

PARTICIPATORY MODEL BUILDING FOR EXPLORING WATER MANAGEMENT
AND CLIMATE CHANGE FUTURES IN THE OKANAGAN BASIN, BRITISH
COLUMBIA, CANADA

by

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ABSTRACT

Studies of climate change impacts on water resources show that some regions may experience negative impacts and additional strain on the ability to meet future demand. However, few practitioners have incorporated climate change into their water planning initiatives. To do so practitioners must first recognize climate change as a concern, acquire climate impacts information specific to their issues and scales, and then assess the potential impacts and adaptation options within the context of the system. Participatory modeling, in which stakeholders are actively involved in the construction of a computer model, is an effective method for accomplishing these tasks. The collaborative process fosters a shared learning experience and the model helps assess future conditions and policies. A year-long participatory modeling exercise was conducted in the Okanagan Basin in south-central British Columbia, Canada. The region's arid, snowmelt-dominated hydrology combined with recent rapid development make its water resources susceptible to climate change impacts. Participants, including water-related professionals, researchers, and representatives of non-governmental organizations, assisted in all stages of model development, from goal setting and issues identification to model calibration and testing. The completed model, constructed in STELLA™, conducts thirty-year monthly simulations of water supply and agricultural, residential, and conservation flow demands for a historic period and for the 2020's and the 2050's, using statistically downscaled climate information from the Hadley, CGCM2, and CSIRO general circulation models. The model suggests that climatic changes could impact the system more severely than population growth. Current projections show reduced ability of the system to meet demand, particularly during the dry month of August, when demand peaks. Adaptation strategies could play a role in maintaining system reliability. Participants found both the process and the resulting model valuable. They found the model to be a relevant and legitimate tool for exploring long-term water management in the Okanagan when used with the appropriate audience and with minor refinements. The model could support further dialogue with the Okanagan community to determine appropriate management options. This methodology is not limited to this case study, but is well-suited for other applications of resource management, policy development, collaborative learning and negotiation.

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CO-AUTHORSHIP STATEMENT

Chapter 3 was submitted to the Integrated Assessment journal and Chapter 2 will be submitted to the Journal of Water Resources Planning and Management. I am the senior author and originated the research including the concepts and ideas, wrote both manuscript, and took major responsibility for development of both papers. My co-authors offered suggestions and are listed in alphabetical order and assisted in the following ways:

- Allyson Beall advised design of the workshops and development of the model, helped with facilitation at all workshops and reviewed manuscript drafts.
- Jeff Carmichael advised design of the workshops and development of the model, helped with facilitation at all workshops and advised the development of manuscript drafts.
- Stewart Cohen, as project PI, ensured that the group model building process and model fulfilled the goals of the overall project. He generated adaptation scenarios and advised the development of manuscript drafts.
- Craig Forster advised design of the workshops and development of the model. He generated the interface level of the model and provided significant advice on the presentation of model results.

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Because the thesis is in a manuscript-based format, some text is repeated in multiple chapters.

CHAPTER 1: LITERATURE REVIEW AND RESEARCH SCOPE

Sustainable development, as defined by the Brundtland report is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland 1987). Since water is a renewable resource, we can meet this objective by avoiding actions which degrade water quality and by limiting our use of water to the rate that supplies are replenished. The American Society of Civil Engineers Task Committee on Sustainability Criteria defined sustainable water resource systems as those that are “able to satisfy the changing demands placed on them, now and on into the future, without system degradation” (ASCE 1998: iv). This is easy to state but challenging to achieve, particularly when natural hydrologic variability is combined with impacts from human development and climate change.

Several elements are required to effectively conduct Sustainable Water Resources Planning and Management. First, the planning must be long-term and consider all of the issues that could affect the system over the long term, such as climate change, population, economic forces, and human values. Second, the assessment of future conditions must integrate as many factors as possible, and analyze the issue from a system context. Third, the assessment needs to involve the local community to enhance the analysis, but also to foster learning among actual planners, managers and users of the resource.

This dissertation describes an application of sustainable planning for water resources in the Okanagan Basin, British Columbia, Canada. The approach follows the above listed elements to the extent possible. The following sections provide detail about the Okanagan Study area, climate change in the water management context, and the fields of “integrated assessment,” “participatory planning,” and “system dynamics.” Selected case studies that applied participatory integrated assessment to natural resource problems are summarized.

1.1 Climate Change and Water Resources Planning

Water managers have always worked towards reducing risk and increasing system capacity to handle ever-widening extreme conditions, but are managers prepared with the tools to adapt to future climate conditions? In the past, climate was assumed to be relatively stable in the timescale that water managers work in, varying around a stable mean (de Loë and Kreutzwiser 2000). Stakhiv (1996) observes that society is constantly adapting in incremental steps and predicts that climate change will simply be an additional stressor to which we must adapt. This practice is generally low-risk as long as changes occur gradually. In the future, climate changes may occur gradually, over several decades, or they could occur as rapid step changes. Most climate models characterize climate change as occurring slowly and gradually, which justifies a reactive “wait-and-see” approach. In contrast, Kashyap (2004) suggests that climate change adaptation is not comparable to historic adaptation because the environmental changes will be more rapid and intense than in the past. The IPCC’s Fourth Assessment Report confirms this idea, stating that heat waves and heavy precipitation events will become more frequent and intense in most areas (IPCC 2007:16). A shift in the climatic mean, combined with the possibility for sudden changes, makes the conventional practice of relying on historic data for estimating future conditions inadequate. New methods for assessing future conditions are required to maintain the reliability of operations over the long term. This is true not only for water resources, but for other industries as well. For example, the insurance industry, which relied solely on historic records for centuries, has also started to consider future climate conditions for assessing hazards and setting premiums (Leggett, 2001).

The impacts of climate change on hydrologic systems will vary widely by geographic location. For example, climate models are generally estimating more precipitation globally but some areas will become wetter while others will become drier (Miller and Yates 2005). Many areas will experience warmer temperatures, which will impact hydrologic storage and timing. Snow-melt driven systems will experience a reduced annual snowpack and an earlier spring freshet (Mote, et al. 2003; Mote 1999; Taylor and Barton 2004). These changes may

impact the timing of available water, reducing the availability of water during the summer irrigation season.

Climate change impact studies are relatively recent, and direct use of the information by practitioners is lagging behind. In 2005, only four U.S. states included climate change in their water resources planning (Viessman and Feather 2006). In Canada, two examples of climate change being incorporated explicitly into water planning are the Trepanier Landscape Unit Water Plan (Summit 2004), which followed from work by Cohen et al. (2004); and work on the Great Lakes – St. Lawrence River Basin (Mortsch and Mills 1996).

1.1.1 Challenges of incorporating climate change in water resource planning

There are three prerequisites that must be met for water managers to be willing and able to incorporate aspects of climate change into their water planning initiatives. First, the water management community must be informed and concerned about climate change. Second, information about potential climate impacts must be translated into terms that are relevant to the water community. Third, the water community must be able to assess the climatic impacts within the system context, including other stressors, changes, and management responses. Each of these tasks contains specific challenges.

There are several reasons for the lack of awareness of climate change among water resource professionals. First, detecting the climate signal is challenging, as the signals are often confused with noise, or not felt directly (Berkhout et al. 2004). In recent years, before climate change had discernable, significant impacts as described in the Intergovernmental Panel on Climate Change's latest report (IPCC 2007), the "signal" was virtual, in the form of scientific predictions. This adds a new dimension of complexity; since there is significant uncertainty in the character of climate change, how we should respond is not clear. Humans respond more readily to stressors that we personally experience than those that we learn about indirectly. The creeping nature of climate change makes it easy to ignore. Because our human nature encourages us to focus on immediate crises, small incremental changes are

disregarded and continue freely until a disaster occurs (Moser and Dilling 2004). Many climate adaptation proponents focus on extreme events; however, in the case of water resources management, the series of small events, or the shift in patterns to a more non-equilibrium dynamic can be more damaging (Dowlatabadi and Yohe 1999; Scoones 2004). For example, damage due to gradual shifts was demonstrated in an analysis of reservoir operation in the Columbia River Basin. Researchers at the Univ. of Washington's Climate Impacts Group discovered that it was the seasonal shifts of inflow that had the most significant impacts on system performance (Payne et al. 2004).

Next, the information typically generated by climate scientists is not directly relevant to local water professionals. In order to incorporate climate change estimates into their planning processes, climate change information must be translated into terms that are relevant to their concerns. While the level of uncertainty in climate estimates makes the information cumbersome, the mismatch of scales is a larger hurdle. Current global climate models provide information at large geographic scales and low spatial resolution, but managers handle small geographic areas and require data with relatively high spatial resolution (Lins et al. 1997). Furthermore, climate change data must be translated from temperature and precipitation to terms reflecting hydrologic impacts.

Finally, even if the first two challenges are surmounted, and concerned water professionals acquire relevant information, there remains the challenge of integrating the information within the system context. For example, climate change is likely to impact not only the availability of water supplies, but also water demand. At the same time, other stressors, such as urban development and economic trends may also affect demand in various sectors. Only by considering climate change in the system context can we estimate future conditions and then evaluate effective responses. To date, most work has focused on specific components rather than the entire system. For example, Downing et al. (2003) assessed the impacts of climate change on various water demand sectors with the caveat that the results need to be considered as one element in a larger system.

1.1.2 Response options to climate change

There are two primary responses to climate change: mitigation and adaptation. Mitigation refers to actions for reducing anthropogenic greenhouse gas emissions to rates at or below the capacity of the earth to assimilate them. However, we have already committed ourselves to many decades of elevated greenhouse gas levels in the atmosphere and the resulting climatic changes. Therefore, adaptation strategies which can reduce vulnerabilities are prudent for coping in the short to medium term. There are several definitions in the literature for "adaptation." De Loë and Kreutzwiser (2000:164) define adaptation broadly as "[a]ny adjustment in a system in response to climate stimuli." Rosenzweig and Hillel (1998) provide a more detailed definition, which includes the idea that adaptation can be social or technical, and that the purpose of adapting is to either reduce the negative impacts or capitalize on the positive effects of climate change.

The Adaptation and Impacts Research Division of the Meteorological Service of Canada, Environment Canada conducted several studies that became the foundation for conducting this research project. The organization's web page describes their stance on the importance of adaptation for Canadians:

Atmospheric change, variability and extremes represent real and present threats to the achievement of sustainable development in Canada. They will continue to affect the health, integrity, development and, thereby, the sustainability of Canadian socio-economic and ecological systems. As such, Canadians' responses to these must include adaptation actions that will reduce their vulnerabilities to atmospheric variability and extremes and that will minimize the negative impacts, maximize positive impacts, and allow them to take advantage of opportunities that arise as a result of atmospheric changes (EC website 2002).

The hope for the organization is "to promote and facilitate adaptation to atmospheric change, variability and extremes and to assist in identifying the need for other response options" (EC website 2002).

If we are to achieve a sustainable society, we must make changes that support mitigation and adaptation simultaneously. There are numerous examples of short-term adaptations that

conflict with mitigation. For example, more intense summer heat waves encourage more use of air conditioners, but air conditioners increase energy use, which increases greenhouse gas emissions. A better response would be to plant trees which shade buildings and provide carbon sequestration. In this project, I focus on adaptation, and do not evaluate mitigative potential. Future research should evaluate alternatives in a mitigation framework as well, to ensure that short-term solutions do not exacerbate long-term problems. In this project, I place higher emphasis on alternatives that reduce water demand than on supply-based alternatives that increase supply. Generally, reductions in use of materials and energy contribute to a more sustainable community.

1.1.3 Reactive versus anticipatory adaptation

Water managers could implement changes now to reduce their vulnerability to future climates, or they could wait and see what the future brings and then respond to these new conditions. The first approach, known as “anticipatory adaptation,” describes investments made today to reduce future risk. The second approach, “reactive adaptation,” prevents unnecessary investment and delays expenditure, but increases system vulnerability. There are strong arguments supporting each view. The Stern Review on the Economics of Climate Change (2006) supports anticipatory adaptation, by concluding that minor annual expenditures (1% of the GDP) are required to manage climate change, but if this investment is not made, the damages to the economy will be severe (decreasing GDP by 20%). Smith et al. (1995) explain that some of the first adaptation debates focused on whether or not reactive adaptation measures were capable of offsetting the negative impacts of climate change. If the onset of climate change is rapid, with frequent extreme events, there may be insufficient time for humans, flora and fauna to adapt; “[t]his makes a case for the necessity of anticipatory adaptation” (Smith et al. 1995:202). On the other hand, studies of several U.S. cities in the 1990s determined that water management systems were already incrementally adapting in response to various external factors; therefore, these systems were robust and resilient enough to handle future climate variability and anticipatory adaptation is unnecessary. “The choice of an anticipatory path requires a profound investment and behavioural changes that cannot be justified by climate change analyses completed to date” (Stakhiv 1996:246).

Middlekoop et al. (2004) explains how world views (regarding nature, society and risk) combined with management styles largely influence choices about appropriate adaptation to climate change. In a study of five international rivers (the Nile, Zambezi, Indus, Mekong, and Uruguay), basin managers felt that a combination of traditional structural and non-structural approaches implemented now would help them to cope in the future (Riebsame et al. 1995). In contrast, an evaluation of public water supply in England and Wales concluded that at this point in time, “no specific actions were necessary to deal with future climate change” (Arnell and Delaney 2006).

1.2 Integrated Assessment

Incorporating climate change in future assessments and adapting to climate change are important, but are only relevant when taken in context. It may be possible that other stressors will exaggerate, offset, or overwhelm the impacts of climate change. Surprising behaviours, such as feedbacks and non-linearities may emerge when numerous factors of influence combine. Therefore, assessments of the future should ideally consider the whole system, with the full array of issues that could change, including climate, economic influences, population, and human values. Integrated assessment (IA) is a field of study that works to do just that.

Several definitions of IA exist in the literature. All agree that IA is a method or process for evaluating complex problems to increase understanding (Rotmans and van Asselt 2002; Risbey et al. 1996). Toth and Hizsnyik (1998:194) noted that all definitions share a commonality in that IA “is an interdisciplinary and policy-oriented synthesis of scientific information,” however the definitions differ in their qualifications. One of the most recent definitions, provided by Rotmans and van Asselt (2002:1), refers to participatory processes (PPs): IA is “an interdisciplinary and participatory process of combining, interpreting and communicating knowledge to allow a better understanding of complex phenomena.” In earlier definitions, PPs were considered one of several approaches to conducting IA; however, Rotmans and van Asselt (2002) claim that participation is now a necessary component for conducting high quality IA.

The aim is thus to analyse, explore and evaluate past, current and future developments in terms of plausibility, desirability and feasibility. Integrated assessments should result in added value compared to insights derived from disciplinary research. IA has the explicit purpose to inform policy and support decision-making. It is important to realise that integrated assessment is not a pure scientific activity. It requires involvement of scientific experts, stakeholders and decision-makers. Communication between those different actors is at the very heart of IA (Rotmans and van Asselt 2002:1).

This recent shift to perceiving participation as a vital component of IA can be attributed to the emergence of new social and scientific philosophies. The post-modern and social-constructivism movements of the late twentieth century recognize that science is means to absolute truth. Often “doing more science” does not reduce or eliminate uncertainty, particularly in dealing with future assessments. Science is not purely objective, but is subject to the values of society and the research community; therefore, science should not be the exclusive leader of knowledge. Academic study does not foster the ability to create a sustainable relationship with our natural world because of the emphasis on “theories, not values, abstraction rather than consciousness, neat answers instead of questions, and technical efficiency over conscience” (Orr, 1991: 99). These views all suggest a need for PPs to address the gaps left by science and to ensure that appropriate value judgments are included in IAs (ICIS 1999).

A related point is that holism, or systems thinking, is replacing the philosophy of reductionism. Holism encourages analysis of the system as a functioning whole. Connectedness, relationships, and context are the tools for understanding whole systems. In contrast, according to the reductionist or Cartesian view systems are comprehensible only by analyzing components in isolation. In addition, this philosophy considers the world a machine, void of spirituality, emotions or values (Capra 1996). These “soft” elements have direct influence on how humans interact with their environment, so they need to be taken into account when investigating ways to solve environmental problems.

It is not a coincidence that these paradigm shifts are taking place during our age of globalization marked by growth and development that has increased demand for resources beyond sustainable limits. Local problems are no longer isolated, but interact across sectors

as well as political and geographical boundaries. These have all contributed to the need to evaluate environmental problems from a systemic point of view, such as using participatory IA methods.

The methods of IA described in the literature are typically categorized as either analytical approaches or participatory approaches (ICIS 1999; Rotmans and van Asselt 2002). Analytical approaches include modeling, scenarios, decision support systems, environmental impact assessment and some risk analysis (Rotmans 1998; Toth and Hizsnyik 1998). Until the mid 1990's, IA modeling was the dominant method (Rotmans and van Asselt 1996; Risbey et al. 1996). However, participatory approaches now play a role in most IA activities. These approaches are not exclusive, but may be used in combination in various stages of the assessment.

IA shares commonalities with Technology Assessment, Risk Analysis, and Policy Analysis. "These research areas also address some kind of complex problem, however, from a specific point of view. The essential difference is that IA aims to integrate knowledge from an a priori integrated point of view" (Rotmans 1998:156). Decision support tools are also related to IA in their cross-disciplinary nature. However, to date, these have most often been developed by experts. Participatory modeling which is a fairly recent approach, will be discussed later in this chapter, as an example of a participatory method.

1.2.1 Benefits, challenges and future directions

The insights gained from IA can inform policy, the public, and disciplinary sciences, resulting in improved decision-making. Rotmans and van Asselt (1996:334-5; also ICIS, 1999:9) list the ways in which IA is able to do this:

- IA places the problem in a broader context.
- IA can assist with trend analysis, eliminating improbable scenarios and evaluating trade-offs of impacts.
- IA can assess alternative actions/response options to the problem.

- IA provides a framework to structure scientific knowledge, and to compare and rank uncertainties.
- IA helps translate uncertainties into risk
- IA can help to identify research gaps and prioritize areas of future research.

Participatory processes can contribute to, and improve, all of these tasks listed.

There are several challenges to conducting effective IA processes. ICIS (1999: 22) provides recommendations for ensuring the longevity and increasing the effectiveness of IA processes:

- Increase transparency of process through better communication and documentation.
- Expand capabilities of analysis through the development of new research methods.
- Involve “end-users” in the process from the start to ensure a good match between the information needed and the information supplied.
- Establish quality criteria to test the quality of IA research, and a “codes of practice.”

The last item listed was raised repeatedly in the literature over the past decade (Dowlatabadi 1995; Rotmans and van Asselt 2002; Rotmans 1998; van Asselt and Rijkens-Klomp 2002). As the field is relatively new, there are no guidelines or standards established to date; however, approaches to establishing guidelines have been proposed. The establishment of guidelines would increase the credibility of IA in both the scientific and political communities. It would also assist in maintaining a productive relationship with disciplinary science. Credibility is necessary if IA is to remain an accepted approach to evaluating environmental problems (Rotmans and van Asselt 1996).

A set of quality criteria is proposed in Rotmans and van Asselt (2002:13-15). These criteria are divided into three classes: analytical, methodological, and usability. These first two help evaluate the internal aspects of the assessment, and aim to address the question, “Have we

done a good job?” Usability, on the other hand, is an external quality, related to the question, “Is the study useful?” Resource managers and policy makers are often the “end-users” of an assessment. Involving these parties in the design of the process improves the likelihood that the product will be useful to – and used by them.

IA also has several methodological challenges associated with it. First, there is no optimal spatial and temporal scale with which to conduct the assessment, as complex problems include aspects that operate on different scales. This leads to a constant struggle between aggregation and disaggregation. Second, IAs contain considerable uncertainty of different types. These uncertainties, from both technical and methodological sources, must be managed appropriately. Third, appropriate techniques must be used or developed to blend the qualitative and the quantitative types of knowledge. Most IA frameworks treat these two as mutually exclusive but there are a number of techniques available to support blending, such as fuzzy logic (Rotmans 1998:164-6).

1.3 Participatory Planning Methods, Including Participatory Modeling

Tell me and I'll forget,
Show me and I may remember,
Involve me and I will understand.

-Author unknown

There are several reasons why stakeholders (which include professionals, interested parties, and the public) should be involved throughout the planning process, rather than just as consumers of research results. The above verse describes one of these reasons. Active, personal engagement fosters learning and changes worldviews better than passive learning activities. Involving stakeholders in model development also supports customization of the model to their needs as model users. Each stakeholder contributes a different perspective on the system. The majority of information available resides in “mental data bases” and has not been written or measured (Forrester 1987), so direct communication is often the only way to

access this information. Stakeholder involvement also helps to build confidence in the model. Throughout the development process, assumptions and uncertainties are communicated. As a result, the users have the information to interpret the results appropriately.

The remainder of this section describes some of the distinguishing characteristics of participatory processes and provides detail on participatory modeling.

1.3.1 Degree of participation

The participatory planning literature includes a wide array of methods and tools with varying degrees of involvement of the participants, from being receivers of information to having decision-making power. Van de Kerkhof (2003:26) provides a detailed ladder of participation as shown in Figure 1.1. There are separate scales for policy making and for scientific practice.

Figure 1.1: Degrees of stakeholder participation in policy making and in scientific practice (from van de Kerkhof, 2003:26).*

Stakeholder participation in policy making		Stakeholder participation in scientific practice
Stakeholder control Delegated power Partnership	High degree of participation	Mutual learning Co-production Co-ordination
Placation Consultation	Moderate degree of participation	Mediation Anticipation Consultation
Information Therapy Manipulation	Low degree of participation	Information

* Concept based on previous work of:
 Arnstein, S.R. 1969. A ladder of citizen participation. In: J. of the American Institute of Planners 35(4). 216-224.
 Mayer, I. 1997. Debating technologies. A methodological contribution to the design and evaluation of participatory policy analysis. Tilburg University Press: Tilburg, The Netherlands.

Methods that contain low levels of participation serve to educate or inform, generally targeting a specific interest group or the general public. As information travels unidirectionally from experts to participants, this level does not support IA. Examples include brochures, mailings, press releases, field trips, information lines, and briefings (Mostert 2003).

Methods which collect information from participants, ranging from consultation through mediation, are classified as moderate participation. Examples include public meetings (which request feedback and comments), interviews, opinion polls, teaching and training games/gaming simulations, focus groups, dialectical debates, scientist-stakeholder workshops, and decision seminars (Mostert 2003; van Asselt and Rijkens-Klomp 2002; van de Kerkhof 2003).

In high levels of participation, some of the responsibility of the project is shared. Participants may contribute to the design of the process or to making final decisions. The process works toward coordination, co-production, or mutual learning. Examples include policy exercises, scenario analysis, negotiations, participatory modeling, policy Delphi, rational discourse, and cooperative discourse. (Mostert 2003; Renn 2003; van Asselt and Rijkens-Klomp 2002; van de Kerkhof 2003).

Some methods can be classified as either moderate or high, depending on how the process is conducted and in which stages the participants are involved. These include planning cells, citizen juries, consensus conferences, working groups, and participatory decision analysis (Mostert 2003; van Asselt and Rijkens-Klomp 2002; van de Kerkhof 2001; 2003).

Moderate degrees of participation foster first-order learning, while high degrees of participation support second-order learning. Van de Kerkhof (2003) describes the differences between first-order learning and second-order learning:

In first-order learning, the new insights that the participants generate mainly relate to the empirical and technical level of analysis. This concerns insights in the 'facts' and expectations on a specific topic. Second-order learning is achieved when the participants gain new insights in the complex relationship

between causal and normative reasoning, which may result in a change in participants' norms and core beliefs that guide their behaviour and that underlie their conception of the very nature of the problem concerned (a paradigm shift) (van de Kerkhof 2003:60).

A high level of involvement is required to foster second-order learning, while a certain degree of distance between the participants and the problem is helpful to limit the discussion to first-order issues. Second-order learning is developed through authentic conflict and argumentation, rather than role-playing or artificial simulation and conflict. Methods such as group brainstorming, gaming simulation, and role-playing result in first-order learning, while dialectical debate and policy Delphi can create second-order learning (van de Kerkhof 2003:61).

1.3.2 Problem type

There are several types of environmental problems and planning processes that are well-defined, so preclude IA. Examples are those that are one-time decisions, such as facility siting decisions (Stave 2003:304). PPs that are most relevant to these well-defined problem types are charrettes, public hearings, and opinion polls.

Van de Kerkhof (2001) describes a framework[†] that maps out problem types in two dimensions. One dimension describes the level of certainty or uncertainty associated with the problem. The other dimension refers to the level of consensus or disparity between stakeholders on the relevant values at stake. The "structured" problem has high certainty and high consensus. IA is not necessary for these problem types. When there is consensus, but high uncertainty, the problem is "moderately structured (ends)." When there is diversity of opinion but high certainty, the problem is "moderately structured (means)," and those problems that have both significant diversity of opinion (lack of consensus) and high uncertainty are considered "unstructured" problems. Participatory IA is most useful in

[†] Framework developed by Hisschemoller (1993) and Hoppe (1989):

Hisschemoller, M. 1993. *De democratie van problemen. De relatie tussen de inhoud van beleidsproblemen en methoden van politieke besluitvorming* (in Dutch). VU Uitgeverij: Amsterdam, The Netherlands.

Hoppe, R and A. Peterse (eds.) 1998. *Bouwstenen voor argumentatieve beleidsanalyse* (in Dutch). Elsevier: The Hague, The Netherlands.

unstructured and moderately structured problems. In well-structured problems, participation generally involves learning all of the available information and developing full consensus. Citizen juries or planning cells, consensus conferences, and participatory planning are examples that typically have consensus as the primary goal (van Asselt and Rijkens-Klomp 2002). The primary goal of IA is typically mapping diversity rather than reaching consensus, so these methods are not always appropriate for IA (Pahl-Wostl and Newig 2003). However, consensus can result from confronting and challenging the diverse views. Examples of methods that may lead to consensus through a process of mapping and challenging the diversity of views are participatory modeling, policy Delphi, and dialectical debate (van de Kerkhof 2003; Vennix 1996).

1.3.3 Profile of participants

Methods are designed for use with either the general public or with stakeholders who have a close connection with the issue (Pahl-Wostl and Newig 2003). Both groups of participants may be helpful in IA, depending on the purpose of their involvement. Typically the methods that engage the general public are used for opinion scoping (some focus groups and some policy exercises) or for reaching consensus on specific issues (citizen juries, consensus conferences, and decision seminars). Methods that engage participants at high levels or for longer durations engage those with concerns about the issue. Since higher levels of involvement require more commitment, it is easiest to engage those with vested interests in the topic. Unfortunately, this can easily create bias by attracting stakeholders that have a professional role in the issue, or have the time to afford through retirement or other means, while excluding the “average” citizen that uses the resource. Providing financial compensation for their time, assigning representatives of interest groups, and using additional mechanisms for communicating with the stakeholder groups can help to engage stakeholders that would otherwise be excluded from the process entirely.

A related issue is the role of scientists in the process. Depending on the problem type, scientists can take on different roles. In structured problems, the scientist is the problem solver. In unstructured problems the scientists may be responsible for identifying and

clarifying the issue, while in moderately structured problems the scientist may take the role of either an advocate or a mediator (van de Kerkhof 2001:12).

1.3.4 Goal of participation

There are two philosophies to conducting PPs. The PP can either be seen as a means toward meeting other goals, or it can be viewed as a goal in itself (van Asselt and Rijkens-Klomp 2002). Participatory IA more often focuses on the outcome of the process rather than on the process itself since the participatory process contributes to generating the assessment, but may focus on both aspects. When participation is viewed as a means to other goals, goals of participation may be: (1) to improve decision-making, (2) to improve scientific practice, or (3) to structure complex problems (Forrester 1999; van de Kerkhof 2003). When the PP is seen as a goal in itself, then conducting the process well is most important. A number of evaluation criteria are relevant: Was the process fair and transparent? How were power imbalances addressed? Did the decision-making process incorporate participant responses, or give power to participants? Did the process foster social learning between and among the scientists and the stakeholders? (Folz and Hill 2001; van de Kerkhof 2003). Did the process accommodate the role of local or traditional knowledge? Learning is an important objective for PPs not only as an objective in itself, but also as a means to improving decision-making, scientific practice and problem structuring.

1.3.5 Challenges in participatory planning

There are a number of challenges to conducting PPs. First, participants are often volunteers, so attendance may be inconsistent and the group composition may change. Second, the political and public context forces a short time period for the work. This frequently creates a “good enough” attitude for the product, limiting ability to develop details. Third, participants may not be willing to change their mental models. Participants may have personal objectives that reduce their willingness to challenge their beliefs. Finally, “group think” and defensive routines may reduce the quality of the process (Stave 2002:160-1).

1.3.6 Participatory modeling

Several fields in the literature use different terms to describe processes in which stakeholders are involved in the development of a model for purposes ranging from shared learning to consensus building. IA literature refers to “participatory modeling,” in fields such as policy analysis and organizational learning, as well as natural resource applications such as water resources and land management. Videira Costa (2005) provides insight on the differences of two related terms. “Group model building,” from the system dynamics community, has most often been applied to organizational messy problems (Richardson and Andersen 1995; Vennix 1996; 1999) but has also been applied to sustainability issues (Stave 2002; 2003). The term “mediated modeling” originated from the ecological economics community in the late 1990’s and has been applied to solving complex environmental problems (van den Belt et al. 1998). A term that has been applied exclusively to water resources management applications is “shared vision planning” (SVP). The methodology was formalized about fifteen years ago by the Institute for Water Resources, U.S. Army Corps of Engineers. SVP combines traditional water resources planning principles, structured public participation, and integrated computer modeling (Palmer et al., in review).

These approaches are appropriate for complex problems, particularly ones where conflict is anticipated. The process can meet one or more of the following goals: foster team learning, share information between stakeholders, foster future vision, develop consensus on the behaviour of the system, and reach consensus on a decision and create commitment to that decision (van den Belt 2004:41-45).

Participatory modeling is founded in the belief that people’s mental models of how a system behaves are based on numerous unstated assumptions, and often contain gaps and inconsistencies. Fuzzy, incomplete, and imprecise mental models can lead to ineffective policy making. Unfortunately, today most policy decision-making processes are not explicit.

Even in the modern age of science and industrialization social policy decisions are based on incompletely-communicated mental models. The assumptions and reasoning behind a decision are not really examinable, even

to the decider. The logic, if there is any, leading to a social policy is unclear to most people affected by the policy. (Meadows and Robinson 1985:3)

Technological tools, including GIS, have proven to be effective for learning and deliberation. The active engagement process increases information retention, inspires creativity, and improves analysis skills (Cloud 2001). The process of sharing mental models identifies points of agreement and points of conflict. The areas of conflict draw attention to the underlying assumptions, and the modeling activity is a tool to make assumptions explicit so they can be clarified and challenged. The process ideally results in a model that describes the structural aspects of the system, while the model simulations provide information about system behaviour (Forrester 1987; Vennix 1996). The model can then be used to explore a range of future conditions or assumptions. Participants may engage directly in the modeling process, or the model may be developed in an iterative process with regular opportunities to contribute (van Asselt and Rijkens-Klomp 2002: 172).

