process for imagining solutions. Further, by arguing against multiple and divergent commonly held myths about the future, we can include a more diverse constituency of participants than might otherwise feel comfortable engaging in the process. A next phase for the basin would therefore be to invite designers and planners to creatively develop strategies given the set of scenario narratives.

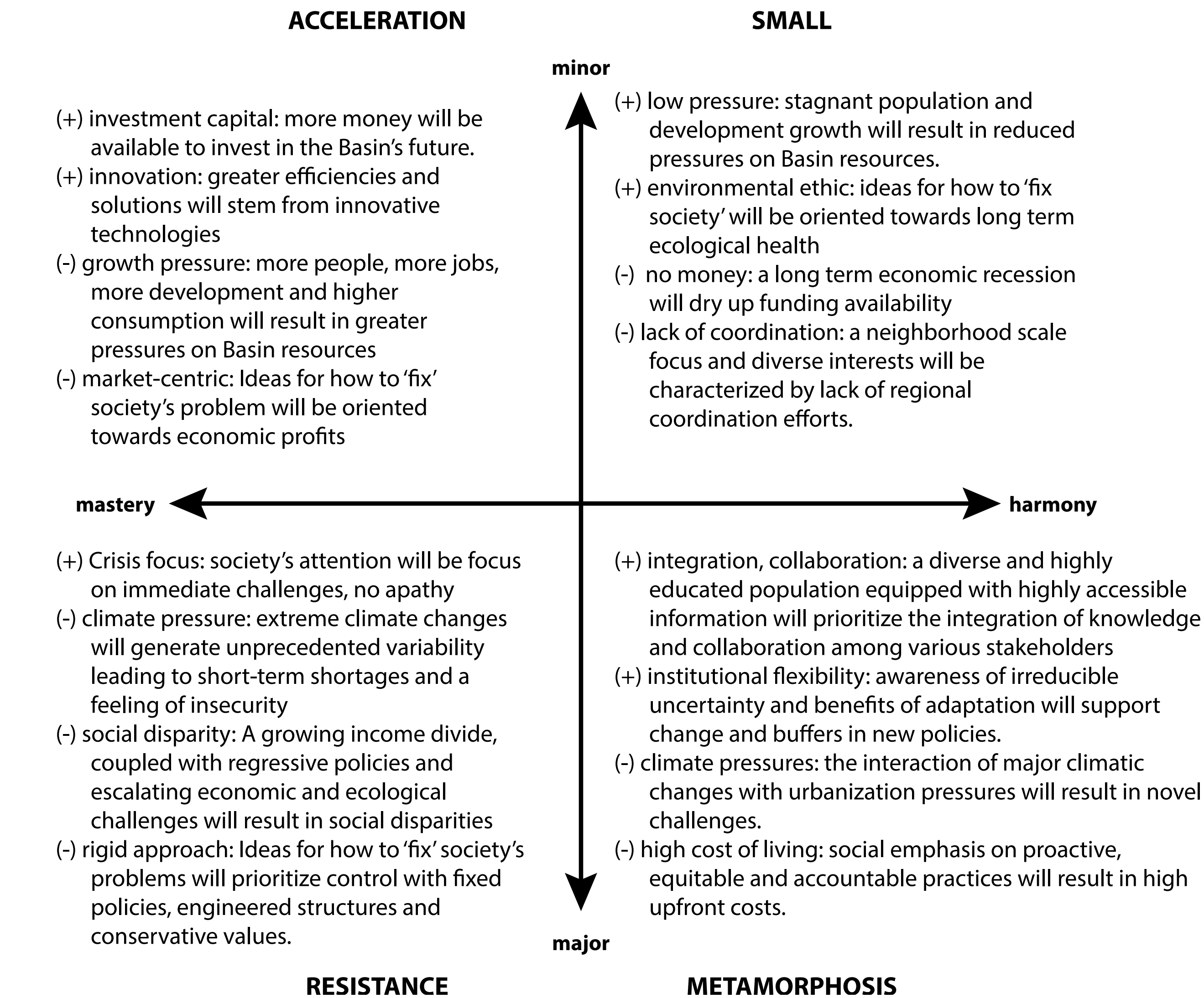


Figure 4.4 Highlighted Opportunities and Risks

to protect rural environment
hiking, camping, skiing
cultural opportunities
awareness of conservation
managing land as urban national forest
increase access
harvesting (timber)
recreation demand
encouraging population growth
institutionalize public lands
global climate impacts
technology concentration (employment center)
new freeway
renewal of tribes
resource extraction
parcelization
transfer Mountain to Greenwat model
salmon recovery and watershed health
Agricultural Drainage Assistance Program
bank armoring
forest protection rules
designate wilderness area
watershed protection measures
dredging
fish habitat protection
water rights
food production
tax incentive (built into rural lands)
conversion to ranchettes
lot size requirements (lower)
flood control
hook properties on septic onto sewer
annexation
export water to treatment plant
farmalnd protection plan (FPP)
public outreach
participante in focus groups, assess and report on distribution of salmon
improve knowledge
manage and remove dikes
3D visualization
include long term history
watershed analysis
land management
understand value of resources
protect by laws and polices
habitat assessment projects
make data publicly available to inform better citizenship
conduct spawning survey
changes in work and family structure
women in workforce. More paid work outside of home
change caregiving for children and elders
change size of housing unit per housing structure
less households with children
more single parent households
Have children later in life
divorces
disparities between earners
social and economic support for families
flexible hours
health and unemployment insurance
support for elderly
consumption
increase in crime and terrorism
live in smaller, more efficient homes
protect Wilderness areas
growth in lowlands and along interstate and highway
build ski resort
generate power on Sultan
use up water storage over summer
more hydropower operations
small dams with small impoundments
forest conversion
fragmentation
Cascade Agenda
protect Basin's forest
afford a rural lifestyle
cluster development
financial incentives for smart development
farm
purchasing financial certainty
makes it acceptable to get less revenue from the land over a large period of time
investment in large forest ownership
timber is going longer distances to be processed
transportation infrastructure (to move wood products around)
rails to trails
trees into energy
facilitating collaborative decision making
leverage assetts
increase regulations
access to informaiton
democratize expertise