Participatory modeling includes a range of levels and timing of stakeholder participation. The resulting model is more a by-product of team learning than a tool in itself (van den Belt 2004; Vennix 1996). Instead of focusing on the completed model as the primary goal, objectives of the process are to “enhance team learning, foster consensus, and create commitment with the outcomes” (Vennix, 1996:101). Consensus does not need to be actively encouraged; if the process is performed successfully, consensus is a natural outcome. Participatory modeling may occur over two days, or it may iterate over multiple years, depending on the context, available resources, and desired level of detail. This method is applicable to various stages of IA, from problem definition through implementation and adaptation of strategies.

1.3.7 Research directions in participatory planning

The field of participatory planning is still developing and there are areas that need attention. An investigation into the applicability, strengths, and weaknesses would provide guidance on the most appropriate and effective applications of the array of tools and methods available. The literature describes several areas for further growth and development: the timing of

participation, a new emphasis on building trust among the parties involved, and some reflection on which projects will actually benefit from PPs.

Early involvement of participants helps create a product that is useful to the end-users of the information. Involving participants in the development of project proposals helps to identify areas of research that are relevant to the interests of the community. Involving participants as early as possible not only serves to empower stakeholders and increase their interest and commitment, but also fosters relationships between the project leaders (researchers, scientists) and the community of stakeholders. According to William Werick (2004), who worked on a number of participatory projects during his career at the US Army Corps of Engineers, trust between project leaders and participants is the key to a successful process. Therefore, early engagement and patience must be part of the design.

Finally, consideration must be given to the appropriateness of participation in the current spectrum of environmental projects. The current philosophy is that all projects should engage the public or selected stakeholders in some way. Thus, the pendulum has swung from projects being exclusively in the hands of experts, to stakeholders participating in all processes. It is possible that the level of involvement of stakeholders should be tailored to the character of the problem. This would be a topic worthy of debate among academics, policy-makers, and the public.

1.4 Systems Thinking and System Dynamics

System dynamics is a useful tool for determining sustainable pathways, because it allows practitioners to examine the whole system as well as detailed components in both the short and the long-term. There are currently weaknesses in our decision-making processes, resulting in ineffective or counterproductive policies. System dynamics can support more consistent, structured processes that will lead to better management of resources, and pave the way to a sustainable society. System dynamics models “help to clarify our processes of thought[,]... help to make explicit the assumptions we are already making[, and]... show the

consequences of the assumptions.” Models are not static, but must change as our goals change (Forrester, 1985:133).

Systems thinking originates from the fields of process thinking, tektology and general systems theory developed in the early 1900's (Capra 1996). Jay Forrester is considered the father of system dynamics, as he developed the theory in the 1950's, drawing on principles of control theory (a.k.a. information feedback and servomechanism) and decision theory (Vogstad 2005). Early applications of system dynamics that have defined the field include the study of urban policy and growth (Forrester 1969); global resource dynamics (Meadows et al, 1972; 2004); and human behaviour in organizations (Senge 1990). More recently, system dynamics has become a tool for stakeholder participation in environmental decision-making. In a case study in which model was created for water resources policy analysis in Egypt, the authors concluded that the model's "transparency allows for more participation and empowerment of the public and all the stakeholders. The suggested framework provides a feedback mechanism that facilitates reaching solutions that enable the society to move away from the status quo according to its present priorities and objectives" (Simonovic and Fahmy 1999:303).

Systems thinking uses mental models, while system dynamics constructs formal models. Mental models have the advantages of being more flexible, rich in detail, and constructed from the largest source of information: collected experience. However, mental models are often fuzzy, incomplete, imprecise, and filled with unstated assumptions and goals. Furthermore, humans, with all their talents, are poor dynamics simulators. The process of creating formal models is a technique for overcoming these weaknesses. Contrasting behaviour predictions with a structured, internally consistent simulation provides the surprise discoveries that promote learning (Radzicki 1997).

System dynamics practitioners generally do not emphasize the final model as a finished product; instead, they propose that the modeling process is critical because that is where the learning occurs (Forrester 1985). In fact, the "most brilliant model and insights have no impact if they are not embedded in an effective learning process" (Jones et al. 2002:202).

Model output is much more meaningful when the user knows the internal relationships that drive the behaviour.

1.4.1 Characteristics of complex systems: rates, levels, and feedback loops

The system dynamics paradigm assumes that things are interconnected in complex patterns, that the world is made up of rates, levels and feedback loops, that information flows are intrinsically different from physical flows, that nonlinearities and delays are important elements in systems, that behaviour arises out of system structure (Meadows 1989:70).

Complex systems contain dominant non-linear interactions (which can rarely be solved analytically), feedback loops, and time and space lags (which muddle cause-effect linkages), as well as discontinuities, thresholds and limits. Two examples of complex systems are ecological systems and economic systems. Taken together, “linked ecological-economic systems are devilishly complex” (Costanza 1996:981).

Systems thinkers are concerned with underlying structure; however, it is rarely apparent. Karash (1999) provides a framework for developing understanding of system structure, through stimulating thinking about the differences between events, patterns, and structure. An event is the answer to: “What happened?” Patterns are identified by considering: “Where are the changes? The contrasts? The continuities?” To identify the underlying structure, the important questions are: “Why and how? What would explain the patterns?” Karash illustrates his point with an example of being stuck in traffic. The event is a car accident that is blocking the road. Patterns include the frequent accidents on this road, daily and weekly traffic patterns, and that drivers are more aggressive at these times. Insights into the structure include: (1) The old, narrow road’s poor sight lines increase accidents when traffic is heavy. (2) Most traffic to major north and south routes is funnelled into this corridor, increasing traffic load. (3) Drivers assume there is no room for police to monitor so they speed, which causes more accidents (Karash 1996).

1.4.2 Complex system behaviour

One reason that systems thinkers are so concerned with system structure is because of the premise that the internal connections within the system have much more control over the system than external forces (Forrester 1987; Meadows 1989; Stave 2003; Sterman 2000). For example, financial analysts look at global politics and external forces to make predictions about the domestic stock market. If systems thinkers were hired on Wall Street, they would spend more time investigating the internal workings of the market than on “external forces.”

When Forrester began studying systems, he discovered that many policies were ineffective, or worse – counterproductive. The internal structure of a system can have strong control over that system’s behaviour, particularly when there are negative, or dampening, feedback loops that dissipate the effects of external forces. Therefore, systems are often highly resistant to policy changes (Forrester 1987).

Luckily, there are still leverage points for influencing a system. Forrester often said, “People know intuitively where leverage points are. Time after time I’ve done an analysis of a company, and I’ve figured out a leverage point. Then, I’ve gone to the company and discovered that everyone is pushing it in the wrong direction!” (Meadows 1997:78). An example of this is when the Club of Rome asked Forrester to show relationships and solutions for the world’s biggest problems – poverty and hunger, environmental destruction, resource depletion, urban deterioration, and unemployment. Forrester’s response was that they were all related through one clear leverage point: Growth. The world’s problems are the costs of growth. The world’s leaders are correctly fixed on growth as the solution to the world’s problems. However, they are pushing in the wrong direction! (Meadows 1997)

Meadows describes nine places to intervene in a system. These points may vary for each application, but in general, they are, in order of increasing influence: (9) Numbers (subsidies, taxes, standards); (8) Material stocks and flows; (7) Regulating negative feedback loops; (6) Driving positive feedback loops; (5) Information flows; (4) The rules of the system (incentives, punishments, constraints); (3) The power of self-organization (evolution,

technical advance, social revolution); (2) The goals of the entire system; (1) The mindset or paradigm out of which the goals, rules, and feedback structure arise.

1.4.3 General model theory

Costanza provides a way of characterizing models as having high generality (conceptual breadth), high quantitative precision (analytical), and high qualitative realism (impact-analysis). Different models emphasize or de-emphasize these dimensions as appropriate for the context and purpose of the model as well as the available information. Due to real-world constraints it is rarely possible, or useful, to create a model that maximizes all three areas (Costanza 1996). For example, statistical approaches to flood frequency analysis are highly analytical, but very low in breadth and realism. The Rational method[‡] for determining peak discharge in a watershed is also analytical and low in generality, but contains more realism than the statistical model. The system dynamics approach may be customized for any type of model; however members of the system dynamics community typically create elegant, highly aggregated models that emphasize the aspects of realism (capturing system structure), as well as generality (including transdisciplinary information). One example is the interactive, educational Snake River Explorer model. The high level of aggregation reduced the model run time to only a few seconds. The integration of ground water and surface water flows into one model eliminated the need to transfer output and input between separate models. These characteristics were important to keeping the model user-friendly (Ford 1996). The Patagonia coastal zone management model provides another example. The “objective was not to describe the system and all trophic relations in great detail, but rather to “scope-out” important linkages between different parts of the system” (van den Belt et al. 1998:80).

In contrast, highly analytical mathematical models are often used for predictive purposes in narrowly defined situations (such as facility siting) and are inflexible and rigid (Cleveland 2001; Ford 1999; Stave 2003). Meadows and Robinson (1985) compares and contrasts system dynamics with econometrics, input-output, and optimization approaches. For

[‡] The Rational method is described by $Q = CiA$, where Q is the peak discharge in the watershed; C is the runoff coefficient based on land characteristics; i is the rainfall intensity; and A is the drainage area.

applications of quantitative environmental analysis, Vogstad (2005) discusses the assumptions contained in cost-benefit analysis, input-output and life-cycle accounting, environmental risk assessment, material flow analysis, and exergy analysis. Bagheri (2005) contrasts different characteristics of water resources models: deterministic vs. non-deterministic, lumped vs. distributed, steady vs. dynamic, and simulation vs. optimization. System dynamics models are typically non-deterministic, dynamic, and simulation-based.

1.4.4 Use of system dynamics models

Primary uses of system dynamics models in environmental applications are either: (1) to increase understanding of the current behaviour of the system (descriptive); and (2) to gain insight into the potential future behaviour of the system (predictive). The models are not predictive in the sense of forecasting or point prediction, but provide general understanding and guide future research efforts (Ford 1999). A descriptive model helps answer questions such as: “What is creating this pattern of behaviour? Why did the policy have no effect?” A model for exploring plausible futures can provide some answers to: “What will happen and what can we do about it?” A common objective for predictive models is to determine what future we really want and then to identify the leverage points we can use to get us there (Hughes 1999). Guiding questions that recur throughout the system dynamics literature are: (1) “Does the system have the potential for overshoot?” (2) “If so, does it matter? Is overshoot something worth avoiding?” (3) “If so, is there anything we can do about it?” (Jones et al. 2002; Hughes 1999; van den Belt 2004).

Exploring system behaviour can be an interesting academic exercise, but to have an impact on the “real world” the insights need to be communicated to the systems’ representative stakeholders, including resource managers and users. Conventional practice has been that “experts” develop models and communicate primarily the results to decision makers, and has had varying degrees of effectiveness. A newer, alternate approach is to engage policy-makers directly in the modeling process. Models created in computer code are not well-suited to engaging those who may not be technically proficient. Participatory modeling requires models with new qualities such as transparency, flexibility, and speed. For example, Nvule

(1993) described his experience with a new system dynamics model and compared it with what they used before. The previous model in Fortran was “inflexible and difficult to use by people not associated with its development. The process of building consensus among interested parties was a drawn out affair due to the time needed to assimilate the Fortran model results” (Nvule 1993: 492).

The system dynamics approach provides benefits over many analytical approaches. These models can: (1) Evaluate and compare policies; (2) Provide immediate feedback to participants on their ideas; (3) Display output in graphs enabling easy run comparison; (4) Engage interest by showing unexpected results; and (5) Help participants understand, stimulate discussion, and build consensus (Stave, 2003).

The structure of a model provides “a consistent and rigorous problem-solving framework” (Stave 2002:143) that can help overcome “some of the problems inherent in linear thinking and compartmentalized, non-participatory decision making” (van den Belt 2004:11). This provides a neutral framework for discussion in which alternatives can be discussed more objectively (Stave 2002). Furthermore, “system dynamics modeling can be effective because it builds on the reliable part of our understanding of systems while compensating for the unreliable part” (Forrester 1987:137). Forrester explains that the observed structures and policies are usually where everyone can agree. Predicting the behaviour of these structures and policies is where mental models fall short, so is commonly the area of disagreement. Making the inputs of the model the parts that are known – the structures and policies, while letting the model simulate and provide the system behaviour, allows more objective and effective debating to occur (Forrester, 1987; Stave 2002).

An effective model includes only the aspects that have a significant role in the behaviour of interest. The editing ease of system dynamics models provides a tool for distinguishing the critical features of a system that define its behaviour. The modeling exercise may recognize aspects which were previously disregarded as unimportant (Faust et al, 2004; Jones and Seville 2002; Stave 2002). Another technique for reducing the amount of unnecessary information in a model is to aggregate temporal and spatial scales. Aggregation does mask detail and reduce the amount of information in the model but it also helps to clarify model

output. Aggregation can preserve general trends and provide quick answers to questions commonly asked by policy makers (Simonovic and Fahmy 1999). It can also provide a broader context for the problem, changing the problem focus from decision makers' specific concerns to the more strategic level (Stave 2002; Stave 2003).

1.4.5 Challenges

There are challenges for using system dynamics for learning and decision support processes with stakeholders or the public. Sterman (2000:35) observes that, although "simulation models and virtual worlds may be necessary for effective learning in dynamically complex systems, they are not sufficient to overcome the flaws in our mental models, scientific reasoning skills, and group processes."

A possible risk when people, non-technical users in particular, use a computer model is "video game syndrome." This occurs when users thoughtlessly press buttons, trying as many different options as they can in the allotted time. Ideally, model users should start by selecting options carefully, then predicting the results, and only then running the simulation (Sterman 2000). Learning occurs when the modelled result is different than the expected result, so this middle step is a critical one.

All models will be "black boxes" to those who are unfamiliar with the underlying structure and assumptions used to build the model. System dynamics models, particularly STELLA™ and related software have graphical model interfaces that assist both technical and non-technical users in learning the model, with the intention of avoiding this problem. Regardless, in order to be accessible, models need to be kept as simple as possible, with a layout that is logical and easy to follow.

1.5 Managing Uncertainties for Planning

A decade ago, Shackley and Wynne (1996) noted:

It is frequently assumed that scientific uncertainty is a problem for environmental policy. Many decision makers and advisory scientists believe that policy ideally should rest on reliable, robust, and hence certain scientific knowledge. (p. 275)

Today, with the development of complex systems science as well as the focus on long-term sustainability, it is clear that additional science cannot always provide all of the answers. Shepherd et al. (2006) found that uncertainty was not an obstacle in implementing new policies when political will and enabling factors were present. However, in other cases, the presence of any uncertainty has been - and continues to be - an excuse for delaying action. One cause of this is the belief that scientific certainty is a prerequisite for building consensus (Shackley and Wynne 1996), and negotiations are delayed until more information is available. The climate change issue provides a prime example of this effect. To date, much of the focus has been on how to reduce the level of uncertainty in climate change predictions. Reduction of some of the uncertainty is reasonable, but uncertainties that are inherent to the system cannot be eliminated. Once inherent uncertainties dominate, then the focus should shift away from reducing uncertainties and move on to clarifying and communicating what is known about the system and determining effective and robust responses.

1.5.1 Inherent uncertainty vs. knowledge uncertainty

Diefenderfer et al. (2005) distinguish two sources of uncertainty: *knowledge uncertainty* and *inherent uncertainty*. Knowledge uncertainty, also referred to as epistemic uncertainty, is due to incomplete knowledge about the system. In modeling, knowledge uncertainties can be gaps in the model's structure or in the data required to support it. If a system contained only knowledge uncertainty, then, in theory, complete knowledge about the system could be achieved through further scientific investigation. In contrast, inherent uncertainty is a result of natural variability in processes such as non-linear and chaotic behaviour patterns; so when

present, no amount of research will generate absolute predictions. The belief that scientific knowledge that supports policy must be certain is a result of falsely assuming that all of the uncertainty present is a type of knowledge uncertainty.

1.5.2 Climate change and modeling

Moser and Dilling (2004) describe the uncertain character of climate change as one contributing reason why the professional water community, to date, has been reluctant to consider climate change in their planning activities. This is unfortunately not an uncommon response when modeling a system – to omit the elements for which we have limited understanding. For example, when the first report by the Intergovernmental Panel on Climate Change was generated in 1990, little quantifiable information was available on the natural feedbacks related to a warmer climate. Therefore, the authors omitted the information from the computer models (Leggett 2001). Unfortunately, when analyses lack elements that help define the behaviour of the system, policies developed from these analyses may not be ideal for the conditions that will be realized.

1.6 Case Studies in Participatory Modeling

This section provides an overview of case studies that used participatory modeling approaches, particularly in natural resources and water planning applications. Most of the case studies reviewed did not discuss inclusion of climate change (with the exceptions of Pataki et al. 2006; Ivey et al. 2004; and Kirshen et al. 2004).

The majority of participatory modeling processes to date used system dynamics models (STELLA, Powersim, Vensim) either as the primary tool, or in combination with other IA models and participatory methods (Cardwell et al. in preparation). One reason for this may be the transparency of these models, which allows active participation and empowerment of those involved in model construction and use (Simonovic and Fahmy 1999). A common alternative to system dynamics are generic simulation models tailored to water related

applications, which also support active engagement of stakeholders by their interactive graphical interfaces (Loucks 2006). Examples include WEAP which was used for collaborative planning in the River Njoro Watershed in Kenya (Jenkins et al. 2005), and MIKE BASIN, applied to the San Francisco public water supply (Borden et al. 2006) and to management of the Lehmi River Basin in Idaho (Borden and Spinazola 2006).

Participatory modeling by definition involves stakeholders in the development process. However, cases that used completed system dynamics models for education can provide insight into facets of stakeholder-model interaction. Two of these case studies noted the model users' backgrounds and prior knowledge significantly influenced their experience. A workshop to test the Snake River Explorer developed by Ford (1996) included faculty, students, and representatives of agriculture and electric power industry, environmental groups, native tribes, state departments and federal bureaus. Those who had extensive modeling backgrounds voiced concern about using such a highly aggregated model to educate the public. However, the remaining participants found that the model's simplicity enhanced their understanding. Stave (2003) developed a high-level model of the Las Vegas water resource system to educate the public and gain support for management policies. Although the insights were obvious to water managers, the tool effectively gave the public an appreciation for the influence of return flows and the constraints on managing the resource.

Forster and Journeay (2004) used a two-stage hybrid of the participatory modeling method to investigate the sustainability of water resources in the Gulf and San Juan island communities off the Pacific coast of British Columbia and Washington State. First, the researchers developed a generic model for an island system, characterizing groundwater and household dynamics. Then, they engaged island communities in turn through meetings with small groups of island residents to customize the model to each island and to discuss policy implications.

Letcher and Jakeman (2003) conducted a participatory IA modeling process for water allocation issues of the Namoi River Catchment in Australia. The authors concluded that the process takes a considerable investment of resources and therefore commitment by the participants. Because of this, the approach is most suitable for complex problems in which

the benefits will outweigh the costs. Furthermore, they observed that advantages to both parties achieved by the learning process can be realized whether or not the completed model is a success.

A collaborative modeling process for the Middle Rio Grande in New Mexico educated the public about the complexities of managing the resource by identifying tradeoffs, lags and feedbacks. One concern was the lack of involvement on the part of policy makers and their reaction to the results; however, several insights from the process were still incorporated into the regional plan (Cockerill et al. 2006; Tidwell et al. 2004).

Hare et al. (2003) compared four natural resource management case studies in Switzerland, Zimbabwe, Senegal, and Thailand to determine factors that influence process design. They identified: project goals, democratic participatory goals, researchers' normative beliefs, existing management power structures, stakeholder numbers, and the scale at which the final decisions need to be supported. These factors can also influence project outcome. Jones et al. (2002) developed a model of the forest industry in the northern-eastern United States with support from an advisory board of local stakeholders. The advisory board was supportive, but the modeling process did not inspire commitment because they did not share the same objectives of the project. Eventually the authors partnered with state forestry officials who shared the goal of sustainable forest management. A contrasting example is a mediated modeling initiative for the San Antonio Watershed in Texas (Peterson et al. 2004) which generated remarkable commitment by the local community. Participants requested to assist with planning meeting agendas, enforced established protocol among disruptive newcomers, and maintained the council after the facilitators' year-long commitment ended.

Participatory modeling case studies vary considerably in their level of breadth and in the issues they characterized. Pataki et al. (2006) and Durfee et al. (2004) describe an application to determine the dominating influences on air quality in the Salt Lake Valley, Utah. Sumer and Lansley (2004) assessed both surface and groundwater sources in the Upper San Pedro Basin in Arizona. Costanza and Ruth (1998) developed ecologic-economics models of the Louisiana coastal wetlands and of the Patuxant River watershed in Maryland. Van den Belt et al. (1998) developed a model for the Patagonia coastal zone, which included sectors for

fisheries, oil pollution from tanker spills, penguins, and tourism. The model of the San Antonio watershed by Peterson et al. (2004) concentrated on social and environmental issues.

A specific application of collaborative modeling has been named “Shared Vision Planning” (SVP). Palmer et al. (in review) describe SVP as a combination of traditional water resources planning, structured public participation, and the use of an integrated computer model. Early applications of SVP used watershed simulation models to train water managers in “Drought Preparedness” workshops (Keyes and Palmer 1993; Keyes et al. 1995; Palmer et al. 1993). Two recent applications of SVP include the Rappahannock Basin in Virginia (Conner et al. 2004) and a project in the Mississippi headwaters that combined simulation with optimization Cardwell et al. (2004).

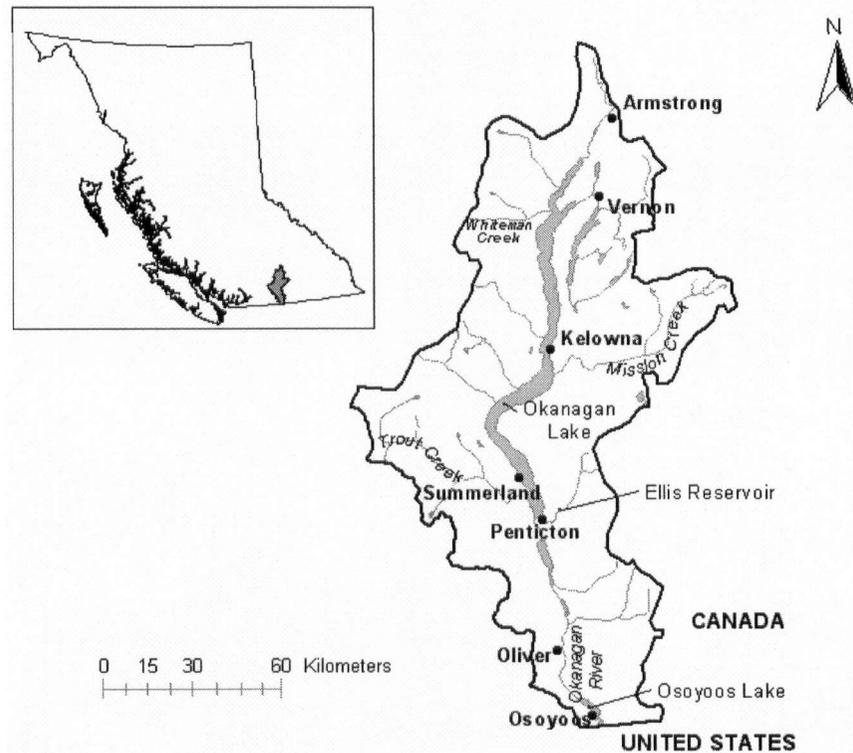
Participatory modeling case studies that explicitly addressed the issue of climate change were much rarer. Selected models developed for SVP case studies were used to assess the impacts of climate change, but only after the stakeholder process was completed (IWR 2003). Pataki et al. (2006) included the climate linkage, but it became a minor part of the project. Another case by Ivey et al. (2004) evaluated the adaptive capacity of a community in southern Ontario, Canada through interviews and data collected from stakeholders, but did not include a formal modeling process. One participatory modeling case study did focus on climate change. Kirshen et al. (2004) actively engaged stakeholders throughout their multi-year process of modeling and evaluating climate impacts on water, energy, transportation, and public health sectors in Boston, USA.

1.7 The Okanagan Project

The Okanagan Basin in south central British Columbia is one of the most arid regions in Canada, with annual average precipitation ranging from less than 300 mm to 450 mm. The long, narrow basin extends 182 km from the Canada-U.S. Border and covers an area of 8200 km² (Figure 1.2). Presently, water resources in the area are under stress due to recent rapid population growth, intensification of irrigated agriculture and recreational activities, and

extensive logging at higher elevations. Drought conditions in 2003 and 2004 resulted in water shortages and major fires. These changes have already raised concerns about the reliability of the Okanagan's water resources. In the future these trends are likely to continue, and may be exacerbated by additional stresses caused by climate change.

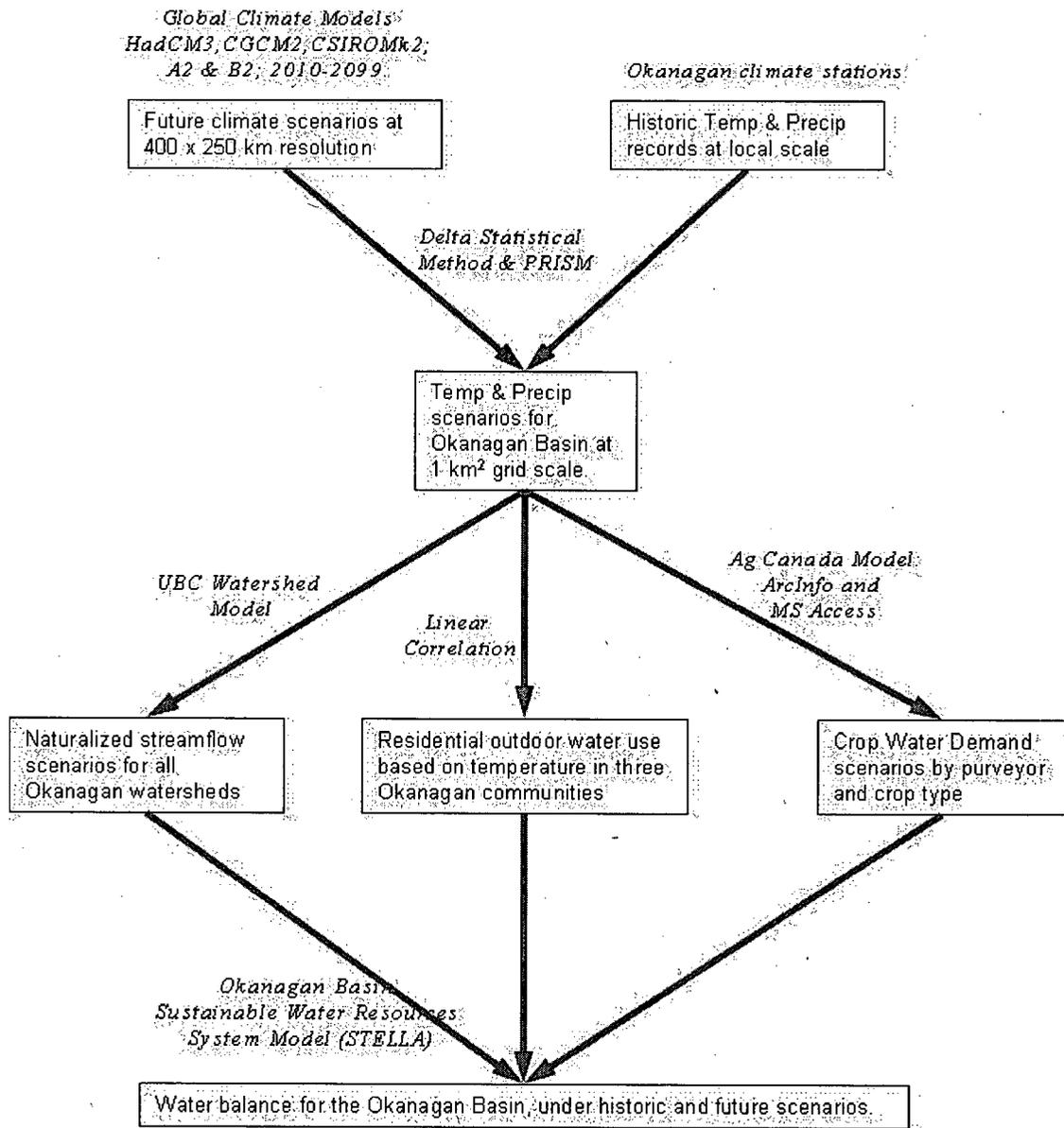
Figure 1.2: Okanagan Basin Map with inset for location in British Columbia (from Cohen et al. 2006).



1.7.1 Previous work

Prior to commencing the work described here, substantial work had already been conducted in the region that allowed this work to happen. Specifically, the early studies (1) generated quantitative scenarios for water supply and demand under climate change; (2) developed positive, trusting relationships with the professional water management community; and (3) increased awareness and concern among this Okanagan community about potential climate change impacts as well as adaptation opportunities (Cohen and Kulkarni 2001; Cohen et al. 2004).

Figure 1.3: Flow chart illustrating the progression from climate models and local records to supply and demand inputs to the Okanagan Sustainable Water Resources Model.. (Sources: Cohen et al. 2004; Neilsen et al. 2001; Merritt and Alila 2006; Neale 2005; 2006)



The work described in this thesis relied heavily on climate scenarios developed for both water supply and demand. Sources of information, from the global climate models to the inputs used, are traced in the flow chart shown as Figure 1.3. Taylor and Barton (2004) generated regional climate scenarios for the Okanagan by correlating global climate model output to local climate stations using the “delta” method, in which the baseline data is perturbed by averages derived from the generalized circulation models (GCMs) (Nielsen et al., 2006). These climate scenarios show mean temperature increases between 1.5 and 4 degrees Celsius throughout the year, with generally wetter winters and drier summers. The regional climate scenarios provided the means for three modeling initiatives in hydrology, residential demand, and crop water demand. Merritt and Alila (2004; 2006) used the regional climate scenarios in the UBC Watershed stream flow runoff model to generate hydrologic scenarios. The results show significant changes to the annual hydrograph from the historic period (1961-90) to the period from 2010 to 2099. All scenarios show a reduced snowpack, an earlier onset of the spring freshet by four to six weeks, and decreases in summer precipitation. Some scenarios also show more intense (peakier) spring freshets. Nielsen et al. (2004) used the climate scenarios to model the impact on agricultural crop water demand. Higher temperatures increase both evapotranspiration and the length of the growing season – two factors which increase crop water demand. As a result, crop water demand scenarios estimate an increase from 12 to 61 percent, as climate change intensifies through the decades. Furthermore, Neale (2005) correlated residential outdoor watering with temperature and detached dwellings for several Okanagan communities, showing that water demand in the residential sector will also increase under climate change. Each of these results on its own tells us important but limited information. Only by integrating these stories can we determine the changes to the water resource system in the future.

Relationships with stakeholders were developed during the five years immediately preceding initiation of this project. Focus groups in early 2001 reacted to single-scenario future hydrographs and generated an extensive list of potential impacts (Cohen and Kulkarni 2001). In 2002, Shepherd investigated and analyzed several communities considered “early adopters to climate change” because they had implemented demand-side management strategies to monitor and/or reduce water use. She identified the greatest challenges to implementing

strategies as: attitudes, perceptions and values; financial issues; and politics and policies (Shepherd et al. 2006). During a series of workshops between fall 2003 and winter 2004, stakeholders investigated the feasibility of implementing adaptation strategies at both the local and the regional scales. Through this, we learned about the community's attitudes, perceptions, and policies related to adaptation options, such as the lack of knowledge about and regulation of groundwater, the belief that water conserved by agriculture will support the increasing urban populations, and that water in the tributaries is perceived to be cleaner than the mainstem lake water (Tansey and Langsdale 2004).

Throughout the stakeholder engagement initiatives, as well as collaborations with related projects, researchers communicated their results on climate change to the Okanagan community. Attendance at the outset in 2001 was low, but steadily increased over time as the message spread that the Okanagan's water resources could be significantly impacted by climate change. By the start of the group model building work described here, results from the climate scenarios were starting to take a role in the development of local planning initiatives (Summit 2004).

1.7.2 Research objectives

The broad purpose of both these earlier projects and the work described here is "to ensure that information is available to Canadian decision and policy makers on: the environmental, social and economic impacts caused by vulnerabilities to atmospheric change, variability and extremes; and viable adaptive responses" (Environment Canada 2002). This project worked toward these goals by encouraging and enabling the region's water professionals to incorporate climate change in their water resources planning initiatives by (a) translating the climate change information into terms that are relevant for the local water community, and (b) engaging them in an exploration of the relevance of climate change in the water resources futures. As a result of these initiatives, water resource professionals are enabled to make better decisions regarding management of their resource, including whether to implement anticipatory adaptation measures or to opt for the reactionary approach.

The research project described in this thesis consisted of two related components: (1) Developing a system dynamics model to characterize water resource futures in the Okanagan Basin, and (2) Conducting a participatory process that actively engages the region's water professionals in the model's development. The participatory modeling process is described in Chapter 2, while a description of the model and a summary of results are provided in Chapter 3.

The purpose of developing the model was to generate new insight into plausible future conditions of the Okanagan's water resources through assessing impacts in an integrated system and identifying dominant feedback loops, lags, and non-linear relations. Specifically, we explored: (a) The current state of the system (through studying recent decades); (b) The effect of climate change and population growth on the balance of future water supply and demand; and (c) The role that adaptation measures might have in future management. Although the model is valuable on its own, the main purpose of the model, in this project, is to stimulate and enhance discussion about water management and climate change among members of the Okanagan community that influence water management.

The purpose of the participatory process was to create a shared learning experience between the study area's water resource-related stakeholders and the research team. Additional goals were to tailor the model to the needs of the participants (the model users), and to foster ownership and trust in the model among the participants. Actively engaging stakeholders who are experts in the issues supported accurate characterization of the system and fostered trust in the model. Participants identified critical features of the system, provided data, and helped with calibration. The participatory process supported learning through hands-on interaction with the model and from discussions with other stakeholders. Through this process, participants increased awareness of potential climate change impacts within the system context and of the complexities in managing the system. These benefits are steps that support ensuring the reliability of future water resources through effective policies and management decisions.

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CHAPTER 2: SHARED LEARNING THROUGH GROUP MODEL BUILDING FOR THE MANAGEMENT OF WATER RESOURCES AND CLIMATE CHANGE IN THE OKANAGAN RIVER BASIN, BRITISH COLUMBIA, CANADA*

Climate change is affecting hydrologic patterns in many regions of the world; however, very few communities have incorporated climate change into their planning initiatives. The purpose of this research was to assist the water resources community of the Okanagan Basin, British Columbia, Canada with incorporating climate change in their planning and policy development and with evaluating their water resources in an integrated system context. This was conducted through a participatory process centered on the development of a system dynamics model. The study focused on the possible impacts of climate change on water resources management and on a wider range of issues jointly defined by the participants and researchers. The products of this process were: (1) A shared learning experience among the participants and the research team; and (2) A simulation model for increasing knowledge about the system and exploring plausible future scenarios and adaptation opportunities. This paper describes the group model building process, while Chapter 3 provides more detail about the resulting system dynamics model.

The primary objective of this effort was to foster a shared learning experience between and among our research team and the Okanagan water management community. We investigated the plausible effects on the integrated supply-demand balance and the efficacy of adaptive management strategies. The emphasis was on high-level scoping and futures exploration, rather than on consensus-building and decision-making. The products of this process enable the Okanagan community to incorporate climate change in their planning activities, and to encourage appropriate adaptation to reduce future vulnerabilities. Specifically, the goals of the process were: (a) To create a shared learning experience that broadens people's

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perspectives and clarifies the complex relationships that define the water resources system; (b) To develop a tool for exploring plausible water resources futures that is tailored to the needs of the Okanagan community; and (c) To foster a sense of ownership and trust in the model among the model building participants.

2.1 The Okanagan Basin

The Okanagan Basin in south central British Columbia is one of the most arid regions in Canada, with annual average precipitation ranging from less than 300 mm to 450 mm. The long, narrow basin extends 182 km from the Canada-U.S. Border and covers an area of 8200 km² (Figure 2.1). The major economic industries in the basin are agriculture, forestry and recreation. Agriculture accounts for approximately 70 percent of annual water use in the basin. The Okanagan River is one of the only tributaries to the Columbia River that still supports viable salmon populations.

Rapid development in recent decades, combined with natural hydrologic variability, has increased concern among water resource managers. In the twenty years between 1978 and 1998 the population in the Central Okanagan doubled and the rest of the basin also experienced rapid growth that far exceeded projections (BC Stats 2006; Canada-British Consultative Board 1974). Drought conditions in the summers of 2003 and 2004 caused water shortages and major fires, leading to a public review of emergency preparedness (Filmon 2004).

2.1.1 Previous initiatives in the Okanagan Basin

Prior water management and climate change research initiatives (Cohen and Kulkarni 2001; Cohen et al. 2004; 2006) provided a foundation for conducting the community engagement process described herein. These early dialogues increased concern for climate change among the region's water management community and established trusting relationships between

members of the research team and key water-related professionals, elected officials, and environmental-interests group representatives in the region.

Figure 2.1: Okanagan Basin Map with inset for location in British Columbia (From Cohen et al. 2006).



First, these studies led focus groups to brainstorm and prioritize a wide array of potential climate change impacts (Cohen and Kulkarni 2001). This was followed by community level and basin-scale workshops, where participants discussed the social, financial and political feasibility of implementing climate change adaptation measures (Cohen et al. 2004; 2006). These consultations with the community informed the research team of the political climate in the Okanagan, as well as residents' attitudes and beliefs about adaptation measures, their water resource, and climate change. Water is a "hot topic" in the region, with at least 68 different governing bodies conducting water-related studies in the basin (Stephens 2006). These early events contributed to increased concern for climate change in the region. Prior to our efforts, climate change was not discussed in local water resource circles. By the time the

group model building project was initiated in January 2005, climate change was the principal issue that drew participants to the table.

The products of these early dialogues were primarily qualitative. The participatory modeling process described herein was initiated in order to continue the learning process. This project built on the earlier studies by continuing dialogue, integrating the sectoral climate impacts into a single model, and creating a means of evaluating the effectiveness of adaptation options. The model supported effective dialogue at the workshops by providing a common visual language, keeping discussion focused, and actively engaging each participant.

2.2 Climate Change in Water Resources Management

In many geographic areas, climate change will have significant impacts, so the conventional method of relying on historic data to estimate future conditions is inadequate. New methods for assessing the future are necessary to maintain the reliability of water resource systems over the long term.

2.2.1 State of the field

The literature contains several case studies in which researchers have conducted impact assessments to identify the impacts of climate change on water resource management of river basins (Lettenmaier et al. 1999; Middelkoop et al. 2001; Mote et al. 1999; Payne et al. 2004; Simonovic and Li 2003). Some climate change assessments also focused on aspects of adaptation (Beuhler 2003; VanRheenan et al. 2004). Two studies from Europe interviewed water managers to determine their reaction to adaptation scenarios (Tol et al. 2003; Arnell and Delaney 2006). Within the climate change literature, only two recent case studies have been identified that interacted with stakeholders during the assessment process. Ivey et al. (2004) evaluated the adaptive capacity of a community in southern Ontario, Canada through interviewing and collecting information from stakeholders. Kirshen et al. (2004) actively

engaged stakeholders throughout their multi-year process of modeling and evaluating climate impacts on water, energy, transportation, and public health sectors in Boston, USA.

These climate change impact studies are relatively recent, and direct use of the information by practitioners is only beginning. In 2005, only four U.S. states included climate change in their water resources planning (Viessman and Feather 2006). In Canada, two examples of climate change being incorporated explicitly into water planning are the Trepanier Landscape Unit Water Plan (Summit 2004), which followed from work by Cohen et al. (2004); and work on the Great Lakes – St. Lawrence River Basin (Mortsch and Mills 1996).

2.2.2 Challenges of incorporating climate change in water resource planning

There are three prerequisites that must be met for water managers to be willing and able to incorporate aspects of climate change into their water planning initiatives. First, the water management community must be informed and concerned about climate change. Second, information about potential climate impacts must be translated into terms that are relevant to the water community. Third, the water community must be able to assess the climatic impacts within the system context, including other stressors, changes, and management responses. Each of these tasks contains specific challenges that this project addresses.

There are several reasons for the lack of awareness of climate change among water resource professionals. First, detecting the climate signal is challenging, as the signals are often confused with noise, or not felt directly (Berkhout et al. 2004). In areas where climate change has not yet had significant impact, the “signal” is only virtual, in the form of scientific predictions. This adds a new dimension of complexity; since there is significant uncertainty in the character of climate change how we should respond is not clear. Humans respond more readily to stressors that we personally experience than those that we learn about indirectly. The creeping nature of climate change makes it easy to ignore. Because our human nature encourages us to focus on immediate crises, small incremental changes are disregarded and continue freely until a disaster occurs (Moser and Dilling 2004). Many climate adaptation

proponents focus on extreme events; however, in the case of water resources management, the series of small events, or the shift in patterns to a more non-equilibrium dynamic can be more damaging (Dowlatabadi and Yohe 1999; Scoones 2004). For example, damage due to gradual shifts was demonstrated in an analysis of reservoir operation in the Columbia River Basin. Researchers at the Univ. of Washington's Climate Impacts Group discovered that it was the seasonal shifts of inflow that had the most significant impacts on system performance (Payne, et al. 2004).

The second challenge to enabling water professionals to incorporate climate change is that the information typically generated by climate scientists is not directly relevant to local water professionals. In order to incorporate climate change estimates into their planning processes, climate change information must be translated into terms that are relevant to their concerns. While the level of uncertainty in climate estimates makes the information cumbersome, the mismatch of scales is a larger hurdle. Current global climate models provide information at large geographic scales and low spatial resolution, but managers handle small geographic areas and require data with relatively high spatial resolution (Lins et al. 1997). Furthermore, climate change data must be translated from temperature and precipitation into terms reflecting hydrologic impacts.

Finally, even if the first two challenges are surmounted, and concerned water professionals acquire relevant information, there remains the challenge of integrating the information within the system context. For example, climate change is likely to impact not only the availability of water supplies, but also water demand. At the same time, other stressors, such as urban development and economic trends may also affect demand in various sectors. Only by considering climate change in the system context can we estimate future conditions and then evaluate effective responses. To date, most work has focused on specific components rather than the entire system. For example, Downing et al. (2003) assessed the impacts of climate change on various water demand sectors with the caveat that the results need to be considered as one element in a larger system.

2.3 Methodology

This section highlights the literature from integrated assessment and participatory modeling. The evolution of the field of participatory modeling is provided, along with a discussion of advantages and disadvantages. Finally, the objectives for this project are defined.

2.3.1 Integrated assessment

Integrated assessment is a methodology that examines a problem in the context of the entire system, ideally incorporating all components that affect the critical issue. Dowlatabadi and Morgan (1993) observed that researchers often only captured those components where information was available. They proposed a new paradigm of integrating subjective, expert-based knowledge with the better-known parts of the system. Engaging stakeholders in the assessment process is one way of accomplishing this. Rotmans and van Asselt (2002) noted that effective integrated assessment cannot be completed by scientific experts on their own, but only through collaboration with stakeholders and decision-makers. Today, stakeholder participation in environmental resource planning and management is common practice.

2.3.2 Participatory modeling

Stakeholder participation in the development of computer models for environmental decision-making is a relatively new field but is rapidly becoming the status quo. Participatory modeling processes have developed from a number of different fields; as a result, there are several names and variations on the parameters by which this work is conducted for purposes ranging from shared learning to consensus building.

Literature in the integrated assessment field uses the term “participatory modeling” to describe applications in policy analysis and organizational learning, as well as natural resource applications such as water resources and land management. According to Videira (2005), the term “group model building” from the system dynamics community has most often been applied to organizational messy problems (Richardson and Anderson 1995;

Vennix 1996; 1999) but has also been applied to sustainability issues (Stave 2002; 2003). The term “mediated modeling” originated from the ecological economics community in the late 1990’s and has been applied to solving complex environmental problems (van den Belt et al. 1998).

Participatory modeling has several advantages (Cockerill et al. 2004; 2006; van den Belt, 2004; Vennix 1996):

- Participants learn the underlying model structure, not only the results. This fosters a higher level of learning.
- The “black box effect” is reduced; assumptions and uncertainties are transparent.
- The model can be customized to the needs of the users, capturing critical issues and presenting the information in a format that is clear to them.
- Increases ownership and trust of the resulting model, and therefore the probability of continued use.

Furthermore, there are several ways in which a participatory modeling process enhances communication and the opportunity for consensus building:

- System dynamics provides a common language that circumvents industry-specific jargon.
- The model organizes ideas into a visual language that helps keep discussion focused, reducing tangents and circumlocution.
- The system dynamics approach encourages a broader perspective and reduces anchoring on individual agendas.
- Individual perspectives are acknowledged and respected by the group when they are included in the model. Once the participants see that their ideas are captured, they no longer feel the need to “soap box” about them.

Disadvantages of participatory modeling, as compared with conventional modeling, are the increased requirements of financial resources, time and logistical planning needed to engage the participants in the process.

Participatory modeling approaches are particularly appropriate for complex problems, especially ones where conflict is anticipated. The process can meet one or more of the following goals: foster team learning, share information between stakeholders, foster future vision, develop consensus, and generate commitment. Specific characteristics of the applications vary widely, depending on the context, available resources, and desired level of detail. The process may take days to years, and may result in a simple scoping model or a detailed management support model. Often the model is not the primary goal, but is simply a means to enhance team learning, foster consensus, and create commitment with the outcomes (van den Belt 2004; Vennix 1996).

An approach applied exclusively to water resources planning and management applications evolved from work on drought planning that began in the mid 1970's. The methodology, formalized as "shared vision planning" (SVP) in the early 1990s has been applied to a number of studies over the past fifteen years by the Institute for Water Resources, U.S. Army Corps of Engineers. SVP combines traditional water resources planning principles, structured public participation, and integrated computer modeling (Palmer et al., in review). Participants are empowered by: (1) influencing the modeling process directly; (2) increasing their knowledge of the physical system and appreciation of the perspectives of fellow participants; (3) being able to use the model independently; and (4) the resulting confidence in the results (Palmer et al. 1993). Six of the case studies did consider climate change, but not until after the stakeholder participation phase (IWR 2003).

2.3.3 Process design: means and ends objectives

In designing the group model building process, we identified primary objectives and actions that could support these primary objectives. The primary objectives are "ends objectives," while the actions that support them are "means objectives." The ends objectives are:

Ends 1: To create a shared learning experience that broadens participants' perspectives and clarifies the complex relationships that define the water resources system;

Ends 2: To develop a tool for exploring plausible water resources futures that is tailored to the needs of the Okanagan community; and

Ends 3: To foster a sense of ownership and trust in the model among the model building participants.

Three means objectives for this process were: (1) Gathering a diverse group of stakeholders; (2) Engaging the participants actively in model development; and (3) Using the system dynamics model as a tool to enhance communication.

Means 1: Gather a diverse group of stakeholders, including the basin's water-related professionals, environmental NGO's, and researchers, that have a role in managing the regions' water resources.

By bringing together people with a variety of perspectives, discussion at the model building sessions can include a variety of issues and reveal different concerns and attitudes across the basin. The gatherings thus become a learning experience for both participants and facilitators.

An additional benefit of gathering a diverse group is the networking opportunity among people who are stewards of the basin's water resources. The relationships developed during the process can build community and support cooperation in times of future drought and water conflict. This benefit is experienced subtly and over time and is thus difficult to measure.

Means 2: Actively engage stakeholders in the modeling process.

Having the participants take an active role in the modeling process helps both Ends 2 and 3. Ownership of the model can only be developed by working directly with it, and the participants must guide the process to ensure that the model suits their needs.

Means 3: Use the system dynamics model as a mechanism to enhance communication

The primary strength of a participatory modeling process is that the system dynamics modeling tool serves as a mechanism for supporting effective communication among a group with varying levels and types of expertise. When communication is not effective, negotiation frequently breaks down because of misunderstandings from unclear verbiage, unstated assumptions, and/or failed logic. The system dynamics model supports dialogue through its explicit, common language that surpasses technical jargon. It also forces people to recognize and clarify unstated assumptions, thereby helping to question the logic based on these assumptions.

Although the focus of this process was not on developing consensus, we established an environment that supported the initial steps of negotiation. Fisher and Ury (1981) explain that effective negotiation avoids the confrontation resulting from personal agendas. Frequently parties enter dialogue having already determined their best solutions. This, however, is not ideal, nor is it usually effective. If, instead, parties begin by communicating their values and objectives, they can work together to identify win-win solutions. In the ideal use of the tool, emphasis is placed on first understanding the system of mutual interest to the parties involved in the process. Only after this should alternatives be discussed.

Using a system dynamics model to enhance communication fosters a shared learning experience with particular emphasis on understanding the inner workings of the complex system. Van de Kerkhof (2004) reports that in first-order learning people simply memorize facts, while in second-order learning people learn processes and relationships. In this work we wanted to foster second-order learning so that the participants would gain an appreciation for how human activities as well as climate change will impact water supply and water demand. These relations provide a foundation for comprehending why some adaptive strategies would be more effective than others, thus encouraging responsible management policies.

The philosophy of system dynamics, referred to as "systems thinking," also encourages second-order learning. Therefore, we selected a system dynamics general software platform to use in this process. System dynamics software packages are flexible enough to integrate

various formats of information. Commercially available software packages (STELLA™ was used in this project) contain a graphical, transparent modeling language and provide tools for building interactive, user-friendly interfaces that are ideal for engaging participant groups with a range of technical proficiency.

Brief written surveys were administered at the beginning and end of the last two workshops that aimed to measure these goals. Participants completed the surveys anonymously and submitted them immediately after completion. Copies of these surveys are attached in Appendix B. Responses are summarized in the Results section.

2.4 The Group Model Building Process

This section highlights how the design of the participatory process worked toward meeting our objectives. Additional details about the process are available in Langsdale et al. (2006).

2.4.1 Participant recruitment

Invitations to join the participatory process were issued to selected individuals and representatives of organizations, rather than advertising publicly, because we wanted to create a diverse and balanced representation of the various organizations and responsibilities related to water resources management in the Okanagan Basin. The invitation list was compiled from the contacts we had established in previous phases of the project, by targeting key organizations and representatives, and through referrals. All participants were invited to attend all of the meetings detailed in Section 2.4.2 and Table 2.1.

Figures 2.2 and 2.3 show an aggregation of the levels of participation attained throughout the series of workshops and meetings. In Figure 2.2, participants are categorized by their affiliation and their major role in Okanagan water management. Affiliations are categorized as: First Nations, Federal, Provincial (BC), Regional District, or Local Governments; Environmental Non-Governmental Organizations (E-NGO); Academia; Irrigation Districts;

Figure 2.2: Attendance at all events by participants categorized by affiliation. Plotted as a comparison to the total number of people, and weighted by the number of events each person attended.

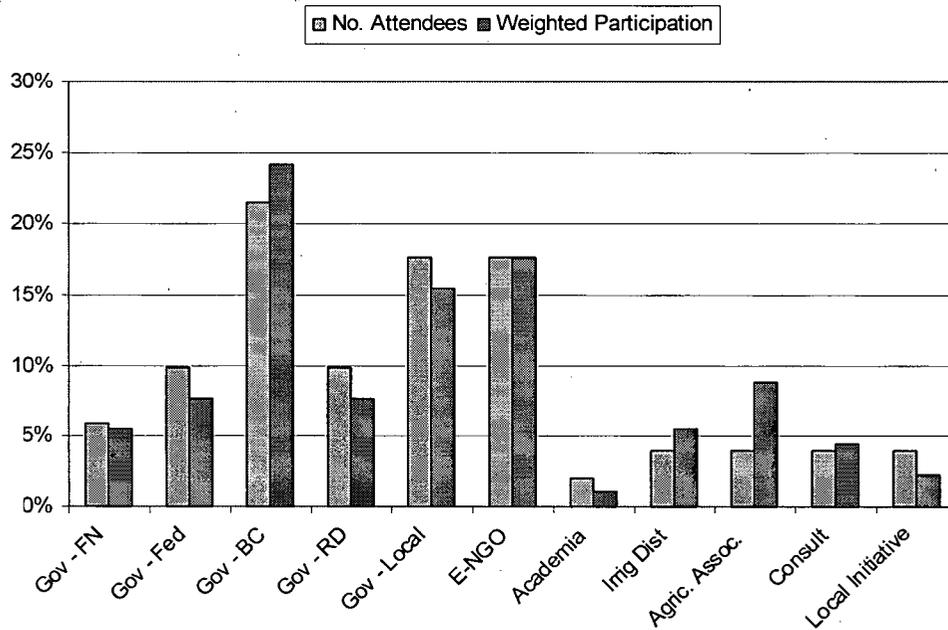
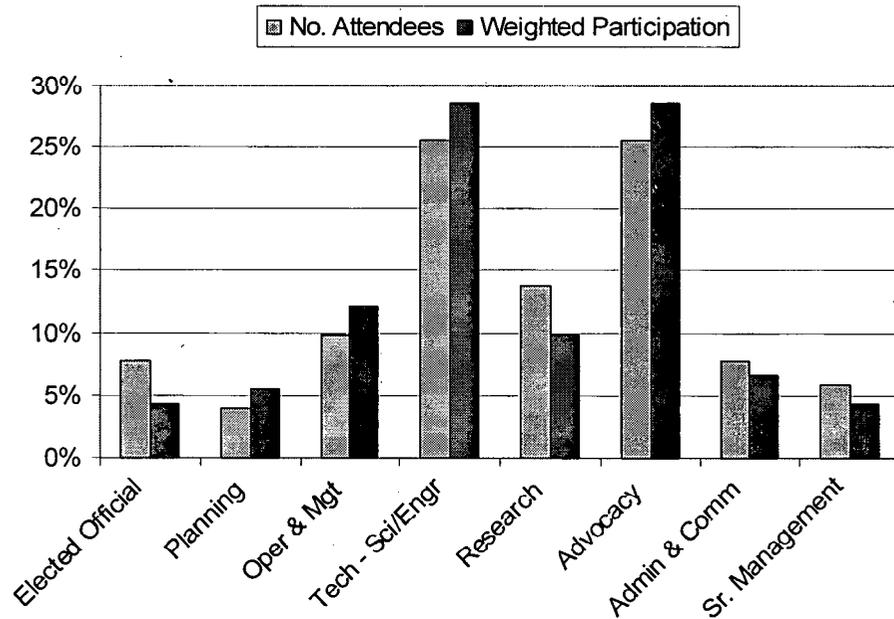


Figure 2.3: Percent attendance of all participants at all six events, categorized by role in Okanagan. Plotted as a comparison to the total number of people, and weighted by the number of events each person attended.



Agricultural Association (BC Fruit Growers Association); Consultancy; or Local Initiative (The Okanagan Partnership). The groups most strongly represented were the Provincial and Local governments and environmental NGOs, each representing greater than 15 percent of total attendance.

In Figure 2.3, participants are categorized by their occupational role according to these types: Elected officials; Community and resource planners; Practitioners in operations and water management; Technical scientists and engineers that provide support from within an agency; Researchers; Advocates (for environment, business or agriculture); Administrative or Communicative roles within an organization; and Senior Managers (who have technical expertise but have advanced to management). The data reveals that roughly half of the total participation was comprised of technical experts and advocates, each of which represented 25 percent of total attendance.

Figures 2.2 and 2.3 plot the number of participants as a percent of the total and an indication of active participation. Active (or “weighted”) participation accounts for the number of events that each person attended according to the following relation:

$$\text{Weighted.Participation}_i = \frac{a_i}{\sum_{i=1}^n a_i} \times 100\%$$

where,

$$a_i = \sum_i (\text{Participant}_i \times \text{No.Events.Attended}_i)$$

i = affiliation type or role

n = total number of affiliations (11) or roles (8)

In Figures 2.2 and 2.3, both the numbers of participants and the weighted participation values are shown as percentages so that the results may be more easily compared. When the active participation bar is higher than the number of participants bar, then attendance by members

of this group was higher than average. For example, attendance by both the agricultural association (BC Fruit Grower's Association) and the Provincial Government was higher than average.

2.4.2 Involving participants in model development

The model development process was divided into six phases, based on the five phases used in the UTES Airshed Study (Forster, personal communication). Members who joined the participatory modeling process were invited to contribute to all six phases to maximize their opportunities to contribute and to stay informed on model progress. Each of the events listed in Table 2.1 emphasized one of these phases. The six phases are: (1) Visioning, (2) System Mapping, (3) Structure Construction & Refining, (4) Quantitative Information Gathering, (5) Model Calibration, and (6) Futures Exploration.

All of the workshops were held in Kelowna because of its central location in the Okanagan. The small group meetings were held in various locations throughout the basin, each hosted by one or more participants at their place of employment.

We engaged the participants through plenary dialogue, hands-on activities, and interaction with the system dynamics model. I chaired each meeting, with support from at least two others in each workshop who facilitated sessions, group activities, and model explorations. In the first and second workshops, I asked the participants to brainstorm objectives for the model including research questions to investigate through use of the model. The objectives and the research questions were closely related. The research questions are summarized as:

- (1) Characterize the current system. What is the current (annual and seasonal) water supply and what is current use or demand? Characterize a basin-wide water budget.
- (2) Characterize the future system: What are the sustainable limits to growth in the Okanagan? What ranges of change are possible to supply, demand, and water quality due to climate change, population growth, increased population density, drought, and land use impacts (from development, forestry).

- (3) What policy levers are effective and how effective are they? What are the trade-offs we will have to make for competing demands? Can we maintain our current quality of life?
- (4) Make the results easily communicated and understandable so that the model can be used to educate decision makers and the general public.

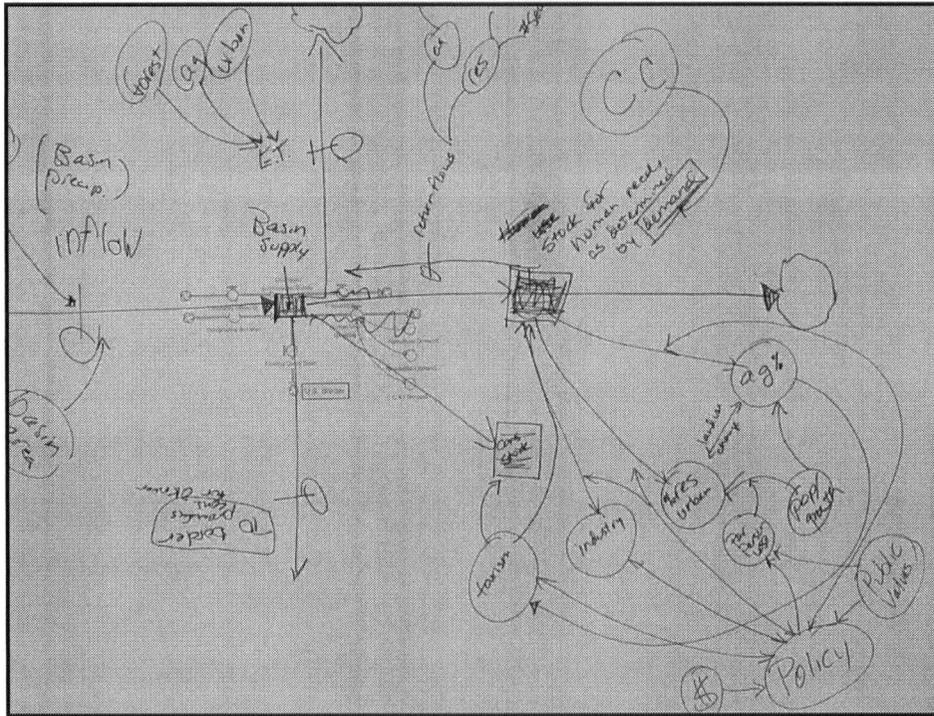
Participant groups also actively supported model development when they created sketches of the important elements that influence water supply and demand in the basin. An example is shown in Figure 2.4. The themes captured by these images served as the foundation for developing the first version of the model. The first working version of the model was presented in the third meeting where participants explored both the model's structure level and the user interface in facilitated groups with three to four participants. Participants evaluated the information captured in the model and made suggestions for further refinement. In Workshops 4 and 5, participants interacted directly with the model, working in pairs at each laptop to encourage dialogue and critical thinking about their model explorations.

The model interface directs users to first simulate and explore historic conditions by reviewing a number of output graphs. Then, the user enters a futures area in which he/she can select scenario settings for simulation period, climate scenario, and population growth rate. Next, the user may test adaptation options and water management policies. Output graphs on the adaptation pages help to describe the options, while more general output graphs reveal the impact on the system's balance of supply and demand. Images of the model's user interface are attached in Appendix C.

Table 2.1: Summary of events in the group model building process

Event	Date(s)	No. of Attendees	Major Tasks/Objectives for Participants
Workshop 1	22 Feb 2005	19	(1) <u>Visioning</u> : <ul style="list-style-type: none"> ▪ Learn concepts of Systems Thinking ▪ Brainstorm/Discuss objectives for model and process
Workshop 2	15 Apr 2005	13	(2) <u>System Mapping</u> <ul style="list-style-type: none"> ▪ Learn capabilities of STELLA™ ▪ Sketch first version of model on poster-sized paper ▪ Discuss appropriate scales & research questions for model to answer
Workshop 3	1 June 2005	10	(3) <u>Structure Construction & Refining</u> <ul style="list-style-type: none"> ▪ Review & evaluate the first computer version of the model, both the model structure and the user interface levels
Small Group Meetings (5 events)	27 Sept – Oct 3 2005	19 total	(4) <u>Quantitative Information Gathering</u> <ul style="list-style-type: none"> ▪ Review updates to model structure ▪ Provide data to fill specific gaps ▪ Evaluate if early results are realistic ▪ Recommend priorities for further model development
Workshop 4	7 Dec 2005	17	(5) <u>Model Calibration</u> <ul style="list-style-type: none"> ▪ Verify historic and future model simulations according to personal experience (using model interface and referring to structure as needed) ▪ Evaluate user interface and selection of alternative management strategies
Workshop 5	26 Jan 2006	13	(6) <u>Futures Exploration</u> <ul style="list-style-type: none"> ▪ Use model to simulate futures and test alternatives management strategies ▪ Discuss insights generated

Figure 2.4: Sketch created by a participant group at Workshop 2 illustrating the important linkages that affect water supply in the Okanagan Basin.



2.5 Results

We evaluated the effectiveness of the process in achieving our ends and means objectives through written surveys at the final two workshops. This section discusses the results of these surveys.

2.5.1 Means objectives

Means 1: Bring together a diverse group of people with a variety of experiences, expertise and values.