air quality studies
analyze natural and human induces climate impacts
fire suppression
focus on ecosystem health and alterantvie ecosystem services
change values, intrinsic values
influencing human behavior
visibility protection
water management
serve as open space close to city (wilderness area)
ozone regulations
wood burning fireplaces
legal statutes to regulate in light of climate impacts
integrating climate change into ESA
salinity protection (dikes)
bicycle trails
rafts and tubes
green building through incentives and policies such as permits
livei n bedroom communites and drive into the city
public transportation
drive until you qualify
direct growth (what the GMA does)
understand larger scale ties betwene building, community and transportation network (location more important than green issues)
housing policy
housing subsidies
connect up cities along transportation corridors
fund new infrastructure
take advantage of tax credits
build smaller housing units
build to meet market demand
carbon nuetral by 2030
emission reductions
Living Building Challenge
no net water use, no net energy use, no net waste
higher density and more diversity in land use
green home market
service tourism
create economic base (tourism)
decentrlize infrastrucrue (energy, water, waste)
volunteering (hikers and climbers)
recommend open space acquisition priorities
river restoration
invasive weed removal
new trails
recreation along I-90 corridor
informal trails
annual pass for timber land access
further and quicker access to recreation areas
closing trailheads
mountain bike innovation (new shocks and brakes allow them to go deeper into pristine areas)
closer to home recreation
identfiy forest roads for repair and continued maintenance
designated dispersed areas (camping)
user fees, mandatory training programs and packing waste out (recreation)
shared staff for recreation
build trails
sustainble management funding
national heritage area
environmental planning
capital project implementation
green building codes
strawberry picking
water export from watershed to urban core
commercial fish industry
participation
public engagement
march for the environment
sustainability movement
industrial pollution (hazardous waste, air pollution_)
single occupancy vehicles
urban food communities
retrofit
make planes
integrated bus system
capital improvements
emergency management
remove levees
purchase floodplain parcels
Shoreline Act
Disaster Management Act of 2000
hazard and mitigation plans
going green
relocation out of the floodplain
track and monitor hazards
public recreation trends
boating
WA State Climate Adaptation strategies
mental health service
gated communities
layoffs
reduce VMTs by 50% in State
transportation technology changes
restrictions to travel (due to price of oil and regulations)
telecommuting
large scale transportation projects
stewardship of existing transportation networks

Figure 4.5 Suggested Basin Solutions

4.5 Illuminate Warning Signals

What do environmental indicators tell us?