The composition of participants shown in Figures 2.2 and 2.3, show that a diversity of organisations and roles participated in the process. No formal analysis was conducted to determine the composition of affected and interested parties who should have been invited. Instead, we relied on the experience gained in previous phases of the Okanagan project (see Section 1.7.1) and the relationships that had been established with local partners to determine who to invite.

Means 2: Actively engage the participants in the model development process.

Opportunities to contribute to model development took place primarily through the series of workshops and meetings. Therefore, participation in model construction can be measured by the activities that took place in these events and by participants' level of commitment, as measured by their frequency of attendance.

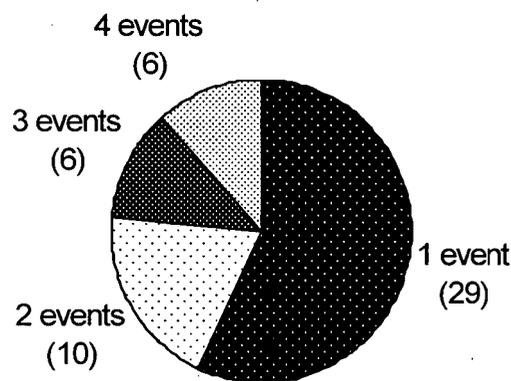
The workshops and meetings allowed participation throughout the entire modeling process, from setting objectives through to calibration and testing. Throughout model development, the participants provided a wealth of information about the details and management of the actual system. They helped to scope issues, evaluated the appropriateness of time and spatial scales, and advised both the model structure and calibration of data.

Previous efforts to develop hydrologic, residential and crop water demand scenarios provided an important foundation for modeling the system, as described in Chapter 3. It was the information provided by the participants, however, that helped to complete the picture by framing the significance of the information in an Okanagan Basin context. The participants provided information on: 1) the volume of storage available and how the reservoirs are managed throughout the year, 2) data regarding sources of water used by different residents, and 3) the pathways for return flows from various treatment facilities. Interesting, and sometimes conflicting, stories regarding the requirements, regulations, and (lack of)

enforcement of instream flows were also provided. New ideas about conservation strategies under consideration were also outlined. The participants, many of whom manage the system on a daily basis, were the best source of information on these issues.

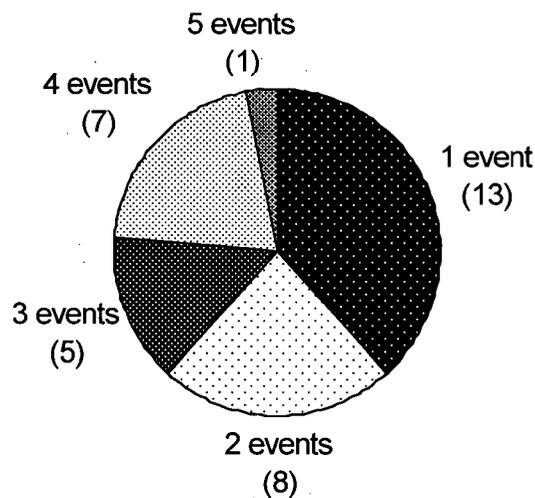
A second measure of how active and committed the participants were in the process is the consistency of attendance. Because participation was voluntary, some fluctuation in attendance was expected. Figure 2.5 shows that the twelve most committed participants attended three to four events out of a total possible of six. The figure also shows that a large proportion of all attendees only attended one event. There are several reasons for this behaviour. First, some people attended only the first event, then chose to or were unable to attend subsequent events. A second reason for the large number of single-event attendees is the round of one- to two-hour meetings in September 2005 took place at several locations within offices around the basin. Several people who were employed at the meeting locations were invited by their colleagues to attend the session. The short format and location allowed people with moderate levels of interest, or simply curiosity, to attend. With some exceptions, most of these “drop-ins” did not continue. A third reason for the high number of single-event participants was that invitees spread the word and invited their colleagues, who joined the process late. In fact, the final session was the first attended for six out of the thirteen present.

Figure 2.5: Participant counts according to the number of events they attended.



Some efforts may help to reduce the instability in attendance. Keeping the group size to a minimum (while still achieving diversity) can increase individual responsibility and ownership to the process. Identifying and emphasizing the benefits that participants will gain from their involvement may help keep their attendance a priority. Financial compensation can also be used to secure a commitment. An alternate approach is to encourage representation by organizations, such that individuals may share responsibilities with their colleagues. There were several instances of this within this project. When participation was evaluated by organization rather than by individual, single-event attendance dropped from 29 out of 51 (57 percent) to 13 out of 34 (38 percent).-(See Figure 2.6.)

Figure 2.6: Organization representation counts according to the number of events attended.



Means 3: Use the system dynamics model as a tool to support and enhance communication

In the group model building process, significant time was spent capturing the essential structure of the system. Water management alternatives were discussed primarily in the last two workshops. Once model building began, there was very little direct confrontation or conflict between participants, as the focus remained on the model. There was certainly a difference between the plenary session in the first workshop, before model construction

began, and plenary sessions at later workshops. At the first workshop the discussion was rather conceptual, with speakers contributing both verbal descriptions and imagery to convey their values and opinions about the future of the basin. Differences in opinion caused some tension among speakers, as well as between the speakers and the facilitator. Certainly, part of the differences can be attributed to the personalities present in the room. However, in later workshops, discussion remained on issues specifically related to the water resources in the basin and centered on (a) learning about what the model included, and (b) suggestions for improving the model. This suggests that the presence of the model in the workshops helped to redirect personal agendas and foster effective communication as required for negotiation (Fisher and Ury 1981)

In the final plenary session of the workshop series, participants shared and discussed the insights that they learned from exploring the model. These included: (a) It is difficult to manage the system when instream flows for sockeye (in downstream portions of the river network) are given priority; (b) Transferring all of the diversion points from the tributary streams to Okanagan Lake (to improve aquatic habitat in the tributary streams) causes the lake level to drop significantly; and (c) Residential (domestic and urban municipal) demand, even under projected rapid growth rates, remains less significant than anticipated in terms of overall percentage of demand. This is largely because the significant increase in agricultural demand due to climate change continues to dominate the demand profile.

2.5.2 Ends objectives

Ends 1: To create a shared learning experience that broadens participants' perspectives and clarifies the complex relations that define the water resources system.

Gathering a diverse group of stakeholders together and providing opportunities to share their perspectives helped to broaden people's understanding beyond their own experiences. Furthermore, through developing and interacting with the model, participants clarified their understanding of the linkages and processes that define the water resource system. When

discussing the model we emphasized causal relationships rather than facts to support second-order learning (van de Kerkhof 2004).

Participants found both the process and the resulting model valuable. Participants assessed their own learning experience in evaluations given at the final two workshops using both numeric scales and written comments. Copies of these evaluation forms are attached in the appendix. Numerical responses for the two workshops are combined and summarized in Table 2.2. Only five of the twenty-five people at the final workshops attended both events. In the post-session evaluations, we asked, "Have your perceptions of future water availability in the basin changed due to this exercise?" The mode of responses was in the middle with "some change", while the median value was slightly lower. Because all of the participants entered the session with previous knowledge about the system (indeed many assist in managing the water resources daily) the weighting towards the left side of Table 2.2 was not surprising. In written comments on the evaluations, five responses noted that the results described a picture that was worse than they previously thought, while two responses noted it was better than they previously thought.

Survey comments suggest that prior knowledge influenced participants' experience of learning. Two of the level "1 - no change" responses (see Table 2.2) noted that they had "a pretty good sense" of the system beforehand. In contrast, an environmental NGO representative said the experience increased his/her learning "[i]mmensely -- The whole scope of the exercise was mind expanding."

Several water resource professionals felt that the experience increased their clarity of system linkages. One participant noted a better appreciation for the "challenges inherent in holistic management" and for the value of "drawing together varied aspects of water." Another respondent showed that he/she grasped the dynamic nature of the system particularly well by observing that the concept of "limits to growth," which was expressed in the early stages, as "How many people can the basin support?" is tempered by our ability to manage and adapt our way through drought.

Table 2.2: Number of responses to the post-workshop evaluation question "Have your perceptions of future water availability in the basin changed due to this exercise?"

	1 No Change	2	3 Some Change	4	5 Major Change	No Response
Workshop 4	2	3	4	0	1	6
Workshop 5	2	4	5	0	0	5
Total	4	7	9	0	1	11

Ends 2: To tailor the model to meet the needs of the community for the purposes of planning and exploration

The suitability of the tool for future exploration will be best evaluated through use over time. However, during the final two workshops, we did ask the participants if they saw potential in the tool. In our survey, we asked, "Do you feel this model is a legitimate and relevant tool to explore long-term water management in the Okanagan?" All respondents agreed with this statement. Several felt that it had the potential for being a useful tool, noting either that it would depend on the user, or that additional updates were needed. As shown in Table 2.3, people's trust in the model increased slightly from Workshop 4 to Workshop 5. This is reasonable because the model was more refined in the final event than in the previous one. Several people commented that it was a good communication and/or education tool for visualizing the future and discussing policy. This is in alignment with the original purpose of the model.

Table 2.3: Comparison of responses by event to the evaluation question: "Do you feel this model is a legitimate and relevant tool to explore long-term water management in the Okanagan?"

	No	Yes	Maybe/Has Potential	No Response
Workshop 4	0	3	7	5
Workshop 5	0	5	5	5
Total	0	8	12	10

Ends 3: To foster a sense of ownership and trust in the model among the participants.

The positive responses summarized in Table 2.3 suggest that the participants had developed some level of trust in the model being appropriate for future water explorations. The second issue, ownership, was measured indirectly by evaluating how familiar the participants were with the model. A commitment to learning about and contributing to the model can both result from and generate a sense of ownership of the model. Therefore, the level of understanding of the model can indicate a feeling of ownership. In the process of learning the model's potential and its limitations and assumptions, the participants learn how to interpret the results most effectively. If participants understand and trust the model they may be inclined to more seriously consider the results and to incorporate them into their own work.

We used surveys to gather feedback from the participants as to what extent they learned about the model. At the two final workshops, we asked the participants to self-evaluate "How well do you understand the model's structure?" in both pre- and post-session surveys. The scale ranged from 1 (not at all) to 5 (very well – I could teach it to someone else). The middle option was defined as 3 (I know what issues are included). Responses ranged from 1 to 4. Average values at each stage are provided in Table 2.4. We speculate that the similar pre-evaluation scores for the two workshops could be attributed to the large turn-over in participation between these two events. Average understanding increased substantially at both workshops between the pre- and post-evaluations. The smaller increase in understanding at the fifth workshop could be partly attributed to the increased complexity of the model that the participants had to learn. However, these changes could also be due to the different composition of each group. For the five participants who did attend both events, it was impossible to determine whether their responses changed, as evaluations were anonymous.

Table 2.4: Average responses on a scale from 1 (low) to 5 (high) for the question: "How well do you understand the model's structure?"

	Pre-Evaluation	Post-Evaluation	Change
Workshop 4	2.3	3.2	+ 0.9
Workshop 5	2.5	3.1	+ 0.6

There were two challenges to fostering ownership. First, as described above, participation in the workshops and meetings was inconsistent. Second, participants did not code the model themselves, but provided information to the facilitators, who then constructed the model outside of the workshops.

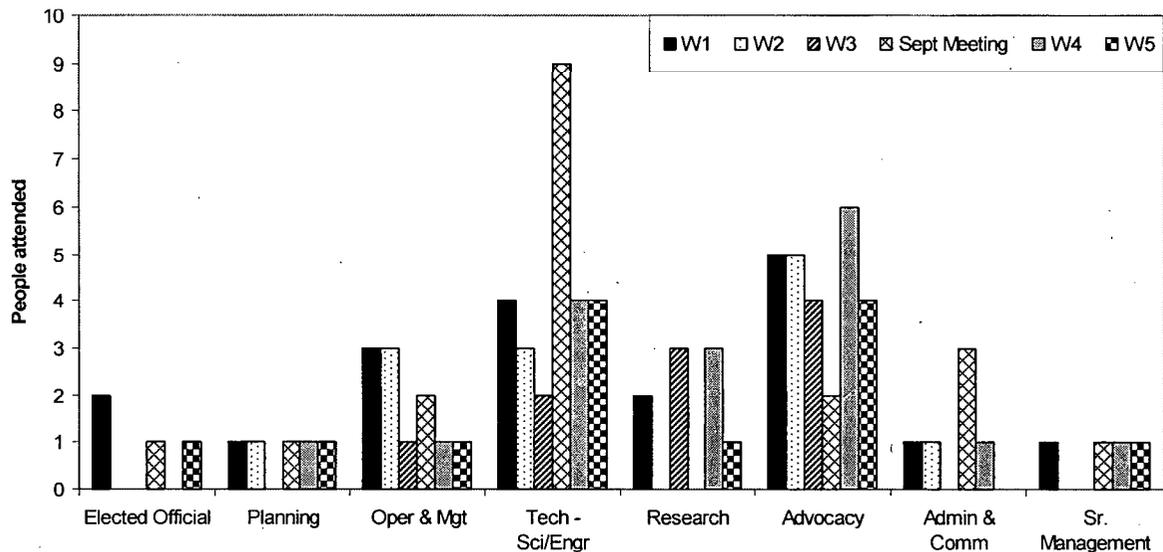
Based on these evaluation questions and comments at the workshop sessions, the participants generally trusted the model, however, their sense of ownership was limited by their limited interaction with it.

2.6 Discussion

2.6.1 Lessons learned

Bringing individuals into a volunteer process is challenging. In the Okanagan Basin of British Columbia, there are currently many water planning initiatives competing for the time and attention of water-related professionals. We made a concerted effort to accommodate everyone's schedules. For example, we intentionally did not meet over the summer months, when many people take vacations, but waited until the end of September to hold the next event. However, late September is the time of both tree fruit harvesting and salmon migration field work. Maintaining communication with participants regarding scheduling can avoid some of these conflicts. Participants have different motivations for attending, so may have varied levels of interest at different stages of the process. For example, we anticipated that the elected officials and environmental advocates would be more interested in the early stages, when objectives were being established, and the final stages, when results were generated and discussed; rather than during the "nuts and bolts" of the model construction. In fact, there was more participation from these two groups early and late in the process as shown in Figure 2.7. This figure also shows that technical experts dominated participation at the September small group meetings, although all participants were invited to attend. This outcome likely resulted from our need to fill particular data gaps, combined with participant self-selection.

Figure 2.7: Distribution of attendance for each of the five workshops and the series of small group meetings, grouped by participants' roles in Okanagan water management.



In this process, we chose to hold five full-day workshops throughout the year. We found this to be the minimum required to enable participants to follow and contribute to model development. More frequent, shorter meetings might have been more effective at keeping the participants updated on model progress, and would have created more opportunities for people to participate. However, in this case, the spacing of the workshops helped us to minimize travel expenses for facilitators, and allotted sufficient time to both revise the model and conduct event planning.

Better familiarity with and ownership of the model could have been fostered without the long summer break when the bulk of the model was assembled. During the workshop sessions, participants raised many questions about model assumptions and requested model documentation for their own reference. Providing model documentation to the participants before or at each session would have been an asset. The documentation will be made available to all participants through publication in Cohen and Neale (2006).

Throughout the process, we encouraged the participants, rather than the project team, to define the process. Our intent was to encourage them to take ownership of the model. This was effective for most of the process, but some ground rules are necessary to make sure that everyone is “on the same page.” Better clarification of the process will also help invitees to know what to expect, which will help their decision to participate. Some examples of ground rules that are important to determine and reiterate throughout the process are: (1) the purpose of the model and its intended use; (2) the expected outcome of process; and (3) the intended model user. In this project, the group model building participants *were* the model users.

Evaluations are critical to understanding the impact of the process. Although we did conduct a number of evaluations along the way, a more structured format to the evaluation process would have more effectively recorded participant learning, the effectiveness of the process, and individual experiences. Evaluations given at the beginning and end of a participatory modeling process could measure evidence of learning about the characteristics of the system. This project measured whether participants thought they learned, but did not measure learning directly. It is challenging to know what learning will occur at the outset of the process, and you want to be careful not to introduce bias through the instrument of measure, whereas the evaluation sheet is informative. One solution is to ask generally about the critical issues and solutions surrounding the topic. What the respondents describe as the critical issues and solutions can provide insight as to how informed they are and how wide their “lens” is. Their responses can help to distinguish if they just know a specific component, or if they are aware of the greater system. Do they know “the” solution, or do they appreciate the complexity of managing the resource?. With the use of a identifying code to keep anonymity, changes in understanding (i.e., learning) can be measured from the beginning to the end of the process.

2.6.2 Possible sources of bias

There are a number of factors that could have introduced bias into this process, influencing the results that we achieved. First of all, the personalities of the facilitators, particularly the chair, define the atmosphere and the attitudes that are present in the room. I chaired all of the

sessions, and tried to be welcoming and appreciative of participants' efforts, as well as maintaining an energetic and positive attitude about the process. Any experienced public speaker is well aware of how their attitude affects their audience, and this phenomenon certainly could have played a role in the workshops.

All participants were volunteers, so those who came must have felt that it was worth their time and money to attend. Therefore, self-selection created bias such that all those who were present already believed in the value of the process. Once a part of it, there were elements that could have motivations why they wanted to process to succeed. They may have felt the need to justify their time to their employer; or it could have been to please the research team - and me in particular, as the nice doctoral student whose future partially relied on the success of the process.

The evaluation of whether the tool is appropriate also contains bias because most people who evaluated it had some level of contribution to it. The responses to the evaluation were intended to reveal if the participants felt it was appropriate, and not serve as an objective evaluation of the tool.

2.6.3 Did this process make a difference?

Through the evaluations and direct communication with the participants, we heard that learning occurred through model construction, but also simply from bringing together a diversity of experience and expertise. Through discussions, many participants gained an appreciation for the values of others. They also gained insight on the complexity of water management. Additionally, the single-disciplinary researchers who participated gained new perspective from the relatively simple, high-level, multi-disciplinary model.

The process did make a difference to the participants, who were positive about the experience. Throughout the process, participants recommended that this work be shared with a wider community, particularly to elected officials and the public. For example, several participants expressed interest in collaborating with related initiatives in the region, including

Smart Growth on the Ground (Siu 2006), an organization that fosters sustainable community design and planning within communities, and the Okanagan QUEST model, a tool to explore urban futures (Carmichael et al. 2004; Tansey et al. 2002; Robinson and Tansey 2006). Furthermore, the resulting model can be used to continue dialogue with the community regarding the evaluation and selection of appropriate adaptation strategies for reducing the negative impacts of climate change on their ability to manage water resources in the basin. Participants' reported satisfaction with the process supports evidence that participatory modeling is an effective tool for fostering communication and supporting effective consensus-building.

The long-term significance of this participatory modeling process to policy development cannot be measured during the timeframe of this project. Decisions are complex and are not based on single factors. Furthermore, decisions are made by many more people than just those who participated in our model building exercise. Since we do not have a control group, we may never be able to measure exactly what changed as a result of our efforts.

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CHAPTER 3: A SYSTEM DYNAMICS MODEL FOR EXPLORING WATER RESOURCES FUTURES UNDER CLIMATE CHANGE*

The purpose of this initiative was to enable and support a water resources community in incorporating climate change projections into their planning and policy development and in evaluating their water resources within a system context. This was conducted through a participatory integrated assessment centered on the development of a system dynamics model. The products of this process were: (1) A simulation model of the water resource system, incorporating future projections of climate change and population growth, as well as adaptation options; and (2) A shared learning experience for both the participants and the research team. This paper describes the model structure and an analysis of model output, while the shared learning process is described in Langsdale et al. (2006) and in Chapter 2 of this thesis.

The model was created to investigate several questions: (a) What is the current state of the system? (b) What effect will climate change and population growth have on the future water supply and demand balance? (c) What role could adaptation measures have on improving or maintaining water resource system reliability despite increased stress from climate change and population growth? Following a brief introduction to “participatory modeling,” this paper presents quantitative results for (a) and (b) and discusses insights related to point (c). The model was constructed as a high level scoping model, with greater emphasis on capturing the structure of the system, rather than on calibrating data. This is appropriate to the objectives, as the model has not been and will not be used for design purposes. The significance of the results presented here is provided in the general trends, rather than in any specific numerical values.

* A version of this chapter has been submitted for publication. Langsdale, S., Beall, A., Carmichael, J., Cohen, S., Forster, C. An Exploration of Water Resources Futures Under Climate Change Using System Dynamics Modeling. *Integrated Assessment*, submitted.

3.1 Climate Change and Water Resources Planning

Are water managers prepared for operating under future climate conditions? Water managers have always worked towards reducing risk and increasing system capacity to handle ever-widening extreme conditions, so some argue that they are ready for climate change. Stakhiv (1996) agrees that society is constantly adapting in incremental steps and that climate change will simply be an additional stressor to which we must adapt. However, these “common-place adaptations” that have been part of daily management practices assumed that climate was relatively stable, varying around a stable mean (de Loë and Kreutzwiser, 2000). It is unknown whether future climate changes will occur gradually, over several decades, or if there will be sudden shifts. Kashyap (2004) suggests that climate change adaptation is not comparable to historic adaptation, because the environmental changes will be more rapid and intense than in the past. However, most climate modeling characterizes climate change as occurring slowly and gradually, justifying a reactive or “wait-and-see” approach. Regardless, the conventional practice of relying on historic data to estimate future conditions is inadequate. New methods for assessing the future are necessary to maintain the reliability of water resource systems over the long term. Certainly the future contains many unknowns, so an effective assessment needs to integrate all known stressors on the system and support the development of strategies that are flexible and resilient under a wide range of future conditions. In many regions, climate change will be one of the significant stressors, so it must be included in any planning initiative. Few communities have done this, however, as assessments of climate change on water resources in Canada are rare (Mortsch and Mills 1996; Cohen et al. 2006 are exceptions). The U.S. is similar, with only four U.S. states including climate change in their water resources planning in 2005 (Viessman and Feather 2006).

For water managers to incorporate climate change issues into their planning processes, climate change information must be translated into terms that are relevant to their concerns. Current challenges include the level of uncertainty in climate change estimates and the mismatch of both spatial and temporal scales. While current global climate models provide information at large geographic scales and low spatial resolution, managers handle small

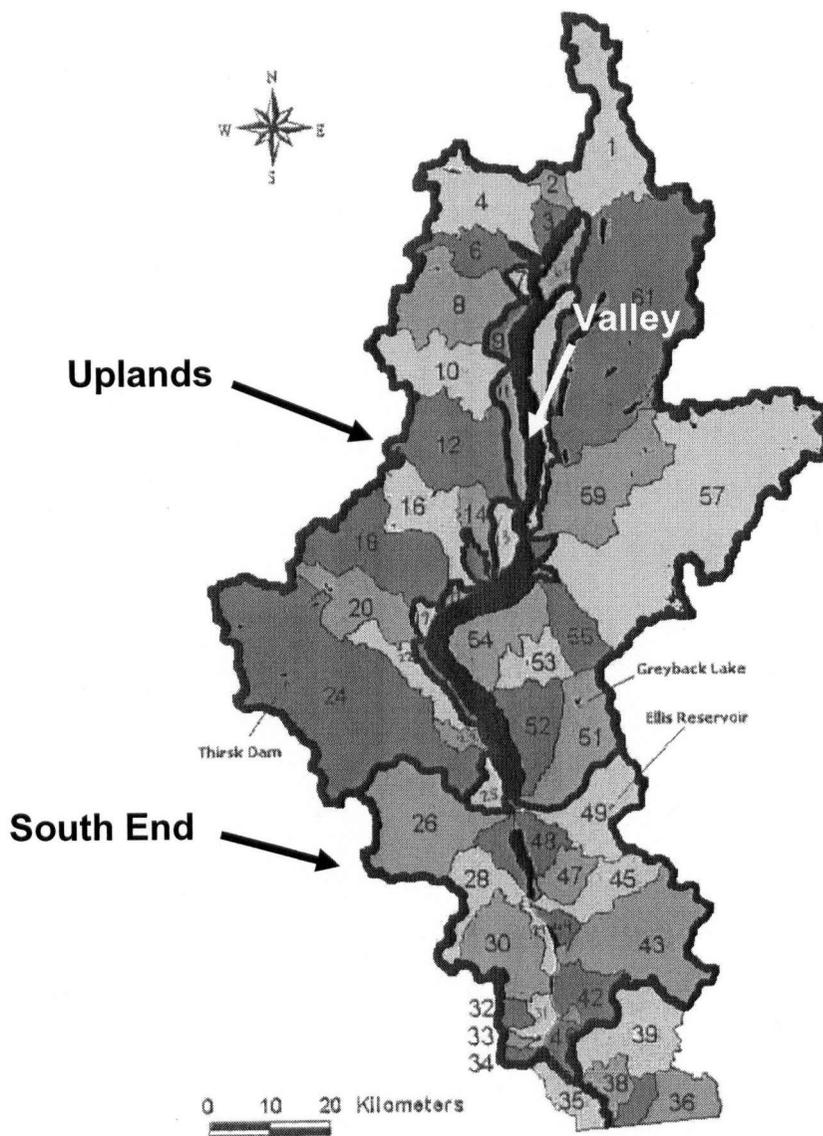
geographic areas and require data with relatively high spatial resolution (Lins et al. 1997). A third challenge is that of translating climate change data into terms of hydrologic impacts. The presence of these issues has, to date, deterred practitioners from bringing climate change into the water management forum. Unfortunately, projections of future conditions that do neglect climate change could be grossly inaccurate, and managers who rely on this information may be unwittingly and unnecessarily allowing vulnerabilities in their systems. While a community can often endure single-year events without permanent losses, a prolonged deficit in the water balance could deplete water storage in reservoirs and groundwater aquifers, and even collapse industries dependent on water.

3.2 The Okanagan Basin Study Area

The Okanagan Basin in south-central British Columbia is one of the most arid regions in Canada, with annual average precipitation ranging from less than 300 mm to 450 mm. The long, narrow basin extends 182 km from the Canada-U.S. Border and covers an area of 8200 km² (See Figure 3.1). The major economic industries in the basin are agriculture, forestry and recreation. Agriculture accounts for approximately 70 percent of annual water use in the basin. The Okanagan River is one of the only tributaries to the Columbia River that still supports viable salmon populations.

In recent decades, rapid development combined with natural hydrologic variability increased concern among water resource managers. In the twenty years between 1978 and 1998 the population in the Central Okanagan Regional District doubled and the rest of the basin also experienced rapid growth that far exceeded projections (BC Stats 2006; Canada-British Consultative Board 1974). Drought conditions in the summers of 2003 and 2004 caused water shortages and major fires, leading to a public review of emergency preparedness (Filmon 2004).

Figure 3.1: Okanagan Basin Map showing the delineation of the Uplands water supply model region that includes all managed tributaries to Okanagan Lake. Numbers correspond to watershed names, which are available in the Table 1 in Appendix D (Original map from Merritt and Alila 2003).



3.3 Project History

Several previous research initiatives focusing on both the physical and social aspects of the system established a sound foundation on which to build this project.

Stakeholder dialogue activities between 2001 and 2004 began communications and developed trust with parties responsible for or interested in water management in the Okanagan. In addition, these activities increased awareness and concern about potential climate change impacts as well as adaptation opportunities (Cohen and Kulkarni 2001; Cohen et al. 2004; 2006). As a result, one Okanagan community included climate change scenarios in their water resources planning document (Summit Environmental Consultants 2004).

Taylor and Barton (2004) statistically downscaled six global climate models to create a range of plausible scenarios for the Okanagan. These climate scenarios show mean temperature increases between 1.5 and 4 degrees Celsius throughout the year, and generally wetter winters and drier summers. Merritt and Alila (2004) and Merritt et al. (2006) incorporated these climate scenarios within simulations by the UBC Watershed stream flow runoff model (Quick 1995) to generate hydrologic scenarios. The results show significant changes to the annual hydrograph from the historic period (1961-90) to the period between 2010 and 2100. All scenarios show a reduced snowpack, an earlier onset of the spring freshet (by as much as four to six weeks in the 2080's), and decreases in summer precipitation. Some scenarios also show more intense spring freshets. Neilsen et al. (2004b) used the climate scenarios to model the impact on agricultural crop water demand. Higher temperatures increase both evapotranspiration and the length of the growing season – two factors which increase crop water demand. As a result, crop water demand could increase by 12 to 61 percent, as climate change intensifies through the decades. Furthermore, Neale (2005; 2006) correlated residential outdoor watering with temperature and detached dwellings for several Okanagan communities, showing that water demand in the residential sector will also increase under climate change in the absence of conservation measures. Each of these results on its own provides important information, but only reflects part of the picture. By considering these

impacts together - in the system context - we can determine the increased risk to the water resource system in the future.

3.4 Methodology

This section reviews the methodology of participatory modeling and system dynamics modeling.

3.4.1 Participatory modeling

Participatory modeling is a recently established approach for conducting integrated assessment but it has already been applied to a variety of fields such as policy analysis and organizational learning, as well as environmental resource applications such as water resources and land management. Participatory modeling is founded on the belief that mental models are based on numerous unstated assumptions and often contain gaps and inconsistencies. The process of sharing these mental models exposes points of agreement and points of conflict. Effective conflict negotiation illuminates hidden assumptions so that they may be clarified and challenged (Fisher and Ury 1981). Participatory model development can focus on characterizing system structure, while model simulations reveal system behaviour, which is less intuitive and which is often the source of confusion (Forrester 1987; Vennix 1996). The model can then be used to explore a range of future conditions or assumptions. Participants may engage directly in the modeling process, or the model may be developed in an iterative process with regular opportunities to contribute (van Asselt and Rijkens-Klomp 2002).

3.4.2 System dynamics

Models used for collaborative modeling in water resources applications include system dynamics platforms like STELLA™ (Cardwell et al. 2004; Costanza and Ruth 1998;

Langsdale et al. 2006; Palmer et al. in review), and Studio Expert (Tidwell et al. 2004). Other types of models which have been used include MIKE-BASIN (Borden and Spinazola 2006; Borden et al. 2006); the Water Evaluation And Planning system model (WEAP) (Jenkins et al. 2005); and OASIS with OCL (Hydrologics 2003). System dynamics software packages are blank slates and can be applied to any problem, while MIKE-BASIN, WEAP, and OASIS are all limited to water resources applications.

System dynamics was developed for the purpose of characterizing complex, non-linear systems through capturing interrelations, feedback loops and delays. Modern system dynamics software packages are ideal for use with a participant group of varying levels of technical proficiency because of their graphically-based model level and user interface. These models can easily manage both clearly-defined and poorly-defined components in the same model. Similarly, they can capture quantitative, physical parts of the system, such as hydrology, as well as intangible parts of the system, such as policies and human responses, so they are quite appropriate for participatory modeling applications.

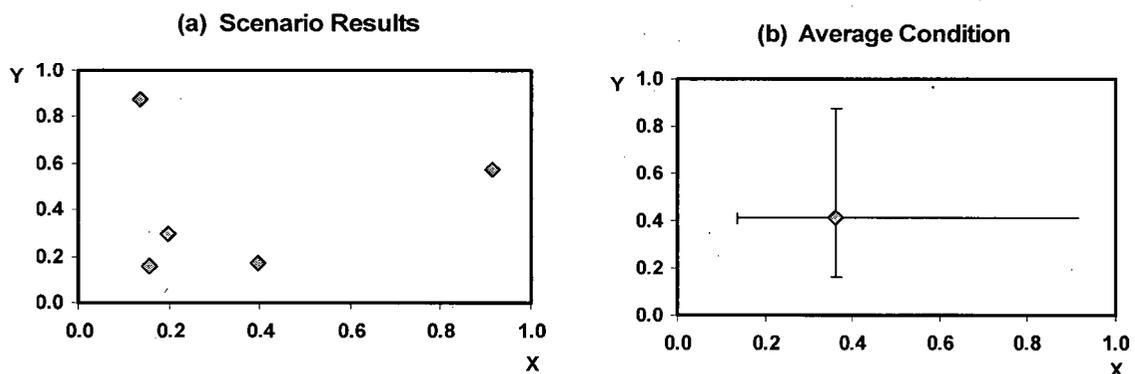
Case studies where the system dynamics approach was applied to environmental issues include: the Louisiana coastal wetlands, the South African fynbos ecosystems and the Patuxent River watershed in Maryland, USA (Costanza and Ruth 1998); water resources management in Switzerland, Senegal and Thailand, and vegetation management in Zimbabwe (Hare et al. 2003); water allocation issues in the Namoi River, Australia (Letcher and Jakeman 2003); transportation and air quality in Las Vegas, USA (Stave-2002); and Patagonia coastal zone management (van den Belt et al. 1998).

3.4.3 Representing uncertainty using scenarios

Scenarios are defined as “plausible combinations of circumstances that can be used to describe a future set of conditions” (Smith et al. 1996). The scenario approach provides an alternative to the convention of aggregating results into an average value and then representing the uncertainty with error bars or statistics, as shown in Figure 3.2. Whether the audience is technically-trained or not, expressing results in terms of scenarios provides a

clearer picture of the range of future states possible. Figure 3.2(a) shows five equally plausible scenarios, while Figure 3.2(b) reports the average of the five scenarios and uses error bars to represent the extent of the individual scenarios. So, both figures represent essentially the same feasible region or decision space. However, Figure 3.2(a) more clearly conveys that any of the five states are equally plausible, while Figure 3.2(b) implies that the average condition is most likely and that the probability of occurrence decreases toward the limits of the feasible region. When users of this information are presented with results as an average, there is a temptation is to focus primarily on the single point, and the importance of the range of uncertainty is lost.

Figure 3.2: Graph (a) shows results as an array of discrete states, while graph (b) shows only the average of the five scenarios, along with error bars that provide the range of possible conditions.



Note that in Figure 3.2, the model uncertainty, based on knowledge uncertainty is not represented. As long as the inherent uncertainties are significantly larger than the model uncertainties, then the feasible region defined by the complete range of scenarios will fully encompass the region defined by model uncertainties (Langsdale, *accepted*)

The simplest form of a scenario analysis generates an array of equally-plausible scenarios. In circumstances when different probabilities of occurrence are relevant, Bayesian Belief Networks may be used to estimate the likelihood of each scenario. Bayesian Belief Networks characterize the cause-effect relationships in a system using conditional probabilities (Ghabayen and McKee, 2006).

The use of scenarios, whether equally plausible or containing assigned probabilities, helps to alleviate several challenges. First, using a framework of discrete scenarios helps to spell out the sources of uncertainty and highlights their inherent nature, which may reduce people's intolerance of uncertainty. Next, explicitly displaying the range of conditions helps to prevent anchoring and overconfidence in a single point (as in the average state). The message that the future could be any of the number of states is continually reinforced. Finally, the discrete scenarios also present the results in a format that is manageable and can be readily used for further assessment. Presenting the scenarios through a decision support tool can further this goal by providing a framework for stakeholders to manage and evaluate the scenarios effectively.

3.5 Description of the Actual and Modeled System

The Okanagan Sustainable Water Balance Model (OSWBM) simulates future conditions by projecting current conditions and overlaying the effects of population growth and climate change on water supply and demand. The purpose of the model is primarily for supporting stakeholder dialogue surrounding the issue of how climate change could play a role in future water management and is *not* intended to optimize design or guide real-time operation. The model can help dialogue participants to learn about the complexities of managing water resources for multiple uses, simulate a range of plausible water resources futures, assess adaptation strategies (and portfolios of strategies), identify data gaps, and prioritize areas of future research.

Here, we provide detail about the Okanagan water resources system and how it was characterized in the Okanagan Sustainable Water Resources Model (OSWRM) using a STELLA™ platform. First, major features and components of the model are described. Then, relationships between these components, which provide more insight into behaviour, are described through the use of a Causal Loop Diagram.

In this text, the term “demand” refers to the volume of water requested by a user group for consumptive or non-consumptive use. The magnitude of demand is not necessarily equal to existing water rights, nor is it always the amount allocated. Modeled demands for agricultural or residential diversions are based on current use patterns in absence of conservation measures or any water shortage restrictions and are referred to as “maximum demand.” The maximum demand is not the maximum possible, but is simply the current trajectory based on normal year conditions. Instream demand and conservation targets are defined by policies with fixed monthly targets. When shortages occur, allocations will be less than maximum demand.

Residential demand includes domestic and other municipal demands. Most out-of-stream water use in the Okanagan can be classified as either agricultural or residential applications. Water to support non-domestic municipal use, such as watering of parks or golf courses, is either averaged into per capita residential use values or counted as agricultural use. Industrial use is very low in the region, and therefore was not separated from residential use in this study. The terms “municipal” and “urban” are less representative because of the water allocation structure in the Okanagan: municipalities frequently serve both residential and agricultural customers.

3.5.1 Components of the Okanagan Sustainable Water Resources Model

3.5.1.1 Spatial scales

OSWRM describes nearly the entire basin, from the northernmost extent to the mouth of Osoyoos Lake (see Figure 3.1). As most people work at the community or regional level, they are typically not aware of whole-basin issues, or how their area interacts with the larger scale. A comprehensive study in the 1970’s recommended basin-scale management of the water resource (Canada-British Columbia Consultative Board 1974). Except for the formation of the Okanagan Basin Water Board, which until recently has had limited scope

and influence, there has been little progress on realizing basin-scale management. Modeling the entire basin provides an avenue for exploration and discussion of the larger perspective.

Participants suggested several spatial scales, from modeling the basin as a whole, to describing all 60 watersheds. A third suggestion was to divide the basin into a few regions based on topography and climate. This last idea was the foundation for dividing the basin into three major regions (Figure 3.1) according to water source type, which participants found to be appropriate when shown at the following workshop. The three sources are: all of the tributary watersheds to Okanagan Lake on which there are human controls (Uplands), Okanagan Lake as well as a few small, unmanaged watersheds contributing to the lake (Valley), and all watersheds that contribute to the mainstem downstream of the Okanagan Lake dam at Penticton (South End). These major sub-basins have areal extents of 5200, 800, and 1500 km² respectively and have distinct climates, topography, and water use patterns. Feedback between these sub-basins is minor, limited to some water cycling by return flows. Otherwise, the relationship between these areas is defined by water that flows through from the Uplands, to Okanagan Lake, and finally into the South End.

This paper describes results for water supply and use from the Uplands. The Uplands region comprises 70 percent of the total land area modeled, so results for the Uplands dominate in an aggregation of results for the basin. Also, because water is used multiple times through the basin, an analysis of the Uplands provides a clear and accurate picture of the relative magnitudes of instream and out-of-stream demands.

3.5.1.2 Time scales

Simulations use monthly timesteps in thirty-year blocks of either a historic period (based on 1961-90 data) or one of two future periods (2010-2039 or 2040-2069). The data gap between 1990 and 2010 was a consequence of our reliance on data from established climate models and previous work that predetermined our simulation periods. The future periods, referred to as the 2020's and 2050's by climate modelers, and the historic years were those used by researchers in the previous phases of this project (see Merritt and Alila 2004; Taylor and

Barton 2004). Monthly timesteps were chosen to capture the seasonal climate shifts while maintaining simulation efficiency.

3.5.1.3 Hydrology

Figure 3.3 summarizes how climate change information was translated into hydrologic impacts that were directly relevant to the balance of water resources and use in the OSWRM. Taylor and Barton (2004) used the delta method to downscale three global climate models (Hadley, CSIRO, and CGCM2) and two emissions scenarios (A2 - high growth in global greenhouse gas emissions; B2 - moderate growth in emissions (IPCC-WG3 2000)) using local temperature and precipitation data. Merritt and Alila (2004; Merritt et al. 2006) generated hydrologic streamflow scenarios for these six climate scenarios. Because all future scenarios are adjustments to the 1961-1990 historic climate data, the pattern is repeated in each time block (Figure 3.4) Included in OSWRM are three climate scenarios, referred to as Hadley A2, CSIRO B2, and CGCM2 B2, for the 2020's and 2050's time blocks. These scenarios were selected because they provided the widest range of behaviour, and thus the widest range of possible future conditions among the scenarios that Taylor and Barton developed. Generally, future climate scenarios predict an annual streamflow hydrograph that has an earlier, more intense spring freshet than in the historic record.

In addition to surface water sources, some Okanagan communities rely on groundwater and diversions from two adjacent river basins. These were characterized in OSWRM. However, aquifer studies have only begun recently, so neither the aquifer volume nor the sustainable yield is known. As a result, the groundwater "aquifers" in the model can provide information about the relative state, but not the absolute state of the groundwater stock. OSWRM assumes that as the communities dependent on these sources increase in population, withdraws will increase proportionately. These contributions are a small portion of the total managed supply, and we assume that maximum sustainable yield (groundwater) or legal limits (adjacent river diversions) will not be exceeded in the range of values tested. However, if this assumption is false, then the results could slightly overestimate future managed supply.

Figure 3.3: Flow chart illustrating the progression from climate models and local records to supply and demand inputs to the Okanagan Sustainable Water Resources Model. (Sources: Cohen et al. 2004; Neilsen et al. 2001; Merritt and Alila 2006; Neale 2005; 2006).

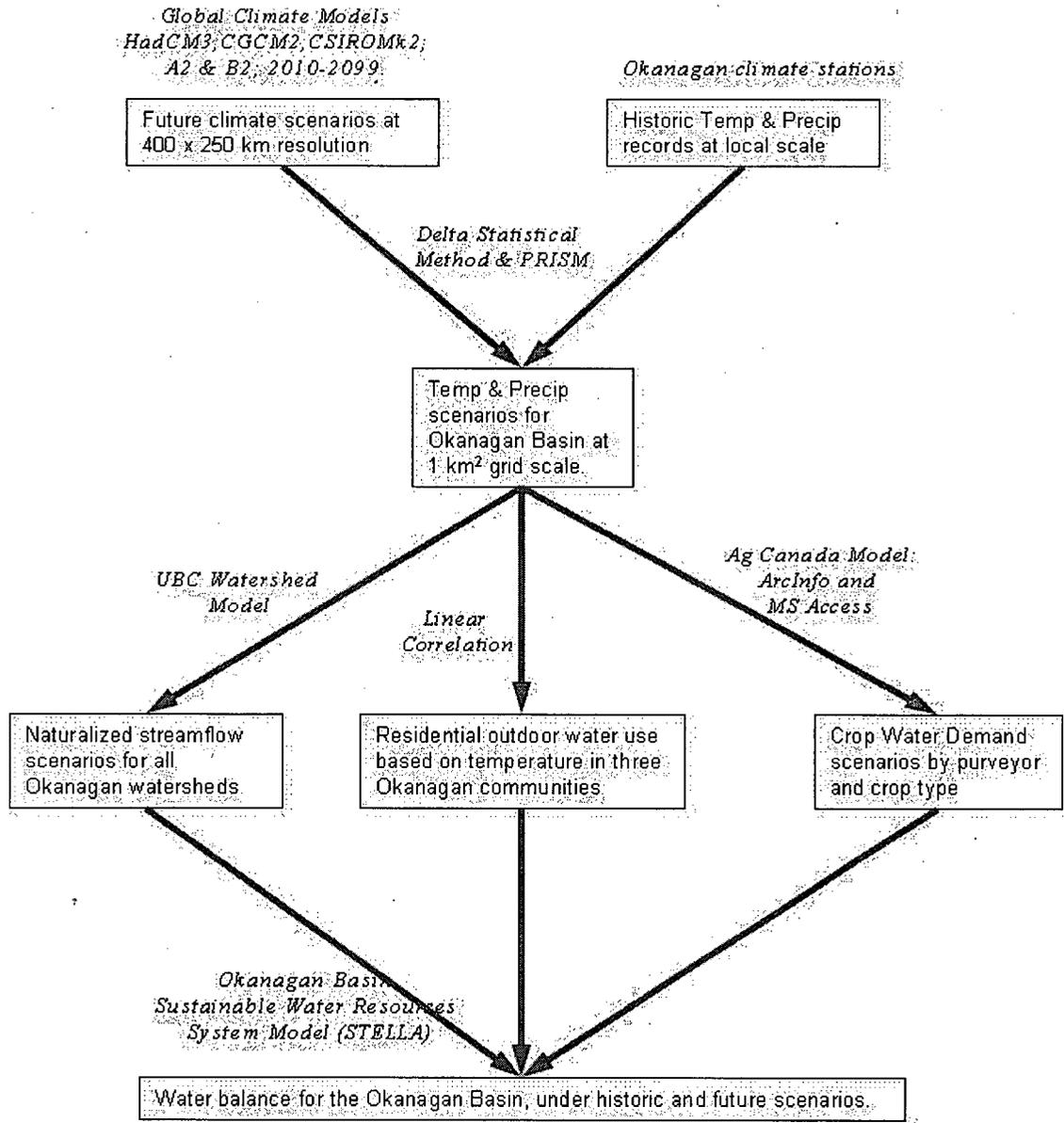
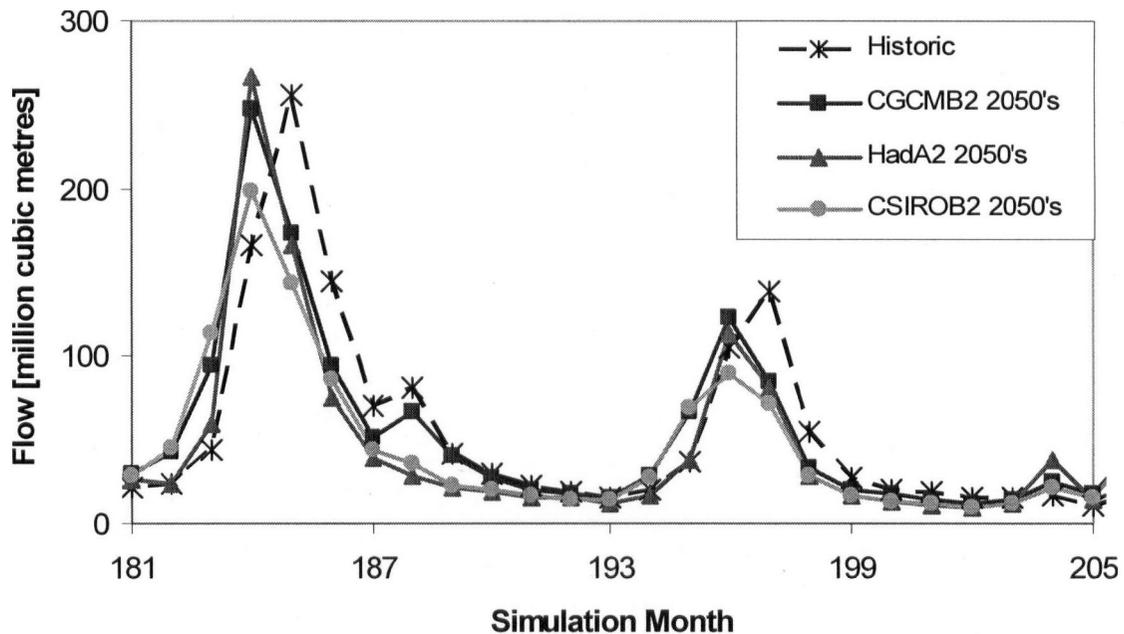


Figure 3.4: Upland streamflow for historic and 2050's climate scenarios. Two years are shown: 1976-77 for the historic scenario, and 2055-56 for the 2050's scenarios.



3.5.1.4 Agricultural demand

Agricultural water demand was based on Neilsen et al. (2004b). The model described in Neilsen et al. generated estimates for crop water demand for major water purveyors by relating demand to climatic and location-based factors. In OSWRM we aggregated this output according to water source and normalized by area and crop type. Each water source region has a single average per land area irrigation demand profile per crop and climate scenario. The normalization of the data allowed us to create options for users to simulate changes both in total land in production and in crop type mix.

The values for agricultural demand were derived by applying water delivery factors on the crop water demand estimates. Nielsen (2004b) assumed that an additional 33 percent above crop water demand is required for transporting water through the soil medium. Thus, irrigating with a rate that is 133 percent of crop water demand is considered the minimum required to satisfy crop needs. This rate is theoretically possible if maximum efficiency can

be achieved through technologies like drip irrigation combined with irrigation scheduling. To estimate actual, current irrigation rates, an additional factor of 30 percent was applied to account for losses from irrigation technologies such as overhead sprinklers and unlined ditches (van der Gulik and Stephens 2005). These factors combine for a total of 73 percent above crop water demand.

3.5.1.5 Residential demand

Residential demand, based on work by Neale (2005; 2006), uses correlations of temperature and outdoor water use, average residents per dwelling, proportions of detached and multi-unit dwellings, as well as average savings realized by a number of demand side management strategies (discussed in detail below). Data generated for selected communities was extrapolated to OSWRM's regions.

3.5.1.6 Instream flow demand and conservation flow targets

Instream flow requirements are included in both the tributaries to Okanagan Lake and the mainstem lakes/river chain south of Penticton. Because water is diverted out of the tributary streams, we assume that instream flow demands downstream cannot be satisfied by water earmarked for diversion. Instead, instream flow demands are exclusive from the out-of-stream demands.

In the tributaries to Okanagan Lake, conservation flow targets defined for several streams as monthly percentages of mean annual discharge (Northwest Hydraulic Consultants 2001) were extrapolated to all tributaries. The "normal" conservation flow target is automatically modified in dry years when not enough water is present in the system to satisfy the target. "Normal" instream demand remains constant because it is based on established policy parameters; however, in practice, this target is modified during droughts.

3.5.1.7 Adaptation and policy options

A variety of water conservation measures for the agricultural and residential sectors are included, such as metering, xeriscaping, and technology upgrades. Policy options are provided for drought management, enabling the user to select different priorities for water allocations. Some of the policy options included on the basic user interface include:

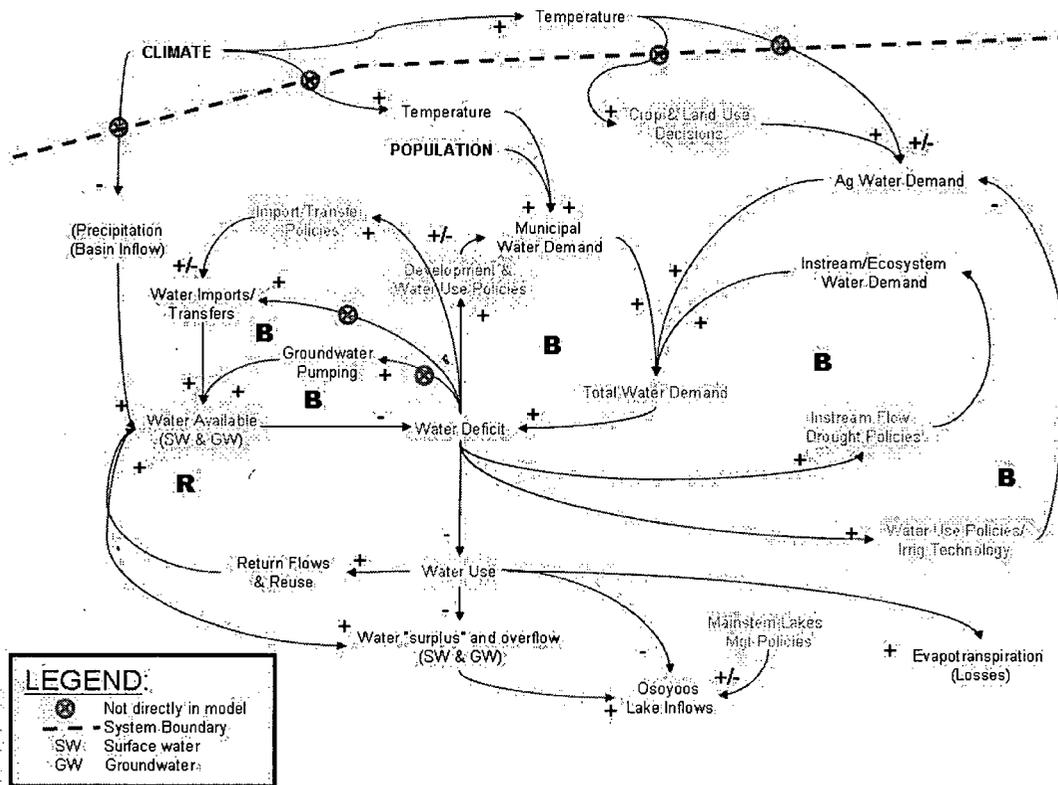
- Implementing agricultural conservation and selecting a level of efficiency
- Implementing residential conservation strategies, including public education, xeriscaping, plumbing retrofit, and metering.
- Modifying residential development patterns, including housing occupancy rate and the ratio of apartments to multi-unit dwellings.
- Modifying sector allocation rules applied during water shortages.
- Implementing a policy to satisfy *all* Upland water shortages with Okanagan Lake water

Advanced options include increasing the capacity of storage in the Uplands and adjusting the irrigated land area for each crop type. A complete list of adaptation and policy options is available in the model documentation (Table 10 of Appendix D).

3.5.2 Dynamics of the system

Here we describe the actual and modeled system through key linkages that define the behaviour of the aspects of interest. Since our main objective is to explore the balance between supply and demands, we characterize the aspects that will increase or decrease the supply and/or the demand.

Figure 3.5: Causal Loop Diagram of the Okanagan Basin water resources system.



3.5.2.1 The causal loop diagram

One tool for illustrating a complex system is a “Causal Loop Diagram” (CLD, Figure 3.5). CLD's are particularly useful for identifying feedback loops and for clarifying the factors that control system behaviour. Since the purpose of OSWRM was to gain a better understanding of the water balance under a variety of times and conditions, we chose “Water Deficit” as the state variable to indicate the condition of the system. “Water Deficit” is directly influenced by “Water Available” and “Total Water Need.” The arrows that connect these elements show the relationship, and the +/- signs indicate the direction of influence. For example, the positive link from Total Water Need to Water Deficit means that as Total Water Need increases, Water Deficit will also increase. The negative link from Water Available to Water Deficit means that as the amount of Water Available increases, the Water Deficit decreases;

there is an inverse relationship. Similarly, as the Water Deficit increases, Water Use is forced to decrease.

3.5.2.2 Water deficit

The Water Deficit is the shortage in water relative to water demand, as expressed by the equation below. In the CLD, the Water Deficit represents an aggregate for the whole basin. The parameter is always zero or positive, as states of water surplus are ignored. More severe deficit conditions are represented by larger magnitudes.

$$\text{Water Deficit} = \text{MAX} (\text{Maximum Water Demand} - \text{Managed Supply}, 0)$$

“Managed Supply” aggregates surface water, groundwater, and water diverted from adjacent river basins, and includes the delay created by reservoirs. “Maximum Water Demand” aggregates the basin’s agricultural, residential, and ecological demands. Forest evapotranspiration is captured as land cover in the UBC watershed model, so is already subtracted from streamflow.

3.5.2.3 Balancing feedback loops

There are several balancing loops that work to alleviate Water Deficit either by increasing supply or by reducing demand. Supply is increased through additional imports and/or groundwater pumping. In the actual system, we know basin residents have supplementary groundwater wells. However, these are unregulated and there is little information on the magnitude, location, or frequency of use. It should be noted that, although groundwater pumping increases supply in the short term, it is probable that surface water and groundwater are closely linked; therefore, groundwater pumping may reduce the amount of surface water available over the longer-term. In OSWRM, only certain communities rely on these supplemental sources, and their contribution increases only as the populations in the communities increase. This balancing feedback of tapping supplementary supplies during drought is not captured.

When deficit is present, mechanisms exist for reducing allocations to each of the three use sectors. Decisions about prioritizing water use and thus, implementation of these mechanisms, is decided at the local scale, often by individual purveyors. Extended periods of water deficit may encourage implementation of conservation measures.

3.5.2.4 A reinforcing feedback loop

Water is reused multiple times on its journey between precipitating onto the ground and exiting to Osoyoos Lake. This phenomenon is captured by a weak reinforcing loop. Water is returned to the system post treatment, or through irrigation returns. Several communities reclaim treated water from residential sources and use it for watering golf courses and municipal parks. The increase in water available reduces the water deficit, which allows for increased water use. Additional water consumption increases the volume of water returned to the system. The reinforcing strength of this loop is highly limited by exit pathways, such as flows downstream, and losses to evapotranspiration or to deep aquifers.

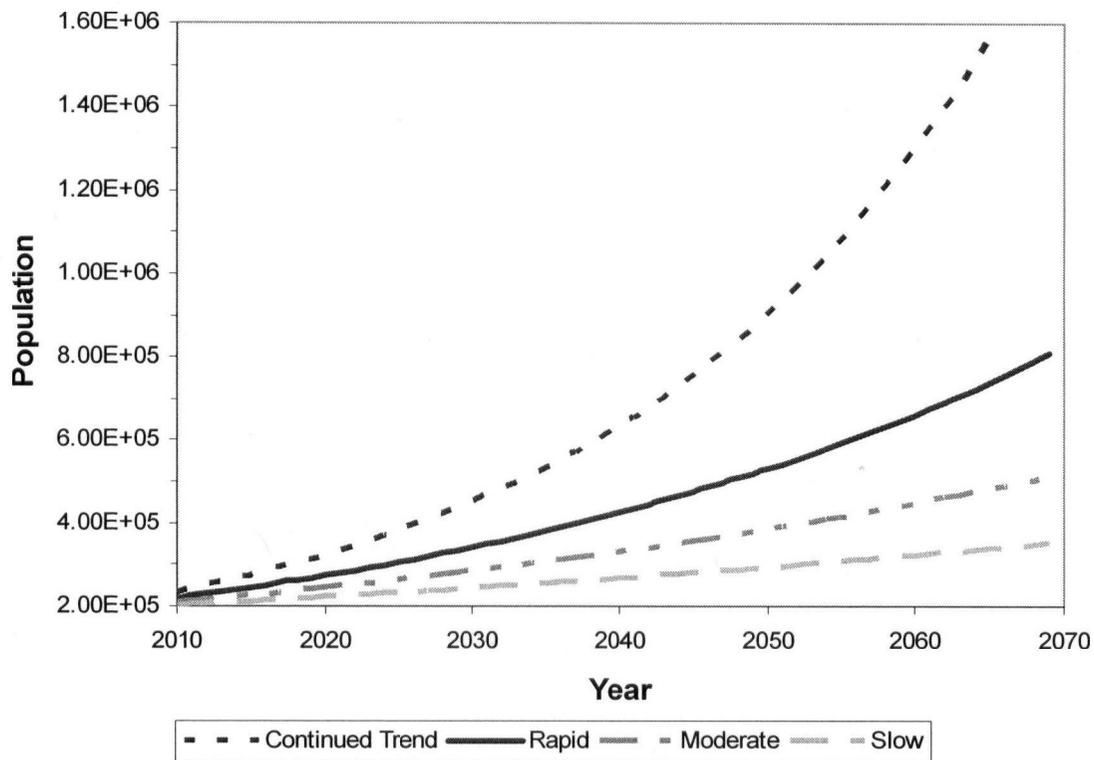
3.5.2.5 External drivers – climate and population

Without external drivers, the system could achieve dynamic equilibrium. However, the external influences of a climate change and population growth disrupt the system. Climate change can affect the water deficit through multiple influence points – decreased precipitation reduces streamflow, and increased temperatures increase agricultural irrigation requirements and residential outdoor watering. In this analysis, we assume population is affected only by factors outside of our system and that it will continue to increase over time. Therefore, without significant water reduction or conservation strategies, residential water demands will continue to increase.

Residential growth rate projections used in this work are based on community and regional plans, as well as work by Neale (2006:2005; also see Appendix D). These rates are significantly lower than the growth rates of recent decades. Figure 3.6 compares the population projections for the three growth rates defined by the community plans (rapid,

moderate, slow) and for the rates from recent history (1961-1990) referred to as “continued trend.” The historic growth rate was significantly higher than projections, so the future estimates of population growth may also be underestimated. For that reason, we emphasize the rapid growth scenario in the results presented in this paper.

Figure 3.6: Population projections for the Uplands water users.



3.6 Results

The results presented in this paper all focus on the Uplands portion of the basin, defined primarily as the managed tributaries to Okanagan Lake and users of this water source. Section 3.6.1 describes projections of maximum future demand compared with managed supply, at a number of scales from thirty-year aggregations to monthly averages. Section 3.6.2 shows feasible allocations associated with the amount of supply available in these

future scenarios. Finally, Section 3.6.3 discusses the role of adaptation as a means of making a smooth transition to the future as described by these plausible scenarios.

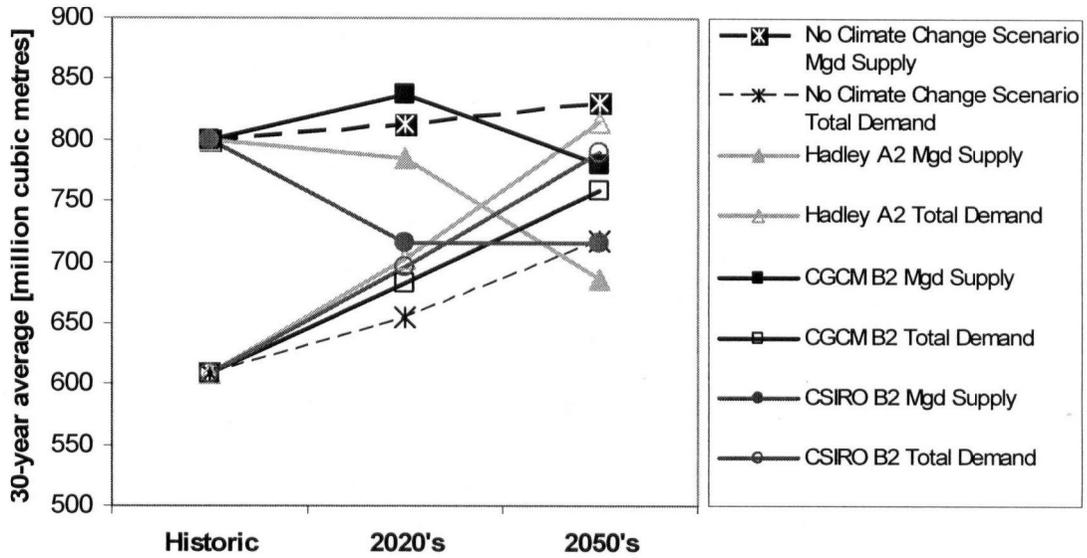
3.6.1 Managed supply vs. maximum demand

Figure 3.7 compares the total managed supply with the total maximum demand in the Uplands Region of OSWRM from the historic to the future simulations. These results are aggregated and reported as annual averages, with one value for each of the three thirty-year simulation periods. Figure 3.7 presents both rapid (a) and slow (b) growth rates to show the sensitivity of the system to population growth. The remaining figures present only the rapid growth scenario unless otherwise noted.