Recall for a moment the canary in a coalmine. This environmental indicator was touted for not only alarming miners about air quality deterioration, but giving them enough time to change their behavior. The problem today is that, while we have amassed an unprecedented volume of environmental indicators, the links to their implications in terms of both system state and required actions are largely criticized as misleading or untimely[67]. There are several types of indicators. State of the environment indicators (as opposed to performance indicators) can be described by the specific element of the model they communicate. For example the European Environmental Agency includes Driver-Pressure-State-Impact-Response (DPSIR) indicators. Warning signals are a specific type of indicator that are intended, like the canary, to provide decision makers a clear sign of future challenges with enough time to act upon them.

The challenge with coupled and complex socio-ecological systems is identifying changes in slow and fast variables as well as potential system thresholds. Ecological systems generally correspond to a stable set of mechanisms; given a minimal level of pressure these mechanisms continue supporting an overall function. A regime shift occurs when the system reorganizes such that variables are attracted towards an alternative stable state. A clear lake, for example, maintains a stable organization of processes including plant growth limited by nutrients and high amounts of oxygen supporting high levels of aquatic vertebrates; given high levels of additional nutrients (e.g. nitrogen) the feedback loop changes. Now, additional algal growth reduces oxygen levels, reducing plant growth and aquatic vertebrates; in turn this reduces nutrient uptake, further increasing nutrient concentrations. A eutrophic lake is an alternative stable state for lakes where nutrient levels are kept high. Once eutrophic, a lake will rarely revert back to being oligotrophic (clear). Eutrophication is the most widespread water quality problem in the U.S.[68]. However, while nutrient input (e.g. fertilization) is not the only variable influencing the regime shift, it is fast and readily visible. Another factor controlling the system is the watershed's ability to retain nutrients, for example through plant uptake. Here lies the challenge. Even if input is severely limited, once upland forests are decimated they can take a very long time to regain the capacity to retain nutrients, a function often replaced by expensive wastewater treatment plants.

Scenarios and warning signals

Scenarios support effective decision making by coupling robust strategies (effective under a wide range of future conditions) with adaptive strategies (specific actions that are employed at future junctions once more information is revealed about the trajectory). To employ adaptive strategies scenarios are paired with a warning signal, i.e. "If we head in this direction, choose option C." Like a collection of colorful canaries, each warning signal is uniquely matched to the dynamics of its scenario as one cannot use the same indicator to warn of both economic growth and economic collapse. Warning signals highlight the emergence of one scenario over another, and should trigger a re-evaluation for strategic decisions.

Shifting thresholds of the Snohomish Basin

One of the challenges of managing complex ecosystems is that managers don't know where thresholds lie and how close current conditions are to those thresholds. Recent research has shown the use of variability and stochasticity as important indicator variables to assess potential thresholds early on [69]. While experimentation helps managers better identify potential thresholds, we generally don't know how close we are to a threshold until we've passed it. Despite this knowledge gap, decision makers must make assumptions about the state of the system in relationship to critical thresholds in order to prioritize actions. The scenarios, representing varied perspectives about how the future unfolds, are partially predicated on hypothetical assumptions about the resilience of the system and proximity to potential thresholds. Figure 4.6 exposes the assumptions of the four scenarios in terms of their current state, thresholds, and change in that relationship over the next fifty years.