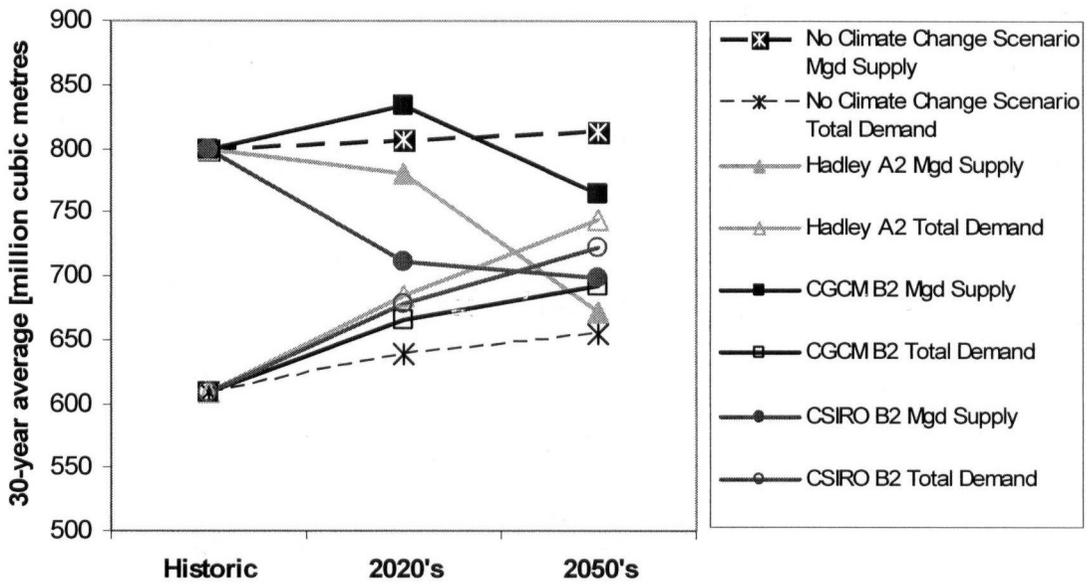
“Managed supply” combines stream flow in the tributary streams with the supplemental supplies and return flows, and includes timing adjustments from the reservoirs. The “No Climate Change” scenario supply data lines show a slight increase over time. This increase can be fully attributed to these supplemental sources and return flows, which are dependent on population. Note that all three climate scenarios contain these minor increases in supply, although they are superimposed by the more dominant decreasing trend that is a direct result of the decrease in basin precipitation due to climate change.

In Figure 3.7, “Total demand” includes the three major sectors: agricultural, residential, and conservation flows. The maximum demand values are based on projections of current use patterns and do not assume any increases in efficiency such as implementation of conservation measures. Maximum demand is independent of supply and may be greater than available supply, even in the historic period. In all of these scenarios the conservation flow target remains constant through time, so changes in demand are all a result of changes to residential and agricultural demands. Agricultural land under production and crop types are also constant; any increase in agricultural demand is due to climate change.

Figure 3.7: Thirty-year annual averages of total managed supply and maximum demand from the Uplands, showing trends through time for multiple climate scenarios with (a) rapid population growth, and (b) slow population growth.



(a) Rapid Population Growth



(b) Slow Population Growth

In the historic period, the average managed supply in the Uplands exceeded the average maximum demand. All of the future scenarios in Figure 3.7 show decreases in supply and increases in demand over the long term. The CGCM B2 scenario does show an increase in supply in the 2020's, but the large decrease in supply in the 2050's still leads to a decrease overall. Average annual demand exceeds supply by the 2050's in the Hadley A2 and the CSIRO B2 scenarios in both the rapid and slow growth scenarios. The CGCM B2 scenario is the least severe, but still shows a smaller gap between supply and demand in the 2050's.

3.6.1.1 Annual variability

The thirty-year annual averages shown in Figure 3.7 show the long-term trends, but conceal the presence of shortages due to annual climate variability. Figure 3.8 and Table 3.1 show annual variability which reveals the magnitude and frequency of annual water shortages. The scatter plot (Figure 3.8) presents managed supply versus maximum demand for each year of simulation from the historic period through the 2050's for a single climate scenario (Hadley A2). The dashed line represents the supply-demand equality, which is the approximate division between conditions of deficit or surplus. Points located above this threshold represent a deficit in the annual water budget. In the thirty-year historic period, there are three years in deficit (one out of ten). By the 2050's, both the Hadley A2 and the CSIRO B2 scenarios show a deficit frequency of about two out of three years, whether population growth is slow or rapid. CGCM B2 is less severe. Table 3.1 summarizes the years in deficit for each of the scenarios and time periods. By the 2050's period, the climate change scenarios estimate shortages occurring every 14 to 22 years out of 30 if rapid population growth occurs. Slow population growth has little effect, with shortages still occurring every 11 to 21 years out of 30. The "moderate adaptation portfolio" includes a selection of strategies which have already been implemented, or are being considered, in one or more communities within the Okanagan Basin, and simulates their implementation at the basin-wide scale (see Section 3.6.3).

Figure 3.8: Annual total managed supply and total maximum demand for the Hadley A2 climate scenario and rapid population growth among Uplands water users.

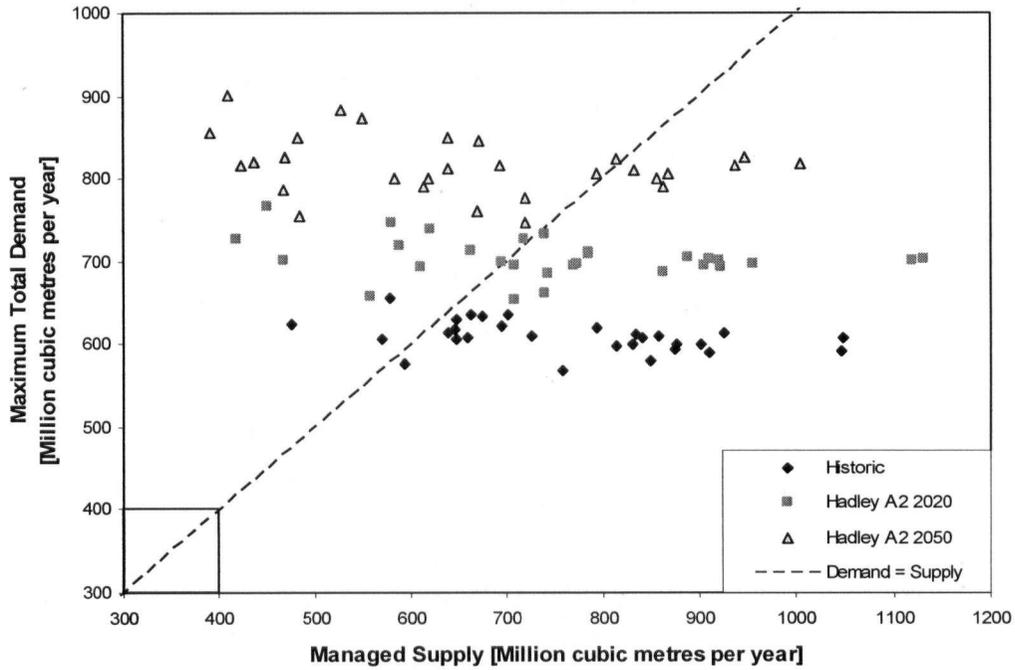


Table 3.1: Summary of deficit years as defined on the scatter plot (Figure 3.8) for all climate scenarios, showing (a) Rapid population growth and (b) Slow population growth.

(a) Rapid Population Growth Scenarios			
No. of years (out of 30) where demand equals or exceeds supply			
	Historic	2020's	2050's
No CC	3	6	10
Hadley A2	--	11	22
CGCM B2	--	8	14
CSIRO B2	--	14	21
Hadley A2 Mod Adapt	--	9	19

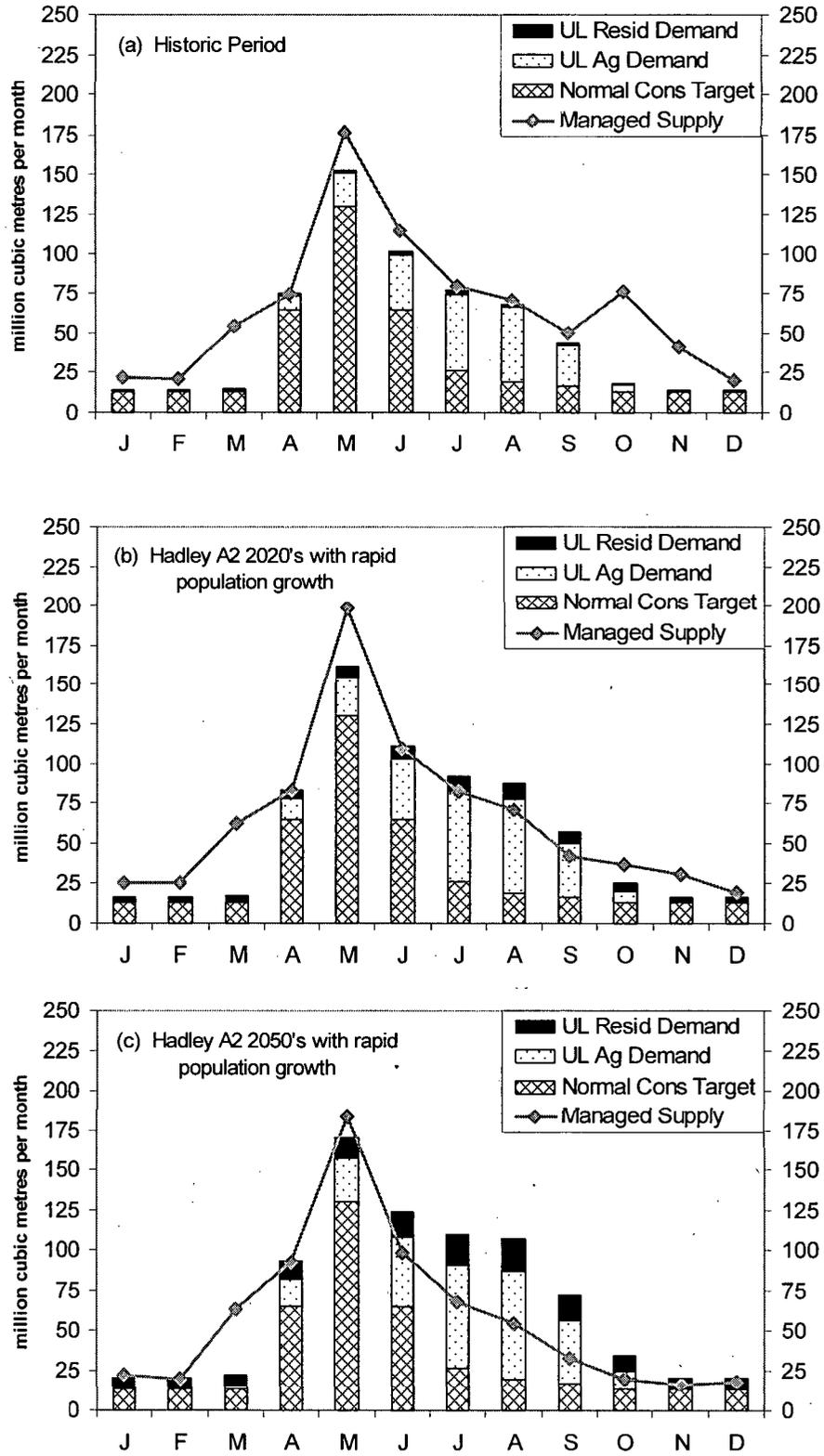
(b) Slow population growth scenarios			
No. of years (out of 30) where demand equals or exceeds supply			
	Historic	2020's	2050's
No CC	3	5	6
Hadley A2	--	9	19
CGCM B2	--	7	11
CSIRO B2	--	14	21

3.6.1.2 Intra-annual variability

Water supply and demand in the Okanagan are unequally distributed through the year, so some of the years that are not in deficit overall may still experience summer shortages. Figure 3.9 shows supply and demand by month, including a breakdown of the three major demand sectors. Managed water supply currently peaks in March as a result of the spring freshet. Total demand also peaks in March, but out-of-stream demands peak in July and August. Instream conservation flow targets roughly follow the historic natural pattern of supply, and the monthly targets are held constant each year. In all of the future climate change scenarios, the spring freshet occurs slightly earlier in the 2020's and 2050's. Managed supply reflects this, as is shown by the increases in April supply through time (Figure 3.9). Because the conservation flow targets are based on the historic peak flow, a slight offset in timing of peak flow emerges. Future residential and agricultural demands increase through the irrigation months (March – October). By the 2020's, the thirty-year averages of demand in July, August, and September exceed the system's capacity to allocate supply. By the 2050's, the deficit during these months is exacerbated and extends from June through October.

In Figure 3.9, conservation demand remains constant through the future periods (because it is defined by policy). Agricultural demand increases with climate change, and residential demand, which historically was rather minor, becomes a more notable, although still small, portion of the profile by the 2050's with rapid population growth.

Figure 3.9: Thirty-year average monthly managed Uplands supply and maximum demand profiles with demand from the three major sectors revealed.



3.6.2 Maximum demand versus total allocation

The volume of water that can be allocated to meet demands is limited by the amount of managed supply available each month. When water shortages occur, water allocations are determined by drought policies and management decisions. The graph in Figure 3.10 shows maximum demand and total allocation over the thirty-year simulation period for several scenarios.

OSWRM allocates water to the three sectors based on interpretations of the current drought policies and management practices that were described by the local stakeholders that participated in the model building sessions. For example, residential outdoor watering restrictions are standard practice in the region, so it is the first sector to be cut. On average, percent reductions across sectors are similar, with a slight priority granted for conservation flows and slightly greater reductions in the residential sector.

In the future climate change scenarios, both agricultural and residential demand levels during the summer increase. At the same time, supplies are generally decreasing overall. Spring melt occurs earlier, and summers are drier, which makes meeting summer and fall demand even more challenging. Critical months by the 2050's extend from June through October, with August becoming the most severe.

The difference between the allocation curves and the demand curves in Figure 3.10 shows how much demand can be satisfied. These are expressed as percentages for both annual totals and August values in Table 3.2. Table 3.2 provides a summary of the percentage of demand met (through allocations) both as an annual summary and for August only. In the historic simulation, 98 percent of annual demand was satisfied, while 95 percent of August demand was satisfied. All of the future scenarios show reduced capacity of the system to meet demand.

Figure 3.10: Thirty-year average annual summary comparing total demand (all three sectors) and total water allocated in the Uplands for the rapid population growth scenarios.

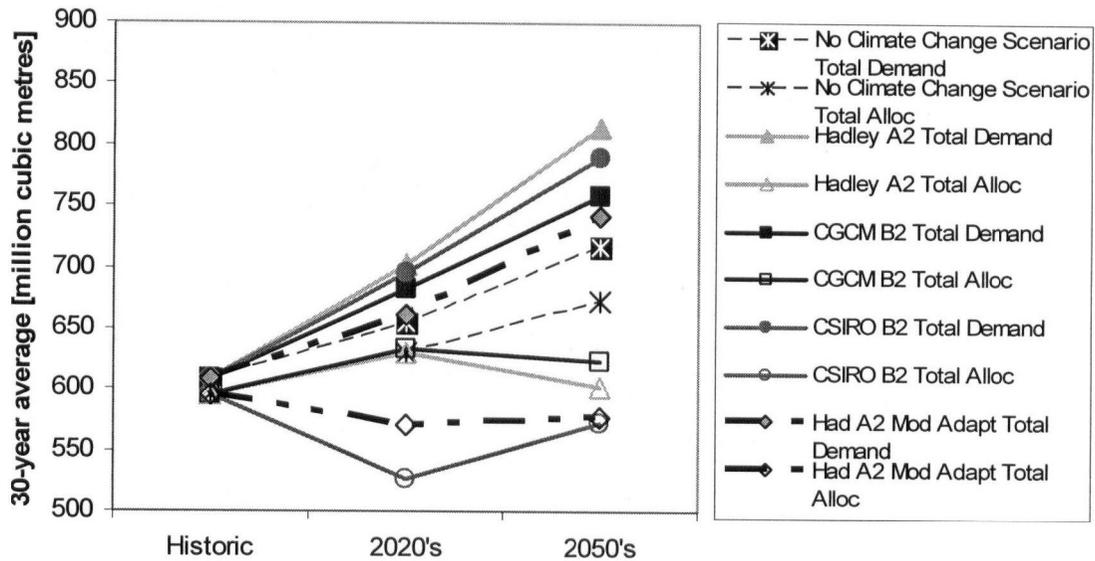


Table 3.2: Allocations as a percent of demand, shown as annual totals and for August, the month with the greatest deficit in the future scenarios.

Percent of Demand Met (Allocations/Demand)	Annual Totals		August Only	
	2020's	2050's	2020's	2050's
CGCM B2	93%	82%	84%	59%
Had A2	90%	74%	79%	50%
CSIRO B2	76%	72%	49%	45%
Had A2 Mod Adapt	86%	78%	81%	55%

3.6.3 Deficit and adaptation

Reductions in demand can be forced during dry years, which will occur with increasing frequency and severity, or they can be voluntary and anticipatory, through the use of anticipatory conservation strategies. Various conservation and adaptation strategies that reduce consumption could decrease the total demand as shown, and may help lessen the frequency and severity of forced allocation reductions.

The scenarios described thus far include several assumptions. First of all, the future “maximum” demand assumes that no additional conservation strategies will be implemented. Furthermore, the scenarios assume agricultural demand will continue to increase as a function of crop water demand without regard to water rights limitations. Residential water demand will continue to increase as a function of the exponentially increasing population. Therefore, conservation measures and/or regard for legal limits may reduce the severity and frequency of deficit.

Figure 3.10 and Table 3.2 include the results of a “moderate adaptation scenario.” This scenario takes some of the current adaptation trends in the region, and extends them to the entire basin. Residential demand management includes public education and metering with charges by increasing block rate. Combined, the strategies may slow residential demand by about 40 percent (Neale 2006). The moderate adaptation scenario also includes a reduction in all agricultural demand, by six percent. (A six percent reduction in total agricultural demand results from an increase in efficiency of 25 percent of the maximum reduction theoretically possible while maintaining current states of irrigated area and crop mix. The conversion is explained in Section 3.5.1.4.) These reductions are not from current levels, but are reductions from the future scenarios without adaptation, as shown in Figure 3.10. Note that future average allocations are also slightly reduced in the adaptation scenarios as compared with allocations in the associated (Hadley A2) no adaptation scenarios. The decrease in average allocation is partly due to the decrease in managed supply and partly to the decrease in demand. The decrease in managed supply is due partly to the decrease in return flows from residential indoor use and partly from storage release adjustments. The wastewater return flows are significant, so as residents use less, the return flows are much less. The remaining supplementary sources are minor. As a result, the reliability of meeting demand in the future does not increase significantly. In fact, it appears to drop slightly in the 2020's, but shows a slight improvement from the no adaptation scenario in the 2050's.

Alternate ways of allocating water to the three main sectors are nearly limitless. OSWRM provides an opportunity for users to explore this feasibility space through numerous optional settings, as described in Section 3.5.1.7. Cohen and Langsdale (2006) show simulation

results from a number of adaptation scenarios, providing some insight into the effectiveness of a range of options available. It is theoretically possible to define this feasible region (i.e. the range of possible combinations of adaptation measures that would produce satisfactory results); however, the boundaries of the region are subjective, dependent on perceptions of risk, changing water technology (e.g. irrigation), and future development choices. Therefore, defining boundaries would be quite challenging. This task is beyond the scope of this project, but is recommended for future work. The purpose of this modeling initiative, couched in a participatory process, was not to identify “the” solution, but to guide the local professional water community in exploring the effectiveness of available policies to support desired future conditions such as increased reliability of the water resource.

3.6.4 Implications for future management

All future climate change scenarios, from 2010 through 2069, show a significant decrease in water supply from the 1961-1990 condition. This decrease may be slightly offset by additional groundwater pumping and diversions from adjacent river systems, however, the limitations of these sources are currently unknown. Simultaneously, out-of-stream (agricultural and residential) demands are projected to increase significantly. Residential water demand is more sensitive to population growth than to climate change, though climate change does accelerate the effect of an increasing population. In contrast, the area of agricultural land in production is quite stable in the Okanagan, but crop water demand is highly sensitive to changes in climate, so irrigation may intensify. Conservation flows are policy-based, and are assumed to remain constant throughout the simulation time period.

All of the climate scenarios show that long-term average allocations may remain close to the levels in the historic simulation, even though the average supply is decreasing. This is because the allocation decreases in the increasingly frequent dry years are offset by the allocations increases to match the greater future demand in wet years. Although the magnitude of allocations remains relatively constant, the reliability of the water supply to meet demand decreases from a historic rate of 98 percent to a range of 72 to 82 percent in the 2050's. Most of this future deficit is due to the impacts of climate change. Population growth

contributed to only a small portion of this reduced reliability, as is evidenced by the “no climate change” scenario. Future simulations without climate change result in allocations that are 94 percent of maximum demand in the 2050’s.

Satisfying demand during the dry season, when irrigation demand peaks, will become increasingly difficult. August may be the most challenging month, with allocations reduced from 95 percent in the historic simulation to between 45 and 59 percent of demand in the 2050’s. Conservation measures may reduce this deficit, however, the “moderate adaptation scenario” which incorporates some of the adaptation measures currently being implemented in the region and extrapolates them for the whole region, does not significantly reduce the deficit. The potential effectiveness of the conservation measures may be slightly dampened by the reduction of return flows from residential indoor use. Indoor water use is, in effect, not a consumptive use. Stricter conservation measures, limiting future residential development, and limiting increases in agricultural demand, may be required to prevent future water conflicts. The agricultural sector may be forced to implement efficient irrigation technologies, change crop types, and/or reduce land under production. As a complement to conservation measures, expansion of supplies may play a role. Cohen and Langsdale (2006) showed that expanded use of Okanagan Lake may be feasible if care is taken to avoid depleting this resource. Expanding groundwater use has not been fully explored. Caution should be applied with expansion of either groundwater or Okanagan Lake as they are not new resources, but are hydrologically connected to current sources.

3.7 Conclusions

The OSWRM is a highly aggregated scoping model intended for the purpose of exploring a variety of future scenarios. Analyzing the results of these scenarios helped to illuminate dominant and controlling system characteristics, such as feedback loops. Identifying parameters to which the system is sensitive also helps to select priorities for future research. For example, reductions in residential water use caused a notable decrease in wastewater

return flows (from residential indoor water use). Refining the portion of residents on sewer, and the portion of water which is returned may increase the accuracy of the model results.

Although the model was supported by numerical data, the focus of the modeling exercise was on identifying the important causal relationships (qualitative characterization) rather than on providing a fully calibrated and validated quantitative assessment. Therefore, when reviewing the results it is more important to focus on the general trends of the future scenarios than on specific values. OSWRM is useful for quickly testing a number of different climate change, population growth, and adaptation scenarios, however, when the Okanagan community is ready to move forward towards design and policy-setting, then more detailed and rigorous studies are recommended.

The results presented in this paper focus on the Uplands portion of the basin for clarity of presentation. At the outset of this work, the common belief was that the dry southern portion of the basin, downstream from more than half of the basin's population, would be most vulnerable to all stressors on the water resources. Intuitively, one would expect that water shortages in the upstream end of the basin would increase in severity as you move downstream. However, to date, watersheds in the Upland tributaries have proven to be most sensitive to drought. The 2003 drought caused severe conflict and resulted in the development of an operating agreement in the Trout Creek watershed, while the South End felt little or no impact. One reason for the lack of sensitivity is that the South End community's two main water sources are quite buffered from climate variation. Surface water supplies used for irrigation are managed by a large extent through operation of the dam on Okanagan Lake, and groundwater used for domestic purposes is typically a stable resource, not immediately impacted by drought. However, the question remains whether long-term strains in the Upland region will eventually trickle down to the South End. Current research on the characterization of the groundwater aquifers will provide some clues to this puzzle. Ultimately, it will be the decisions that the residents and water managers make that will have significant influence over the future of water resources in the Okanagan Basin.

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CHAPTER 4: CONCLUDING REMARKS

This dissertation describes a participatory modeling project which explores the issue of climate change related to water resources in the Okanagan Basin, British Columbia, Canada. Chapter 1 begins with a description of how the water resources planning and management field is responding to climate change, including challenges and response options. The chapter continues with a review of current literature in the fields of integrated assessment, participatory planning, system dynamics, and the combination of these fields which forms participatory modeling. Finally, the Okanagan Basin case study is introduced. Chapter 2 describes the participatory processes applied in the Okanagan case study as well as the response of the participants, while Chapter 3 describes the system dynamics model that resulted from the process and presents an analysis of model simulated results for multiple future scenarios. This chapter provides an overview of the work, and discusses objectives, results and conclusions. I conclude with possibilities for continuing research in this project, for new applications of this methodology, and for advancing the methodology.

This project shows that participatory modeling can be an effective tool for creating and structuring dialogue on the issue of climate change in natural resource planning and management. Gathering a diverse group of stakeholders with different perspectives and experiences brings to the table a breadth of ideas necessary to have informative dialogue, while development of and interaction with the model provides a common language with which to discuss and characterize the complex system as described by participants. These advantages work toward keeping the dialogue focused on the issue at hand. Exploring model output helps participants to question their own understanding of the system, which fosters learning about processes and relationships, rather than just facts. This more sophisticated type of knowledge is a prerequisite for developing effective policies to manage the system. Although it was not measured in this project, this form of dialogue among diverse stakeholders, supported by an interactive model, may inspire creativity surrounding solutions to the problem.

The model results show that climate change may, in fact, significantly impact the Okanagan's water resource balance by increasing the frequency and magnitude of water shortages. The scenarios show that the impacts of climate change on the system are significantly more intense than the impacts due to anticipated levels of population growth. The combined impacts from climate change and population growth create water deficit conditions that exceed historic conditions. Anticipatory adaptation measures have the potential to reduce the intensity of future water shortages. A continuation of model-supported dialogue with the Okanagan's water resource stakeholders could assist in the evaluation of management alternatives and decision making.

Published case studies (Cardwell et al. 2004; Cockerill et al. 2006; Connor et al. 2004; Costanza and Ruth 1998; Jenkins et al. 2005; Jones et al. 2002; Keyes and Palmer 1993; Kirshen et al. 2004; Letcher and Jakeman 2003; Palmer et al. 1993; Peterson et al. 2004; van den Belt et al. 1998; van den Belt 2004) show that the participatory modeling approach is an effective tool for engaging communities in dialogue about managing natural resources applications. The present work shows that the method is effective for engaging participants in a policy dialogue and an interactive learning experience on the topic of climate change.

4.1 Project Summary: Objectives & Results

The two major components of this thesis were to conduct a participatory process and to develop a system dynamics model. The participatory process had three primary objectives: (1) To create a shared learning experience among the participants and the research team; (2) To tailor the model to suit the needs of the community; and (3) To foster a sense of ownership of the model among the participants. The purpose of constructing the model was to explore water resources futures in the Okanagan Basin, with specific attention to the influence of climate change and population growth, and to the role of adaptation strategies on maintaining reliability in the water resources system.

4.1.1 The participatory process

Participatory modeling was selected as the methodological approach because it is an effective tool for both characterizing the system and communicating the information to relevant parties. The expert stakeholders who participated in the modeling process were the best resource for certain numerical data. I could have acquired this information from them regardless of their participation in the process. However, the benefit of their active involvement was that it created the opportunity for all participants to share their perspectives and knowledge of the water resources system. The workshop activities were designed to draw out this knowledge and educate the modeling team on the important components that needed to be characterized to assess the current and future state of the region's water resources and management options. These activities included generating system diagrams and a historical timeline, discussing relevant issues, and providing feedback on the model. As a result, the modellers created a richer description of the system than they would have in absence of the participatory advisors. In addition, the interaction with the local community provided a more rewarding experience for the research team.

The effectiveness of the participatory process in meeting our objectives was measured through surveys in the final two workshops. Gathering a diverse group of stakeholders together and providing opportunities to share their perspectives helped to broaden people's understanding beyond their own experiences. Furthermore, by developing and interacting with the model, the participants clarified their understanding of the linkages and processes that define the water resource system. In discussing the model, we emphasized causal relationships rather than facts, to support second-order learning (Folz and Hill 2001; van de Kerkhof 2004).

Participants found both the process and the resulting model valuable. When asked if their perceptions of future water availability in the basin changed due to the exercise, the majority of respondents selected a middle response ("some change"), while the median value was slightly lower. Those with the least knowledge about the water resource system experienced the most learning. Several participants noted a new appreciation for the complexity of the system and in managing it effectively.

Information and feedback gathered from the participants throughout the workshop series supported the development of a model that was relevant to those who manage the region's water resources. All participants surveyed at the final two workshops responded that they felt the model is, or has potential to be, a legitimate and relevant tool to explore long term water management in the Okanagan. The majority of respondents described parameters for effective use of the model; that it would be useful with the appropriate audience or after additional refinements were made. Several people commented that it was a good communication and/or education tool for visualizing the future and discussing policy.

Because the model had become rather complex by the fifth and final workshop, and because half of the attendees had not attended previous events, they spent considerable time familiarizing themselves with the model. This illuminates the fact that the investment of time and resources required to bring newcomers up to speed makes sharing attendance responsibilities with colleagues less than ideal. More structured guidance would have helped lead the participants through specific explorations in the time allotted. Simplifying the model's user interface is recommended for increasing the efficiency and effectiveness of any future model exploration sessions.

In the early stages of designing the participatory modeling process, I wanted the participants to be as active as possible in the development of the model. For practical reasons, the participants did not build the model directly, but they did contribute substantial information that supported construction of the model. By the final two workshops, participants felt, on average, that they were familiar with the issues included in the model. The opportunity for participation provided by the six sessions over a twelve-month period, combined with the low rate of continuity in participation, may not have been sufficient for the participants to feel that it was "their" model. However, it was not practical to have the participants constructing the computer version of the model. The limitations on time and financial resources, as well as the interest and skills of the participants, defined the scope of participation in our final design of the sessions.

4.1.2 The Okanagan Sustainable Water Resources Model (OSWRM)

The OSWRM is a highly aggregated scoping model intended for the purpose of exploring a variety of future scenarios. The modeling exercise focused more on qualitative characterization than on quantitative calibration, so when reviewing results should also focus more on the general trends of the future scenarios than on specific values. The model is useful for quickly testing a number of different climate change, population growth, and adaptation scenarios; but not appropriate for policy or engineering design. This section highlights findings from the generation of future scenarios and describes implications for future management.

In the future scenarios, water balance is shown to be more sensitive to climate change than population growth. Climate change may decrease supply while increasing water demand in multiple sectors. Figure 4.1 shows the simulated decreases in supply and increases in demand through time, for the Hadley A2 climate scenario. Furthermore, climate change may exaggerate the offset in timing between supply and demand peaks, as the spring freshet will occur earlier in the year. This effect will increase the challenge of meeting demand during the summer irrigation season.

An analysis of model results compared total water demand (the amount that irrigators, residents, and the aquatic ecosystem would use if they could) with total water allocation (the amount that could be provided to meet this demand). The volume of water that can be allocated is limited by the amount of managed supply available in each monthly timestep. When water shortages occur, water allocations are determined by drought policies and management decisions. The graph in Figure 4.2 shows maximum demand and total allocation over the thirty-year simulation period for several scenarios.