Examples of signals and actions in the Basin

Warning signals and respective adaptation strategies need to be developed with a specific goal in mind. The focal issue of the Snohomish Basin Scenarios is too broad to effectively define all-encompassing warning signals. Table 4.3 represents examples of warning signals that differentiate critical fast variables shifting across the four scenarios and their significance. Congruent with those changes are guidelines for potential actions that would support ecosystem provision over a longer term. These actions were selected specifically not because they are robust, but because they are fairly effective under the narrow conditions of each given scenario.

4.6 Identify Robust Strategies

Robust vs. Optimal Strategies

Optimal strategies are engineered to be the most effective approaches given a set of conditions. Robust strategies are selected to be effective under a wider range of conditions. A simple example is soccer cleats vs. sneakers: soccer cleats are optimal if you are playing soccer, but if you are not sure which sport you will be playing after school, it may be wiser to bring a pair of sneakers. Certain contexts make the selection of robust strategies more appropriate than optimal: unacceptable failures, diverse stakeholder interests and highly variable and uncertain futures.

Scenarios and Robust Strategies

One of the challenges of traditional decision-making is that it is predicated on the idea that we can identify an optimal strategy. However, this assumption is based on the ability to predict and quantify the probability of risks. The further we look into the future, the more the uncertainty increases, reducing planners' ability to quantify these risks. We may be able to assess the probability of impacts due to the trajectory of change of one variable, but when we couple the multiple uncertain trajectories of two or more variables, that may greatly diminish our ability to quantify future risks (Figure 4.7)[60] .

The key benefit of the alternative scenarios comes from anticipating impacts that lie beyond the probable estimates based on past observations alone. Instead of focusing on a single prediction extrapolated from past trends, scenarios focus on multiple uncertain drivers and expand the assumptions of predictive models to illuminate otherwise unforeseen interactions between individual trajectories. Scenarios therefore expose a wider set of 'plausible outcomes' in order to support more robust strategies [46].

Testing the sensitivity of the system to extreme divergent future conditions is generally done with a limited set of variables. For example, we have estimates for how a major vs. minor climate change affects water supply in the Puget Sound, in terms of the change in timing of precipitation coupled with temperature change (and implications on snowmelt). These estimates have further been coupled with high vs. low population growth (influencing demand) [1]. However, two very important drivers have been left out of the equation. The first is the change in land cover and its implication on water flows (especially groundwater flows); the second is the potential change in agricultural water demand over the next 50 years.

When considering alternative long-term water supply strategies, what are the benefits and costs of alternatives such as a new ground water tap, reservoir, and seasonal dam to detain snowmelt, upland forest protection and gray water infrastructure? How do these strategies compare given changes in population growth vs. the rate and location of urban development, the stability of hydrological flows or the available capital and technological advancements? Scenarios help decision makers imagine possible critical sensitivities and thresholds in the system and explore acceptable risks.