Note that in the future climate change scenarios both agricultural and residential demand levels during the summer increase. At the same time, supplies are generally decreasing overall. Spring melt occurs earlier, and summers are drier, which makes meeting summer and fall demand even more challenging. Critical months by the 2050's extend from June through October, with August becoming the most severe.

Figure 4.1: Annual total managed supply and total maximum demand for the Hadley A2 climate scenario and rapid population growth among Uplands water users.

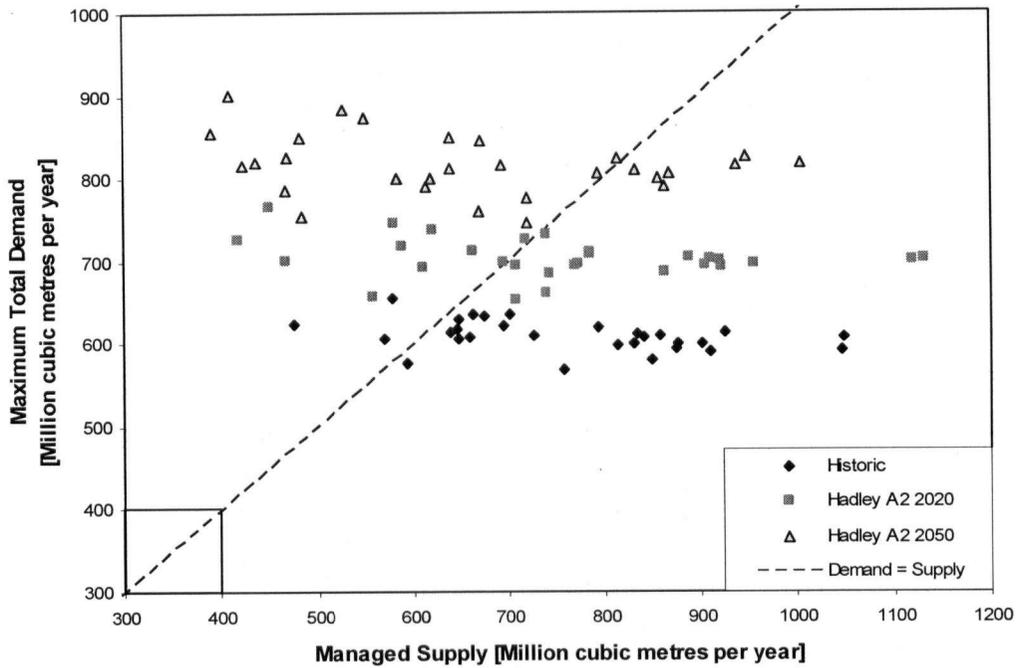
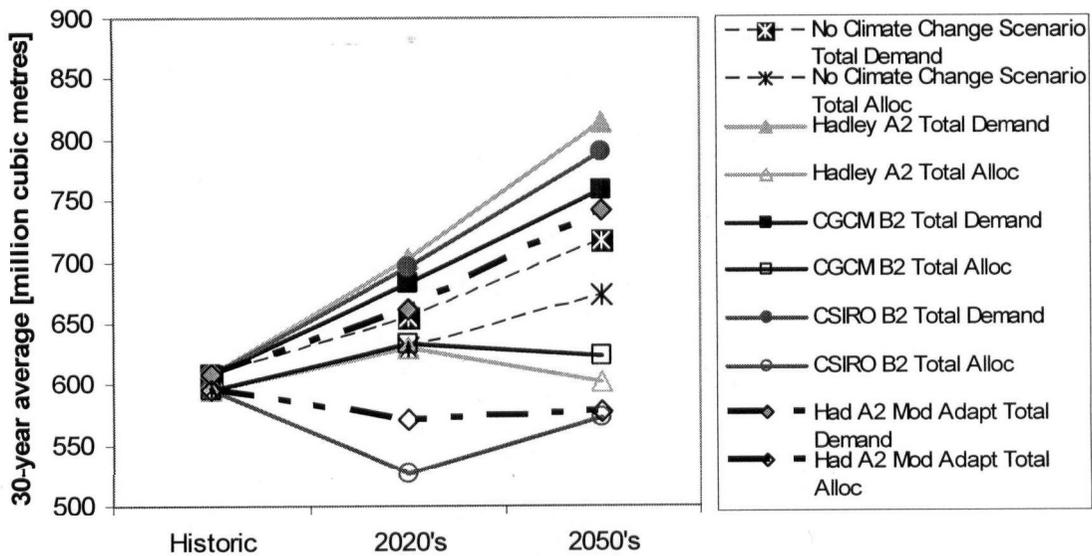


Figure 4.2: Thirty-year average annual summary comparing total demand (all three sectors) and total water allocated in the Uplands for the rapid population growth scenarios.



The difference between the allocation curves and the demand curves in Figure 4.2 shows how much demand can be satisfied. These are expressed as percentages for both annual totals and August values in Table 4.1. Table 4.1 provides a summary of the percentage of demand met (through allocations) both as an annual summary and for August only. In the historic simulation, 98 percent of annual demand was satisfied, while 95 percent of August demand was satisfied. All of the future scenarios show reduced capacity of the system to meet demand.

Table 4.1: Allocations as a percent of demand, shown as annual totals and for August, the month with the greatest deficit in the future scenarios.

Percent of Demand Met (Allocations/Demand)	Annual Totals		August Only	
	2020's	2050's	2020's	2050's
CGCM B2	93%	82%	84%	59%
Had A2	90%	74%	79%	50%
CSIRO B2	76%	72%	49%	45%
Had A2 Mod Adapt	86%	78%	81%	55%

All of the climate scenarios show that long-term average allocations may remain close to the levels in the historic simulation. However, as the future simulations show decreasing overall supply and increasing demand, the reliability of the water supply to meet demand decreases from a historic rate of 98 percent to a range of 72 to 82 percent in the 2050's. Most of this future deficit is due to the impacts of climate change. Population growth contributed to only a small portion of this reduced reliability, as is evidenced by the "no climate change" scenario. Future simulations without climate change result in allocations that are 94 percent of maximum demand in the 2050's. Satisfying demand during the dry season, when irrigation demand peaks, will become increasingly difficult. August may be the worst month, with allocations reduced from 95 percent in the historic simulation, to between 45 and 59 percent of demand in the 2050's.

Chapter 3 presents a "moderate adaptation portfolio" that includes a selection of strategies which have already been implemented, or are being considered, in one or more communities within the Okanagan Basin, and simulates their implementation at the basin-wide scale. The

adaptation portfolio includes agricultural efficiency improvements, residential metering, public education, as well as slight shifts in the urban development patterns of housing type and occupancy rate. These adaptations do reduce the magnitude of deficit in each simulation; however, they do not fully compensate for the climate change impacts. More proactive adaptation measures will be required to prevent conflict or harm due to water deficit in dry years in the future. A wider array of adaptation measures is presented in Cohen and Langsdale (2006).

4.2 Impact of Research Results

Before starting this process, work by Cohen et al (2001; 2004) had led the Okanagan water resource community to confront what impact climate change could have on their snow-melt dominated system, and to start evaluating some of the response options that they could take. This process brought the community further along the path of considering climate change in their water resources planning and management by providing a tool that can integrate both supply and demand scenarios. The active participation of stakeholders allowed the community to learn from one another and to contribute to the stories that the model tells us of current and future conditions. The extremely positive response by the participants suggests that the experience will be remembered as they continue to play a role in the region's water management. The learning that took place, whether it changed their initial ideas, or reinforced what they already knew, should give them more confidence and motivation to include climate change in future work.

Throughout the process, participants recommended that this work be shared with a wider community, particularly to elected officials and the public. The resulting model can be used to continue dialogue with the community regarding the evaluation and selection of appropriate adaptation strategies for reducing the negative impacts of climate change on their ability to manage water resources in the basin. The satisfaction that was expressed by the participants with the process supports evidence that participatory modeling is an effective tool for fostering communication and supporting effective consensus-building.

The long-term significance of this participatory modeling process to policy development cannot be measured during the timeframe of this phase of the project. Decisions are complex, and not based on single factors. Furthermore, decisions are made by many more people than just those who participated in the model building exercise. Since I do not have a control group, I may never be able to measure exactly what changed as a result of these efforts.

4.3 Lessons and Recommendations

This section describes several lessons that I learned through this experience, and provides recommendations for future applications of this methodology.

Fostering commitment from volunteers is always challenging. In the Okanagan Basin, there are currently many water planning initiatives competing for the time and attention of water-related professionals. Furthermore, individuals have different motivations for attending, so may have varied levels of interest at different stages of the process. Strongly encouraging consistent attendance and maintaining communication with participants regarding scheduling may help to foster more commitment to the process.

More frequent, shorter-duration meetings could be more effective at keeping the participants informed on model progress and at providing opportunities for participation. This participatory modeling process occurred in five full-day workshops held over a twelve-month period. However, the desire for more frequent meetings must be balanced by logistical realities. A minimum amount of time is required between meetings for model revisions and event planning. The time that facilitators, modelers and participants can give to the process must be considered. Also, financial resources of the project are often a limiting factor.

Providing model documentation to the participants before or at each session would have been an asset. During the workshop sessions, participants raised many questions about model assumptions and requested model documentation for their own reference.

Facilitators should repeatedly inform participants of ground rules of the modeling process to keep everyone “on the same page.” Clearly articulating ground rules of the process can also help invitees decide whether or not to participate. Some examples of ground rules that could have been stated more frequently in this project include: (a) the purpose of the model and its intended use; (b) the expected outcome of process; and (c) the intended model users.

Evaluations are critical to understanding the impact of the process. Although we did conduct a number of evaluations along the way, a more structured format that uses more precise measures of actual learning or attitude change) would have more effectively recorded participant learning, the effectiveness of the process, and individual experiences. Evaluations given at the beginning and the end of a participatory modeling process could measure evidence of learning about the characteristics of the system. However, it is challenging to know a priori how and where learning will occur, making it difficult to know what to measure at the outset.

4.4 Future Directions

This section presents ideas for continuing the participatory modeling work in the Okanagan case study region, for expanding applications of participatory modeling to other areas related to climate change, and for advancing the participatory modeling field.

4.4.1 Potential for continued efforts in the Okanagan

The severity of future climate scenarios indicates that continued evaluation of management options is advisable for ensuring reliable water resources into the future in the study area. Furthermore, the participants’ attendance at the modeling events, and their enthusiasm for the topic showed that there is sufficient interest in the topic to support additional efforts. Specific actions that could be taken to maintain stakeholder dialogue and outreach are to:

- (1) Continue engagement of the participatory modeling group to provide further opportunity to evaluate adaptation strategies and discuss policy implications. Facilitation should guide the exploration process through a structured process such as decision analysis, and could result in the identification of feasible adaptation portfolios.
- (2) Use the model as an educational tool among a wider audience, targeting policy makers and the general public. Dissemination of knowledge through the community may encourage voluntary water conservation, encourage effective water management policies, and foster public support for those policies.

A number of model refinements would increase the effectiveness of the use of the model in these stakeholder engagements. Suggested refinements include the following tasks:

- (1) Calibrate the Valley region of the model. Add Okanagan Lake evaporation.
- (2) Calibrate the South End portion of the model. A major obstacle to accurately modeling this region is characterizing the managed releases from Okanagan Lake which are defined by a complex set of rules that help balance both quantity and quality demands of multiple uses in the lake and in the river downstream. Some of these multiple uses include supporting aquatic species, providing flood control management, and maintaining recreational access, all of which must be managed within operational constraints. The coarse monthly time step, combined with the lack of forecasting, made calculating realistic lake releases challenging. Output from the prospective Fish Water Management Tool (Alexander et al. 2005) for the Hadley A2 2050's scenario, which will be available in spring 2007, could provide assistance on this issue.
- (3) Increase the level of detail in the adaptation strategies. In particular, specific agricultural adaptation strategies need to be identified, and their benefits quantified.
- (4) Simplify the user interface by reducing the amount of navigation required. Consider creating predefined adaptation portfolios to reduce the number of choices the user

must make. Provide a directory of all adaptation options available. Reduce the number of output graphs and ensure that the graphs are effective and concise indicators of the state of the system.

- (5) Expand the model to include information about the groundwater resource. Important linkages to be captured in the model are the rates of surface water – groundwater interaction, and the relationship between current groundwater use and sustainable yield of the aquifer. Current research initiatives, including the Groundwater Assessment in the Okanagan Basin led by Natural Resources Canada, and a Canadian Water Network project led by Dr. Diana Allen at Simon Fraser University is beginning to provide this information, so this may be a feasible project in the near future.
- (6) Add financial costs of implementing and operating adaptation measures, building on adaptation cost studies provided by Hrasko and McNeill (2006).
- (7) Add a spatial component to residential growth, such that limits of development at chosen population densities are tested.
- (8) Incorporate the effects of land use changes (residential development, forestry, etc.) on hydrology.

4.4.2 New applications for participatory modeling

The participatory modeling approach is not limited to local resource management applications, but could support other aspects of the climate change dialogue. The significantly delayed and geographically-displaced feedbacks make system dynamics models ideal tools for characterizing and exploring the climate change problem. New climate-related applications could include working with local citizen groups to increase awareness of climate change and to encourage behavioural changes. A participatory modeling process could help citizens understand how their life choices affect the global climate. At a larger scale, the methodology could assist in global climate policy-making, such as the Kyoto protocol and

emissions-trading schemes. Pioneers in the system dynamics community have proven that the model is well-suited to characterizing global issues. Examples include the Limits to Growth studies by Meadows et al. (1972; 2004) which examined issues of population, food, industry, resources, and pollution; and a behavioural climate-economy model by Fiddaman (2002) that conducted a policy analysis and the role of Kyoto. Given that a global climate model has already been developed, it may be feasible to use this model as a foundation for a participatory process involving representatives of climate negotiating parties. The model could serve as a means to validate or refute various worldviews and test assumptions that negotiating parties make about policy impacts and effectiveness. The potential benefits of smoother negotiations and more effective global-scale policies could easily outweigh the investment costs. High stakes, global policies for complex problems are being negotiated regardless, so an investment to ensure these policies are fair and effective is prudent.

4.4.3 Advancing the field

Participatory modeling applications to natural resource planning and management are relatively recent, but are rapidly becoming more prevalent. The methodology developed from several different research fields, and to date, no research has been completed assessing the various tools and processes available and for what case studies they are most applicable. “[I]n the face of the proliferation and ad-hoc experimentation with participatory methods, there is still a lack of accumulated knowledge on the strengths and weaknesses of each tool in meeting the objectives set by the evolving policy context ... [A]dditional research on the comparison and complementarity between participatory modeling and other deliberative methods” is recommended (Videira 2005: vii-viii). To fill this gap, an extensive analysis of case studies in the literature and an evaluation of the strengths and weaknesses of the range of tools and approaches currently in use are required. Specific tasks could include: (1) Creating a typology for classifying the case studies according to model and decision-making process; (2) Critically comparing simulation model platforms applicable to facilitating stakeholder involvement in water resources planning and management and their applicability to case study typologies; (3) Critically comparing participatory decision-making processes and their applicability to case study typologies; (4) Assessing the compatibility of the models

and the decision-making processes. This work would help to unify the now seemingly disjointed projects in existence, provide guidance to practitioners regarding model and process selection, and identify knowledge gaps and areas of future research.

As clearly shown through this research, the participatory modeling methodology offers to increase our capacity to explore complex problems and to prepare for uncertain futures. Didactic investigation of this field will increase our ability to train others to conduct these processes. As the approach spreads to a wider array of applications and to new audiences, society will be better equipped to collaboratively negotiate local solutions for the global problems looming before us.

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APPENDICES

Appendix A: Behavioural Research Ethics Board Certificate of Approval

Appendix B: Workshop Evaluation Forms

Workshop 5 Pre-Evaluation

1. **How many previous events (workshops in Feb, April, June and Dec 2005, and meetings in Sept/Oct 2005) have you attended (not including this event)?**

0 1 2 3 4 5

2. **What role do you play in water resource planning or management in the basin (water manager / provincial govt / elected official / NGO / other)?**

3. **How well do you understand the model's structure?**

No knowledge
of model

1

I know which issues
are included

2

Very well – I could
teach it to others

3

4

5

4. **Do you feel your participation in the sessions contributed to the development of the model?**

Yes No Undecided

- a. If yes, what ideas or data were you able to contribute?
b. If no, what minimized your participation in the development of the model?

5. **Has your participation in the sessions increased your knowledge and understanding of the state of water resources in the Okanagan?**

Yes No Undecided

- a. If yes, what have you learned through these sessions (either procedural, collegial, or substantive)?

Workshop 5 Post-Evaluation

1. **How many previous events (workshops in Feb, April, June 2005 and meetings in Sept/Oct 2005) have you attended (not including this event)?**

0	1	2	3	4	5
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2. **What role do you play in water resource planning or management in the basin?**

3. **How well do you understand the model's structure?**

No knowledge of model		I know which issues are included		Very well – I could teach it to others
1	2	3	4	5

4. **Has your participation in the sessions increased your knowledge and understanding of the state of water resources in the Okanagan?**
 - a. If yes, what have you learned through these sessions (either procedural, collegial, or substantive)?

5. **Have your perceptions of future water availability in the basin changed due to this exercise?**

No change		Some change		Major changes
1	2	3	4	5

 - a. Please explain.

6. **Do you feel the model captures the major factors that influence water resources in the Okanagan, now and in the future?**

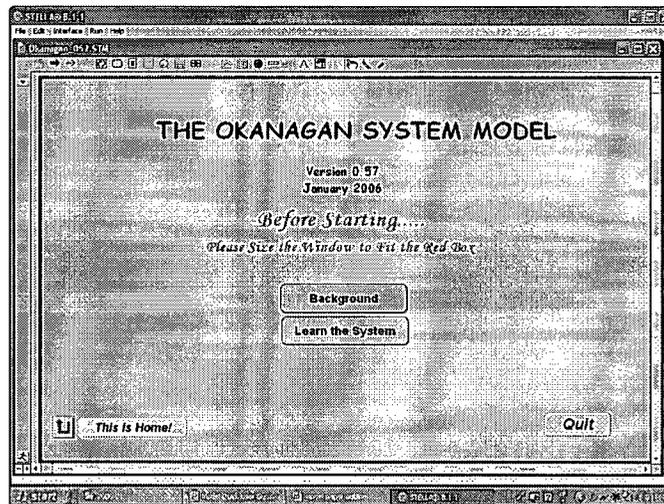
Not at all		Some factors		All factors
1	2	3	4	5

 - a. Can you identify important factors that are missing?

7. **Do you feel this model is a legitimate and relevant tool to explore long-term water management in the Okanagan? Briefly explain (use the back if necessary).**

Appendix C: The Okanagan System Model: Quick Reference

The Okanagan System Model: Quick Reference



*A Brief Introduction to the Okanagan Water
Management & Climate Change System Model*

Version date: January 2006

Stacy Langsdale

University of British Columbia

TABLE OF CONTENTS

- I. Purpose of the Model
- II. Methodology: Participatory Modeling & System Dynamics
- III. Major Data Sources
- IV. Navigating the Interface
 - 1. Background
 - 2. Learn the System
 - 2. Review Simulated History
 - 3. Explore the Future
 - 3.1 Future Scenario Options
 - 3.2 View Consequences
 - 3.3 Test Policy Options

I. PURPOSE OF THE MODEL

The purpose of this initiative is to assist the Okanagan community in fostering sustainable water for their future. To do this, they need an aggregated picture of the stressors that may play a role, as well as information about the effectiveness of various strategies to reduce vulnerabilities in water resources system.

In the Okanagan, climate change and population growth are the major stressors expected to negatively impact the balance of supply and demand. Previous growth estimates were too conservative—the population of the central Okanagan doubled in the 25-yr period from 1975 to 2000—and this rapid rate is likely to continue. Bringing climate change into the conversation carries additional challenges. People are uncomfortable with the level of uncertainty in climate change estimates. Furthermore, most work has been conducted at the global scale, with results being reported in terms of long-term average changes in temperature or in precipitation. Regardless of the challenges, bringing climate change into the conversation increases the opportunity to prepare for the future.

One mandate of the Adaptation & Impacts Research Division of Environment Canada is to encourage awareness among communities of the importance of adapting to climate change. One step in this process is translating the results of global climate models into impacts that are relevant to local communities. Prior to the modeling phase, researchers at Environment Canada (B. Taylor, M. Barton) downscaled the results of selected global climate models (GCMs) to the Okanagan Basin. Three models provided a range of plausible impacts, making the range of uncertainty more explicit. Next, these climate change scenarios (expressed as temperature and precipitation changes) were used to simulate changes in the hydrologic system as well as crop water and residential demand. Thus, the climate change information was translated into terms that were more meaningful to the local water community. This information became the foundation of the Okanagan Model.

In creating this model, we wanted to provide information about the current and future supply-demand balance of the Okanagan's water resources, and to allow water professionals and related interests to explore the effectiveness of an array of alternative management options, but also to learn why they are more effective, through increased understanding of the system.

II. METHODOLOGY: PARTICIPATORY MODELING & SYSTEM DYNAMICS

A model is useful for the purposes outlined above because the Okanagan's resources are a complex system. The human capacity for understanding complex systems is surprisingly limited. Even when a person can understand each relationship between parts separately, a System Dynamics model is useful in that it can track each of these relationships simultaneously. Furthermore, it can track delays and feedback loops that frequently are the sources of unexpected results.

This model is a decision support tool, not a decision maker. It does not optimize, nor is it appropriate for use in system design or operation. It is, however, very useful for gaining an appreciation for the system as a whole, and for identifying general trends and probable behaviour.

Anyone who has made an important decision in his/her life knows that decisions are not based exclusively on facts and data. Values and beliefs, historic and cultural contexts, and attitude about risk all play important roles in decisions. The field of Integrated Assessment acknowledges that science doesn't have all the answers and that local experts also play an important role. Since the purpose of our initiative is to provide support for decision making, it is important to include the end-users in the modeling process. Therefore, model development took place within a "Group Model Building" process, involving local experts, water professionals and related interests from the initial stages through to delivering the product.

This approach is called "Participatory Modeling" within the Integrated Assessment literature, and "Group Model Building" within the System Dynamics community. Both academic areas have documented several recent case studies using this approach, but few that incorporate climate change.

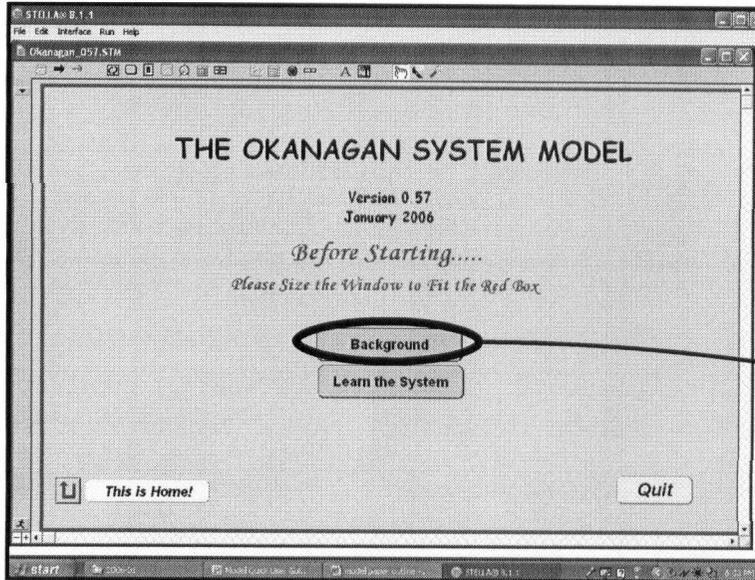
III. MAJOR DATA SOURCES

Climate Scenarios	<i>Global CC models downscaled (Taylor, Barton, 2003)</i>
Hydrologic Scenarios	<i>UBC Watershed Model (Merritt & Alila, 2005)</i>
Crop Water Demand	<i>Agriculture Canada Model (Nielsen et al., 2005)</i>
Residential Demand & Cons. Strategies	<i>Master's Thesis, Royal Roads (T. Neale, 2006)</i>
Conservation Flow Targets	<i>Trout Creek WUP Guidelines (Epp & NHC Report)</i>
Okanagan Lake Operational Rules	<i>FWMT Apprentice Guidebook (Alexander, Symonds & Hyatt, 2005) & Symonds—personal communication</i>
Return flow pathways	<i>Epp, Reeder, Cotsworth — personal communication</i>

IV. NAVIGATING THE INTERFACE

This section walks you through some of the main areas of the interface level, to help you get a sense of the navigational “map.” This will show you some of the key features of the model and prepare you for exploring it.

1. Background

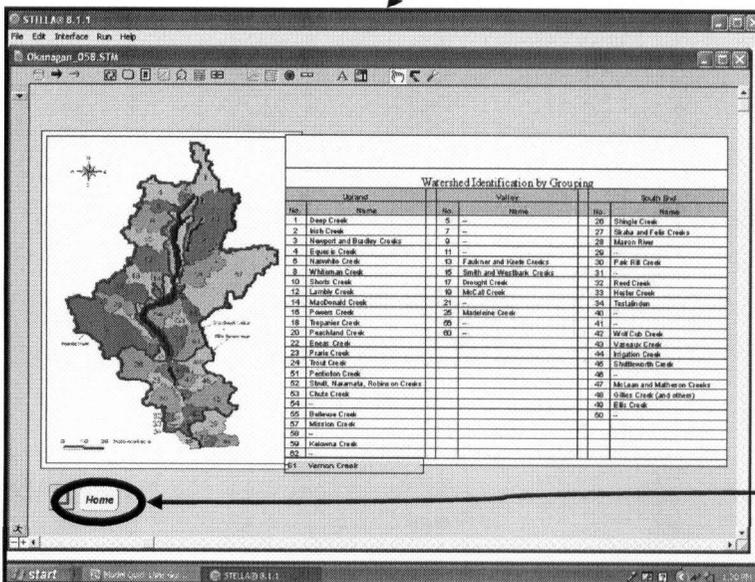


When you open the model, you will see the “Home Page:”

Background Page:

Select “Map of Water Supply Source Areas”

Figure 1: Home Page



Note the model has been divided into three water source areas:

- Uplands = Tributaries to Okanagan Lake
- Valley = Okanagan Lake
- South End = Sources from the outlet of Okanagan Lake 2 Penticton to the inflow to Osoyoos Lake.

Select “Home”

2. Learn the System

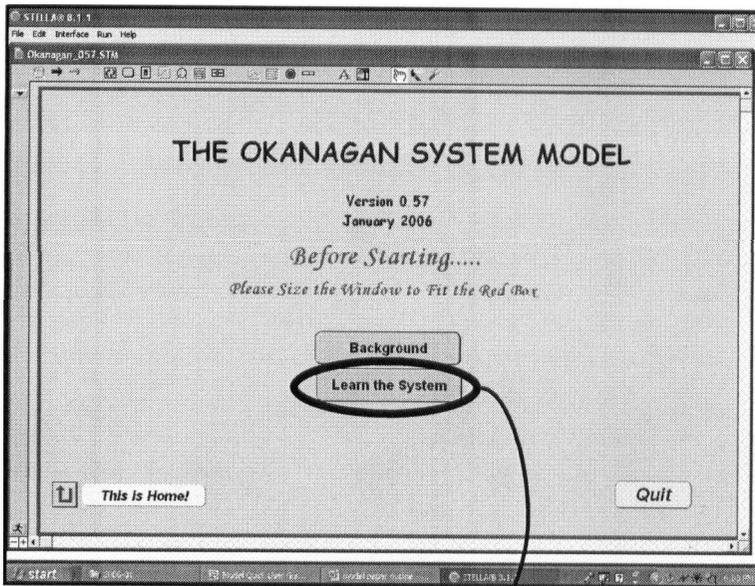


Figure 3: Returned to the Home Page

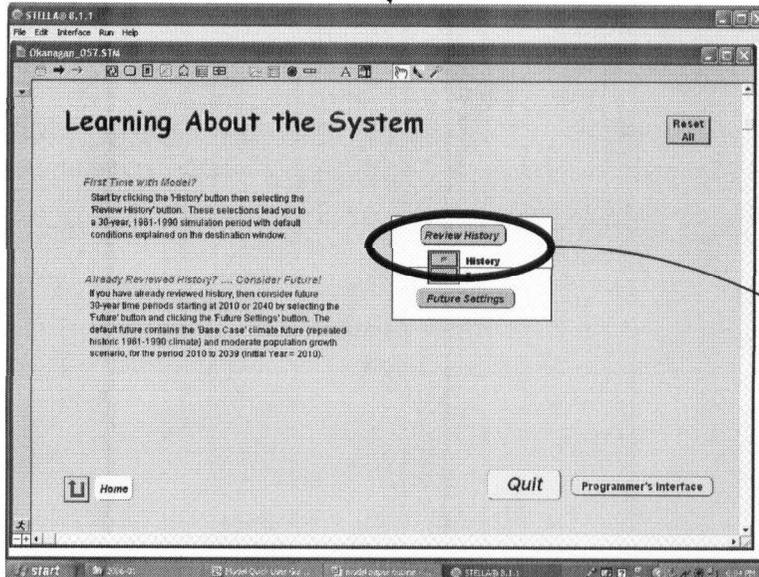


Figure 4: Learning about the System Home Page.

On this page, select whether you want to explore historic conditions, or simulate the future

In the model, this page is referred to as "Learning."

Check that the History button is on, and then click on the purple "Review History" button.

3. Review Simulated History

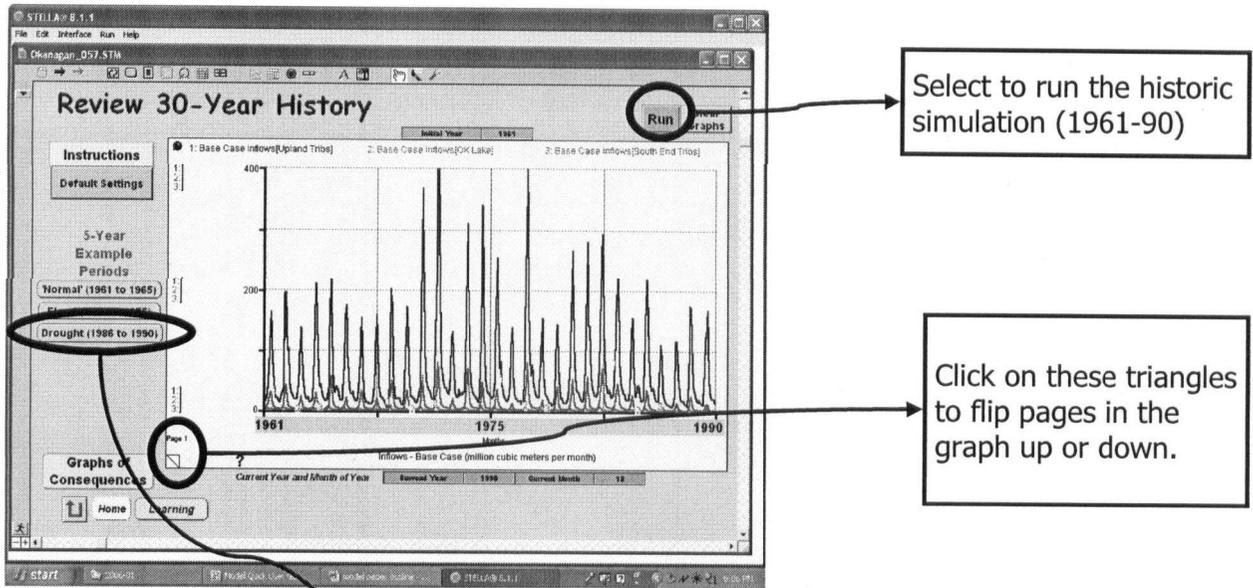


Figure 5: 30-Year History Main Page with 1st graph of pad showing.