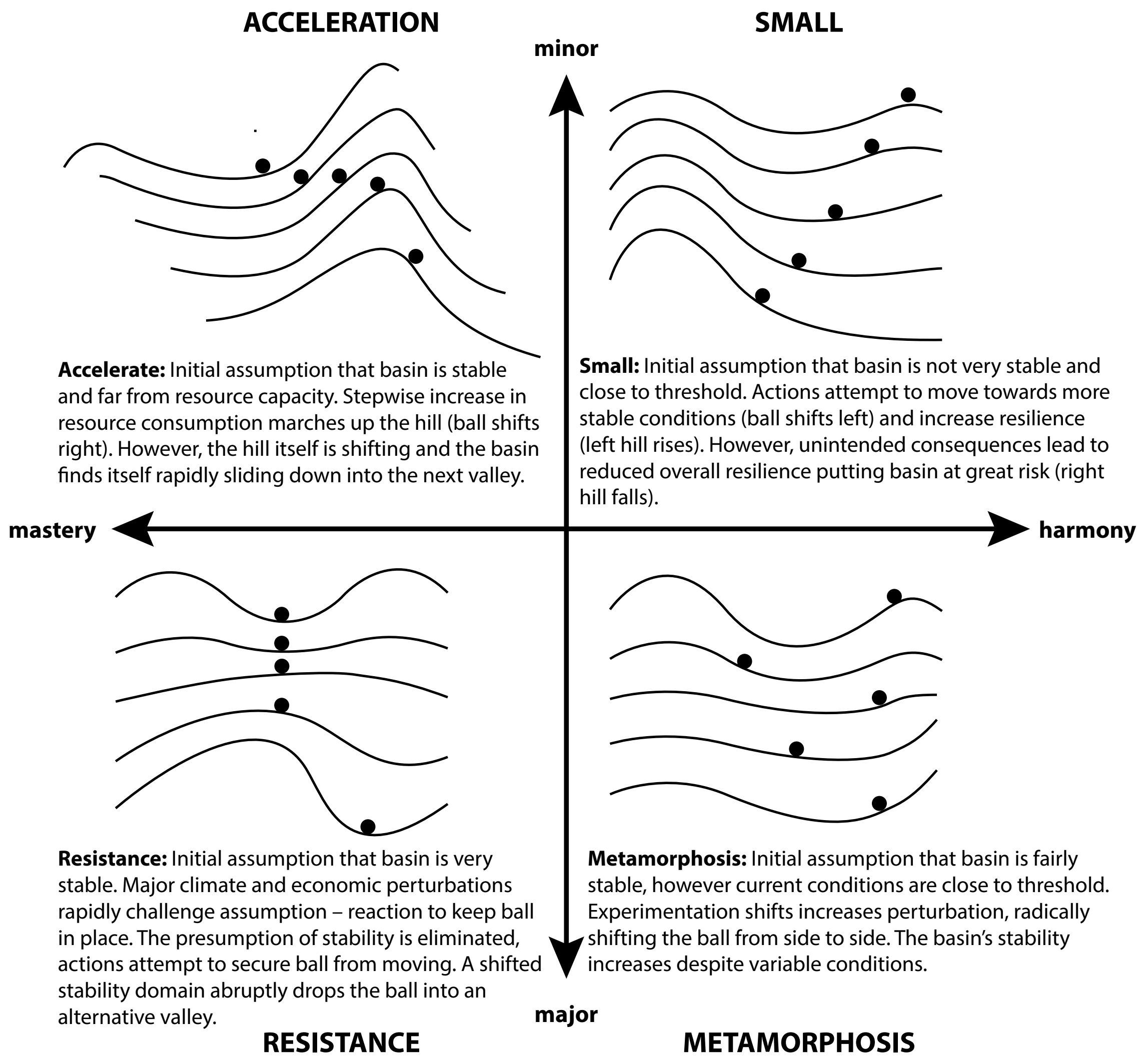


Figure 4.6 Scenario Assumptions for State, Stability and Change

Ball and Cup Diagram: The ball and cup heuristic has been used in literature to describe the movement of ecosystems between alternative stable states. The ball represents the state of the system, while the cup represents a stability domain. Pressure (perturbation) shifts the ball left and right (e.g. resource consumption) along the landscape (line). Meanwhile, the landscape shifts as the ecosystem becomes more or less stable (e.g. the cup becomes less deep and riparian buffers are removed). Resilience can be described as the ability of the ball to stay within the current cup (valley).

Table 4.3 Example Signals and Actions

	Accelerate	Small	Resistance	Metamorphosis
Indicator Description	**Rate of growth** permits, patents (buildings, income, wells, patents	**Size and numbers** many small organizations, businesses, resource parcels, approaches	Level of **borrowing:** household loans, ratio of imports, drilling deeper	**Political momentum** backed by approval and implementation
Significance	Unsustainable growth rate -> resource depletion	Many small units -> lack of coordination; lose resources despite good intentions	Increasing ratios of borrowing -> selling out our future.	Low approval and implementation levels -> paralyzed by complexity
Overall Guidance for Action	Focus on incremental changes that support net benefits through additional growth. In other words, for every 'acre' or 'tree' or 'gallon' you remove, you put > 1 back. For example, low impact development.	Top down support (not enforcement); for example outreach that reinforces regional priorities through individual actions. Example: regional invasive removal plan with articulated tasks.	Sacrifice today to invest in region long term. Raise discount rate while subsidizing local sustainable products. Example: agricultural flood insurance.	Transparent, integrated and adaptable guidelines for decision-making. For example, a criteria for density allocations based on public input

Divergent conditions represented by the Snohomish Basin Scenarios

Scenario planners do not attempt to identify every alternative future condition, but rather the most divergent, or extreme trajectories that influence the focus issue. For example, one can look at the various climate emissions models with implications for temperature change, or only at the highest and lowest. The challenge is coupling the trajectories of multiple drivers in such a way that the final emergent storyline is both realistic (plausible) and divergent. Planners can then use the final set of future conditions to test the efficacy of alternative options and identify robust strategies, or a package of strategies.

The four Snohomish Basin Scenarios were created by crossing the extreme endpoints of the magnitude and variability of climate change (a major vs. minor outcome) and social values governing the relationship between society and nature (mastery vs. harmony). These two drivers were selected by the Science Team as they represented the most important and uncertain trajectories influencing the basin's ability to maintain ecosystem services out to 2060. Within these four frames, variables associated with twelve other driving forces (e.g. demography, economics, natural resources, investments) are animated. Appendix 3 describes the specific trajectories of variables associated with each of these drivers by exploring past and future trends and their relationship to other drivers.

The specific outcomes of the multiple variables interacting within the narratives of each scenario are not model outcomes, but rather hypotheses based on the conversations with multiple basin experts. In order to test the costs and benefits of specific strategies, planners will need to develop quantitative assessments of targeted variables.

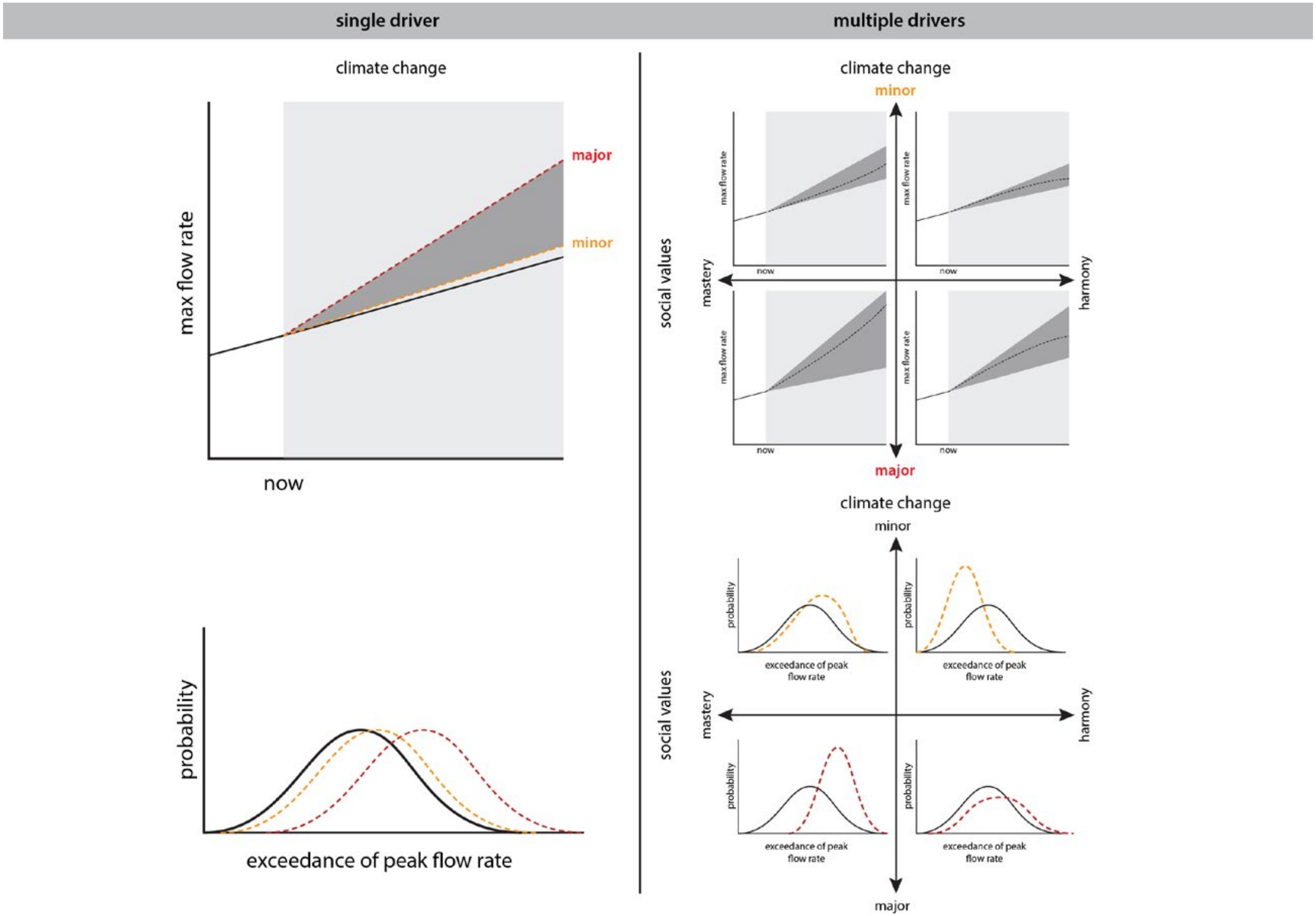


Figure 4.7 Single and Multiple Driver Risk Assessment

However, the storylines of the scenarios can challenge and expand the boundary conditions set by those models, to explore future pressures that may otherwise be overlooked. Figure 4.8 represents the 6 major trajectories depicted by the Snohomish Basin scenarios.

	Accelerate	**Small**	**Resistance**	**Metamorphosis**
Climate Change	Minor - B1	Minor - B1	Major -A1B	Major - A1B
Social Values	ambition, success, control, competence	peace, interdependnece, equity, environmental protection	ambition, success, control, competence	peace, interdependnece, equity, environmental protection
Worldviews and Governance	human ingenuity and knowledge surmount all obstacles, deregulation spurs innovation	persistence is possible only in a decentralized system with minimal demands	impose static goal, maximize central control	multiple stable states and shifting system stability; institutional and political flexibility
Employment, Population and Wealth	fast growth, high income - high tech and service jobs	slow growth, low wealth, aging, natural resource oriented	unstable growth, construction and government sectors, uneven wealth distribution	stable, moderate, diverse growth
Changes to the Built Environment	extensive, impervious, innovative	minimal, low-funds, local-scale	uneven, uncoordinated, reactive	urban, diverse, long term
Ecosystem Pressures	strong decline - urban pressure outweigh investments	slight decline - minor pressure but no coordinated investments	thresholds surpassed - resources are pushed beyond limits	decline and rebound - buffers and diversity relieve pressures

Figure 4.8 Snohomish Basin Major Future Trajectories

Notes

1.The study area is the Snohomish Basin, or Water Resource Inventory Area 7, hereafter referred to as 'the basin.'

2.Carbon stocks were estimated and compared per WRIA using 2007 land cover classifications for Puget Sound Basin and carbon factors per land cover supported in reference.

3.The Snohomish Basin Scenarios, or 'The Scenarios' refer to the overall Snohomish Basin project including both the specific four scenarios developed and the overall process.

4.Acres of urban land is estimated by aggregating impervious area of parcels by decade built (for 1960, 1970, 1980, 1990 and 2000) within the Snohomish Basin.

5.The Central Puget Sound Region, hereafter referred to as 'the Region' includes the four county area of King, Snohomish, Kitsap and Pierce.

6.Based on parcel level assessment of 2010 land use capacity as estimated by PSRC's UrbanSim model in conjunction with high estimates of population growth.

7.Several experts represent more than one agency, department or tribe.

8.The shared conceptual model is the product of both individual and group interviews during the summer of 2010 and the Conceptual Model Workshop, held in November 2010. During interviews, Science Team members were asked to articulate conceptual maps or models that depict how they see the Snohomish Basin's future. Interview notes were synthesized and shared as three alternative conceptual models, which were then elaborated on at the Conceptual Model workshop.

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