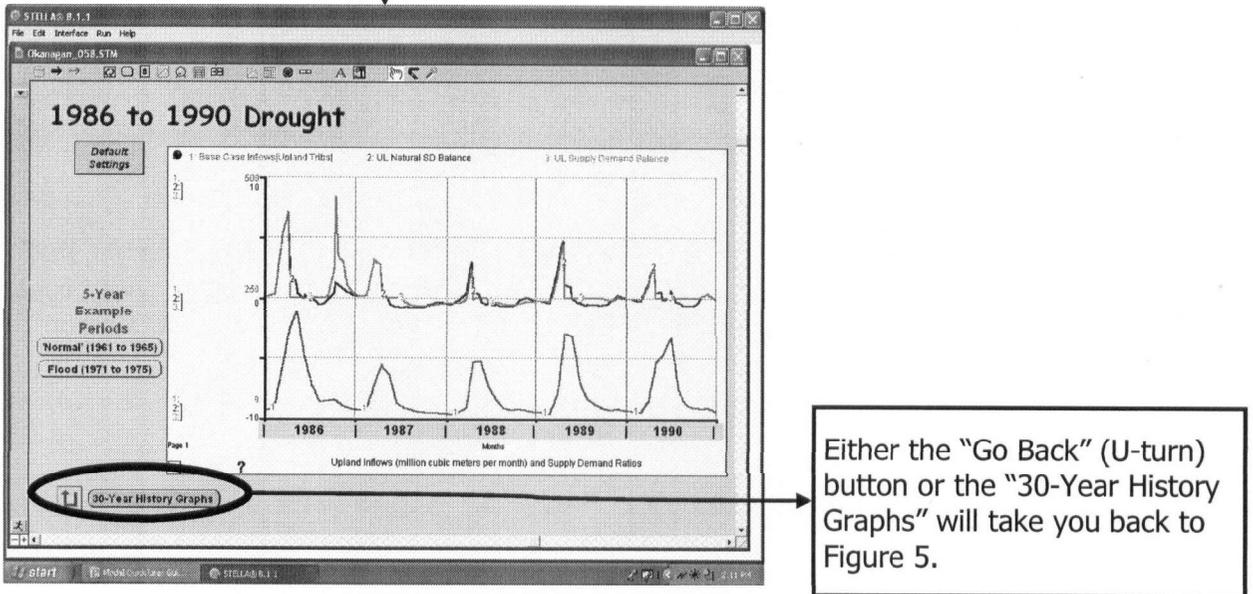
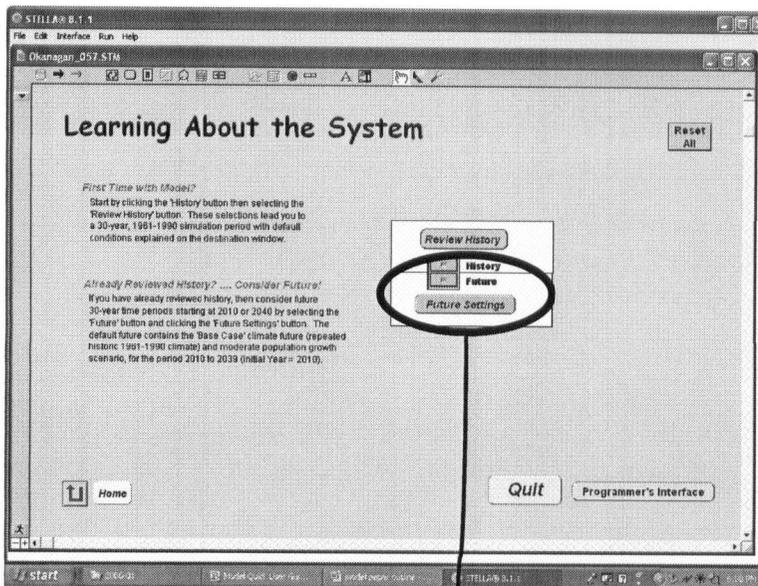


Figure 6: Detail for the 5-Year Drought 1986 –1990.

Next, we will discuss the Future Section. Return to the “Review 30-Year History Page” and then select the button labeled “Learning” to navigate back to the Learning About the System Home Page.

4. Explore the Future



To run future simulations, turn on “Future” and then select “Future Settings”

Figure 7: Returned to Learning About the System Home Page.

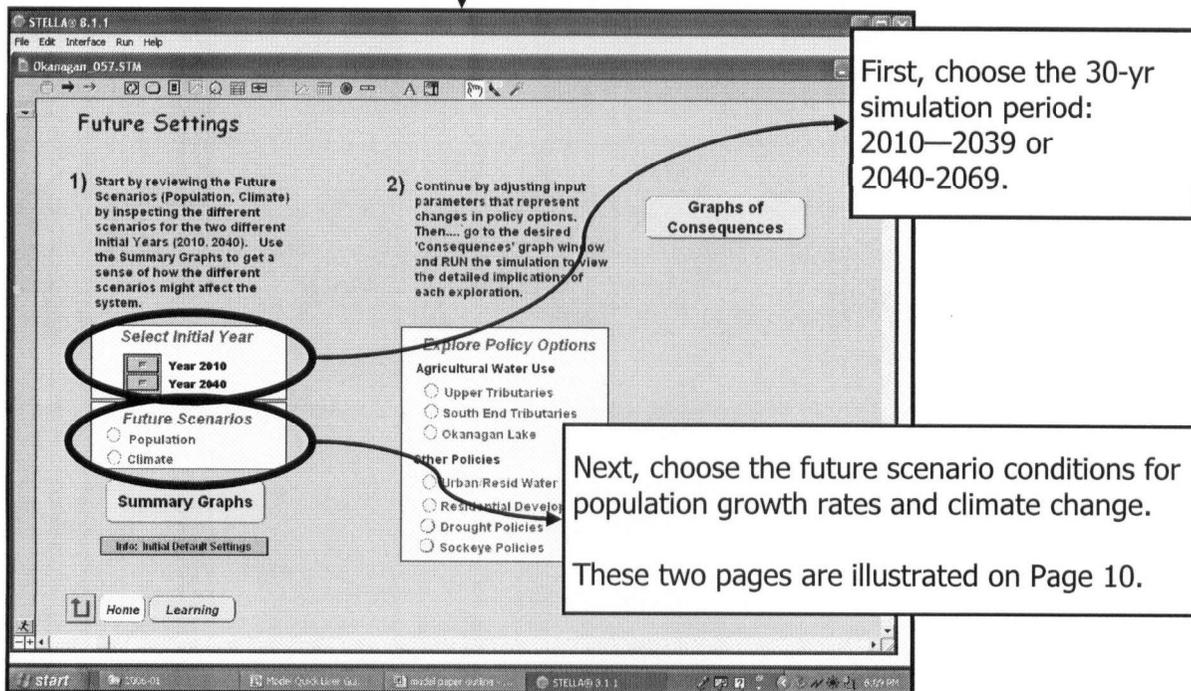
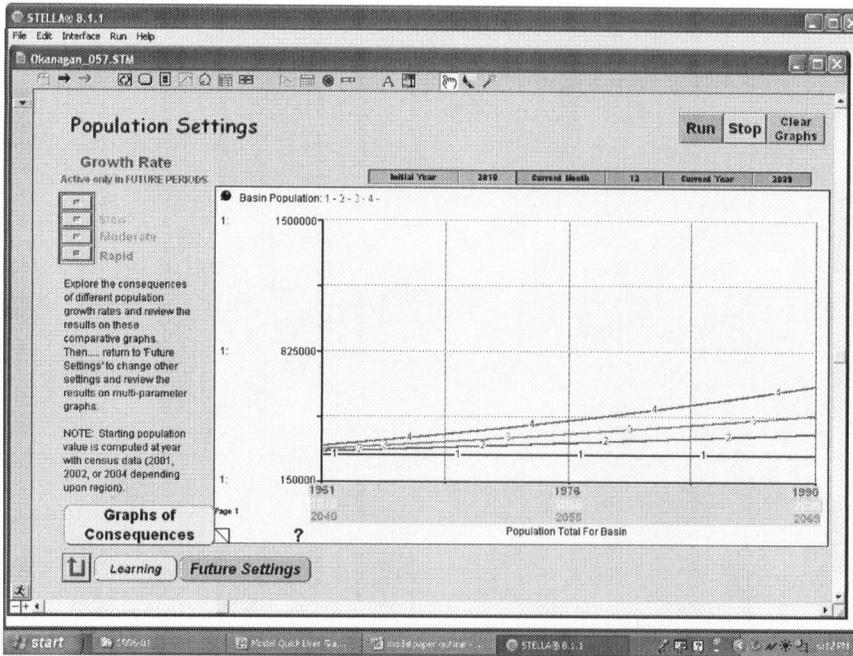


Figure 8: Future Settings Page. This is the Command Centre for your setting for simulations of the future. *Remember this page is called “Future Settings” as you will return here often.

4.1 Future Scenario Options

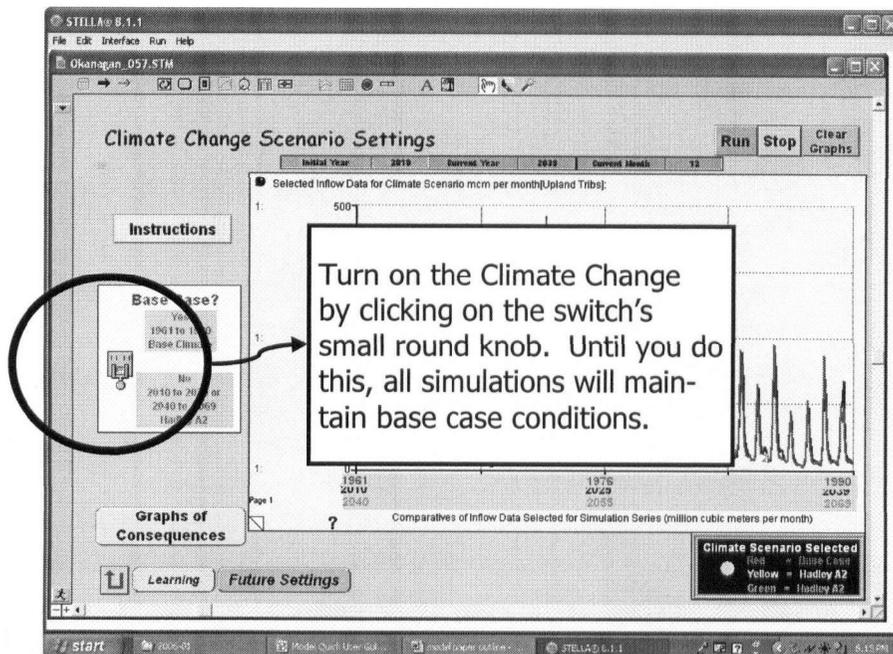
Here we select the rate of population growth into the future (Zero, Slow, Moderate, or Rapid) and “turn on” climate change. The population growth rates in each setting vary by regional district, based on official estimates.



This plot is a comparative graph. When you run additional simulations, previous output will be maintained. Plotted here are the range of future population scenarios for 2010—2039.

* Comparative graphs can only plot a single parameter. Multi-parameter graphs will clear with each new simulation.

Figure 9: Population Growth Settings Page.



This model contains only one scenario—Hadley A2, which is one of the more severe of the moderate scenarios.

The graph shown is comparing the inflow hydrograph for two simulations—Base Case (1) and Hadley A2 (2).

Figure 10: Climate Change Settings Page.

4.2 View Consequences

Most pages have a navigation button labeled, “Graphs of Consequences.” Selecting this button brings you to the menu page shown in Figure 11. Each menu item leads you to a page of output graphs related to that topic. The first item, “Supply Demand Issues” is shown here (Figure 12). This page provides supply and demand balances for the Uplands and Valley areas.

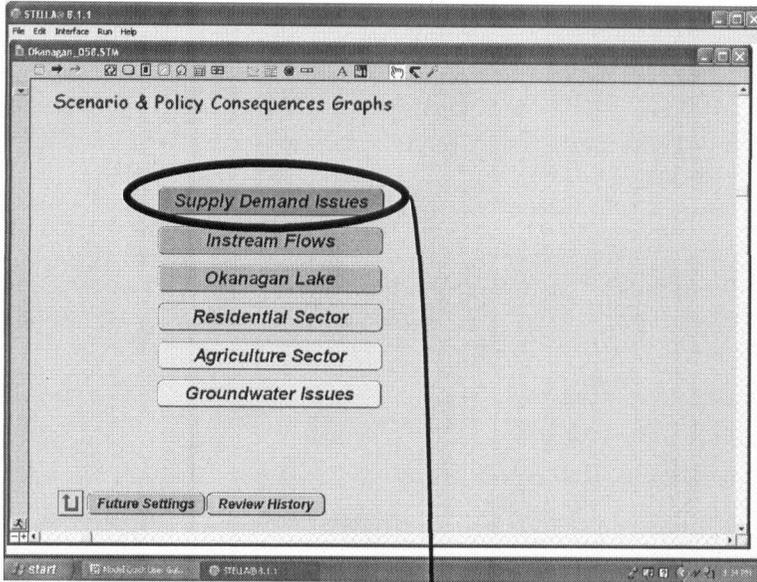
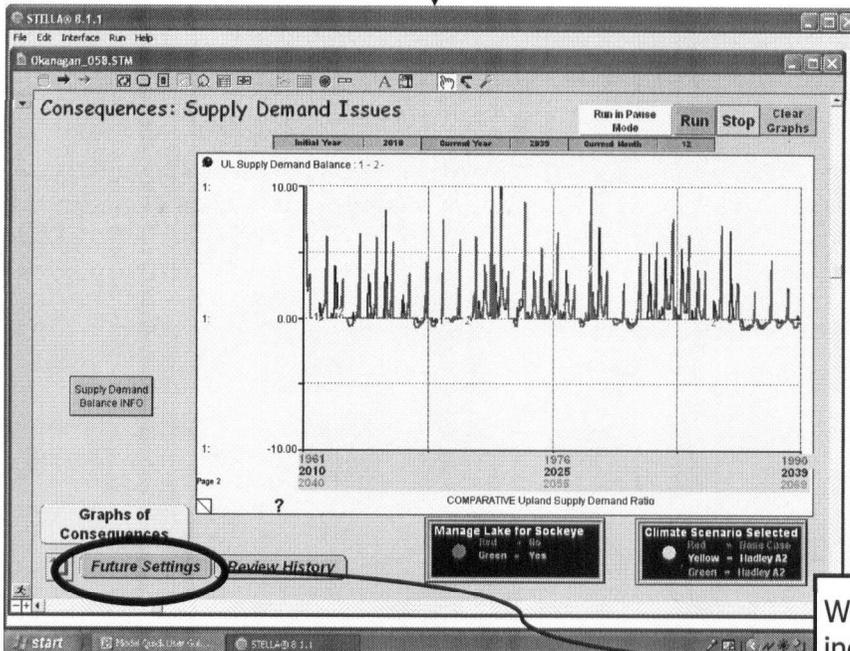


Figure 11: Menu for Consequences Graphs.



Supply and Demand are expressed as a normalized difference. Thus, positive values represents a surplus condition, while negative values reveal episodes of shortages.

This graph compares results for the Base Case (1) and Hadley A2 (2) scenarios.

When you are finished exploring the consequences pages, select “Future Settings” to return to the Command Centre.

Figure 12: Consequences Relating to the Balance of Supply and Demand in the Uplands

4.3 Test Policy Options

If you are not happy with what the future could bring, then do something about it! The model provides numerous policy options that could affect water management in the future. The Urban/Residential Use Options are shown here in Figure 14.

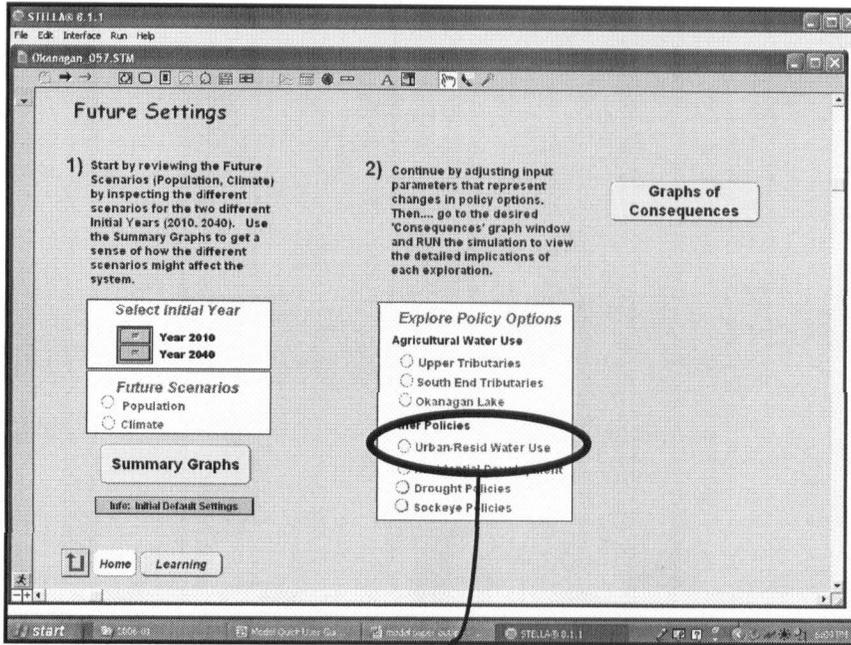


Figure 13: Back to the Future Settings page to Explore Policy Options.

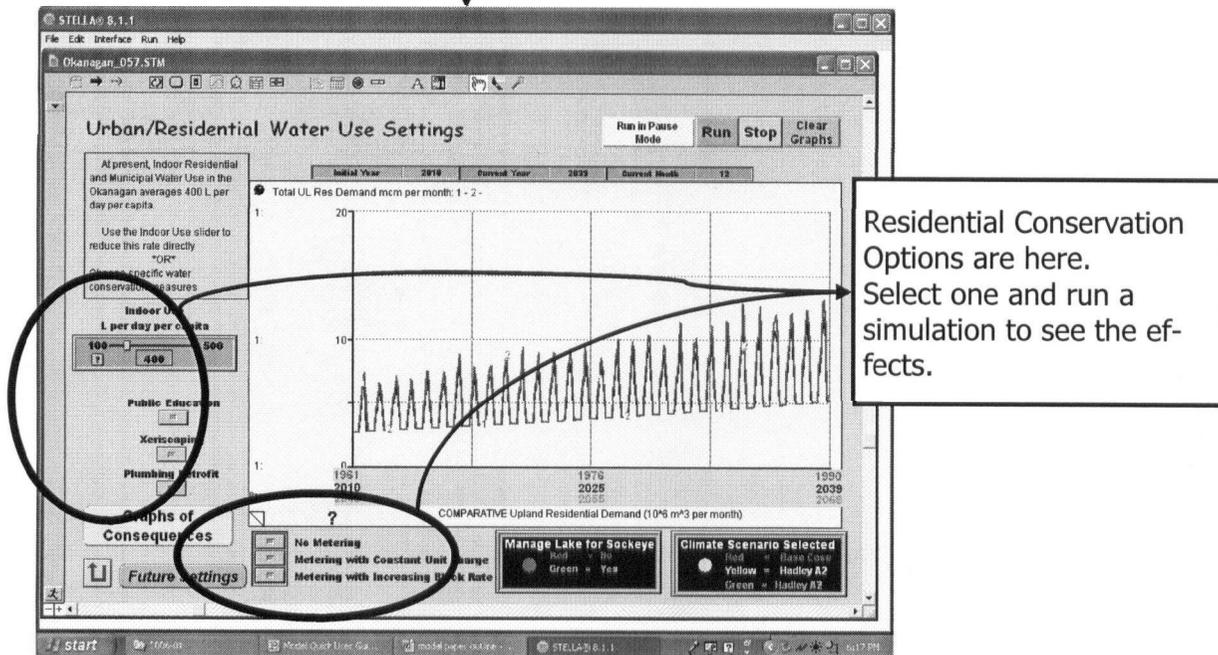


Figure 14: Policy Options in Urban/Residential Water Use.

**Appendix D: Model Level Documentation for the Okanagan
Sustainable Water Resources Model**

Model Level Documentation
for the
Okanagan Sustainable Water Resources Model

Version 1.62.1
April 2007

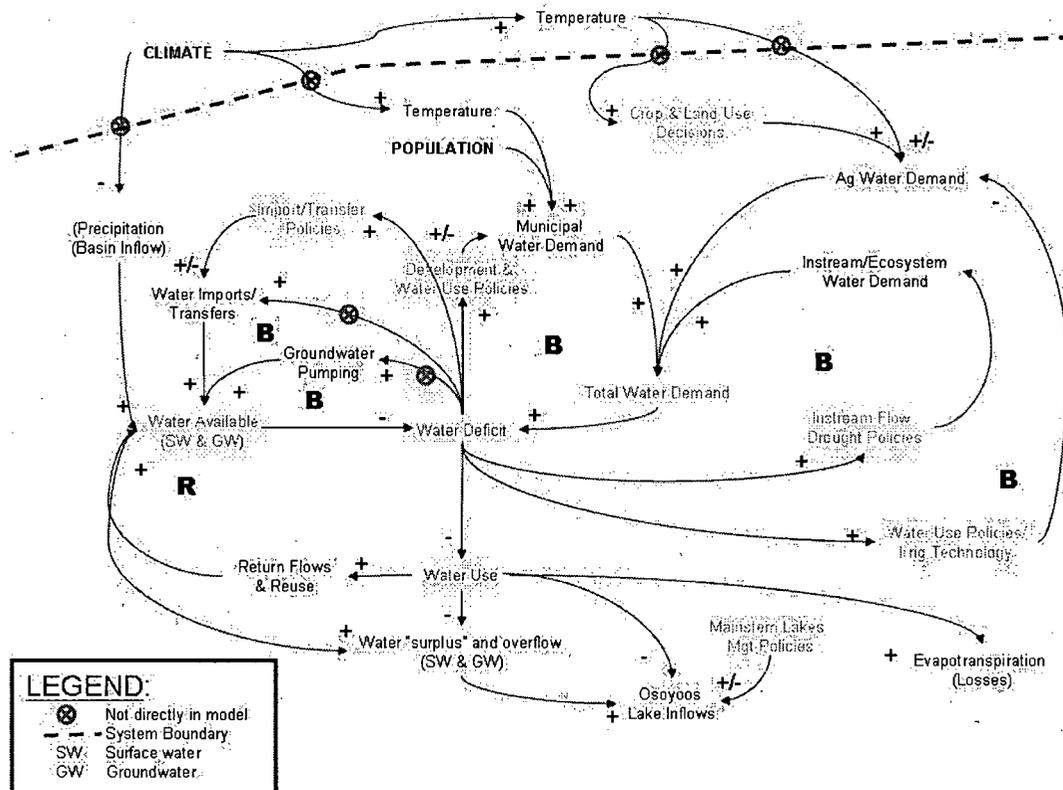
Stacy Langsdale
Institute for Resources, Environment
and Sustainability
University of British Columbia

I. Overview

The Okanagan Sustainable Water Balance Model (OSWBM) simulates future conditions by projecting current conditions and overlaying the effects of population growth and climate change on water supply and demand. The purpose of the model is primarily as a tool to support stakeholder dialogue on the issue of long-term water management. The OSWBM is not intended to support design or operation. The model can support users in learning about the complexities of managing water resources for multiple uses, generate a range of plausible water resources futures, assist users in assessing adaptation strategies (and portfolios of strategies), identify data gaps, and prioritize areas of future research.

Error! Reference source not found. is a causal loop diagram of the Okanagan water resources system. This diagram shows the important relationships and feedback loops that drive the behaviour of the system.

Figure 1: Causal loop diagram of the Okanagan water resources system, with boundaries of modeled system noted.



II. Climate Change Scenarios

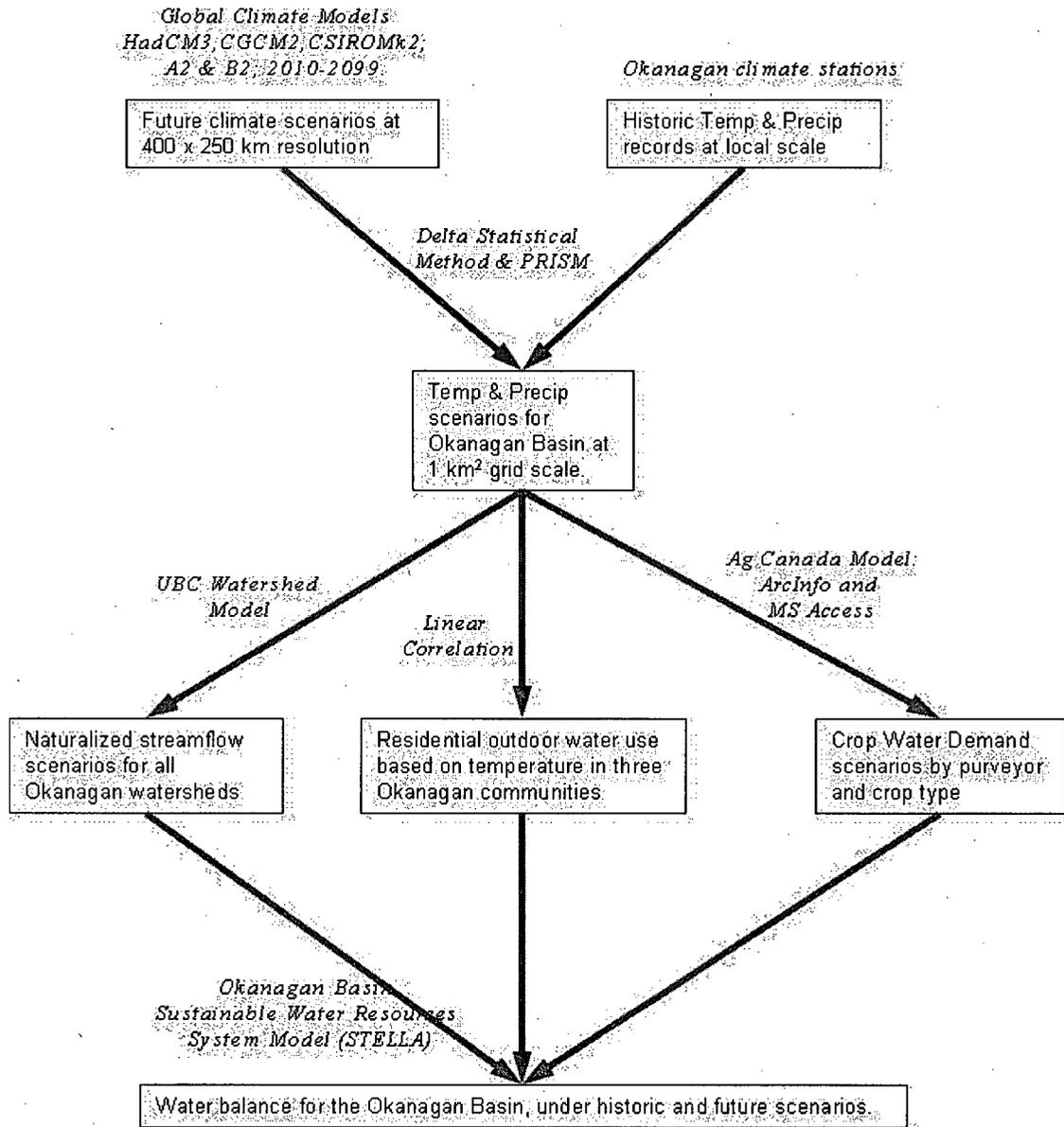
The information in the model regarding climate change is based on work by Taylor and Barton, who down-scaled global climate model output to the Okanagan scale. The climate scenarios are based on the results of three global climate modeling teams, with two emissions types from each. Simulations are generated in thirty-year time blocks, identified as the 2020's (2010-2039) and the 2050's (2040-2069). Data was also generated for the 2080's (2070-2099), but was not added to this model, as the participant group felt it was unnecessary. Planning initiatives typically consider twenty-year projections, and occasionally fifty-year projections. The participants expressed concern that longer projections would contain too much uncertainty to be informative. The new climate condition is held constant over each thirty-year period. This version of the model includes three climate scenarios, which were selected to show a range of possible futures: Hadley A2, CGCM B2, and CSIRO B2. Details about these climate scenarios can be found in Cohen et al. (2004).

The model does not include output directly from global climate models, but incorporates translations of the climate scenarios into supply and demand impacts. In this way, the model captures the linkages from climate change to hydrologic inflows and to and agricultural water demand. In addition, residential outdoor use is correlated to the temperature component of climate change.

Temperature scenarios are also based on the thirty-year scenario periods. These temperature scenarios were smoothed to create a gradual temperature change over the thirty-year period, rather than having a uniform temperature shift in each thirty-year time block. Smoothing was performed on the temperature shift due to climate change only; monthly and annual variability was maintained.

Figure 2 shows how the climate change scenarios were utilized and translated and input into the model.

Figure 2: Flow chart illustrating the progression from climate models and local records to supply and demand inputs to the Okanagan Sustainable Water Resources Model. (Sources: Cohen et al. 2004; Neilsen et al. 2001; Merritt and Alila 2006; Neale 2005; 2006).



III. Water Supply

Hydrologic Scenarios

Hydrologic scenarios were generated for all of the subwatersheds in the Okanagan Basin. Details on this work are published in Merritt and Alila (2004). These scenarios were based on the Climate Scenarios generated by Taylor and Barton (2004) and were generated using the UBC Watershed stream flow runoff model (Quick 1995).

Climate scenarios produced information about precipitation and temperature changes. This information was fed into the UBC Watershed model to generate 30-year hydrographs for each watershed. In most of the watersheds, particularly those in the higher elevations that receive a significant portion of precipitation as snow, increased temperatures decrease snowpack and induce an earlier spring freshet.

The UBC Watershed model was used to simulate natural streamflow, with no management of dams. In each of the 50+ watersheds, the simulation was based on the location of the stream gage. No groundwater interaction was modeled. Calibration focused on matching peak flows rather than minimum flows (Merritt and Alila 2006; 2004).

The watershed data are aggregated into three groups: *Uplands*, *Valley*, and *South End*. *Uplands* include all managed watersheds that are tributaries to Okanagan Lake. *Valley* includes a few small unmanaged watersheds that are tributaries to Okanagan Lake. *South End* includes all watersheds that feed into Okanagan River and the mainstem lakes between the outfall of Okanagan Lake and the inflow to Osoyoos Lake. Figure 3 and Table 1 shows the placement of each watershed into the three water source groupings.

Most simulations were based on the historic period 1961-1990. However, several watersheds did not have complete data records during this period. Most commonly, data was missing from 1961-1968. In these cases, I correlated watersheds with missing data to adjacent watersheds of similar size. Because the use of the data is in an aggregated state, the accuracy of calibration to each stream is less critical than maintaining the order of magnitude of the aggregated total.

Figure 3: Map of the Okanagan Basin showing the delineation of the three model regions defined by water source.

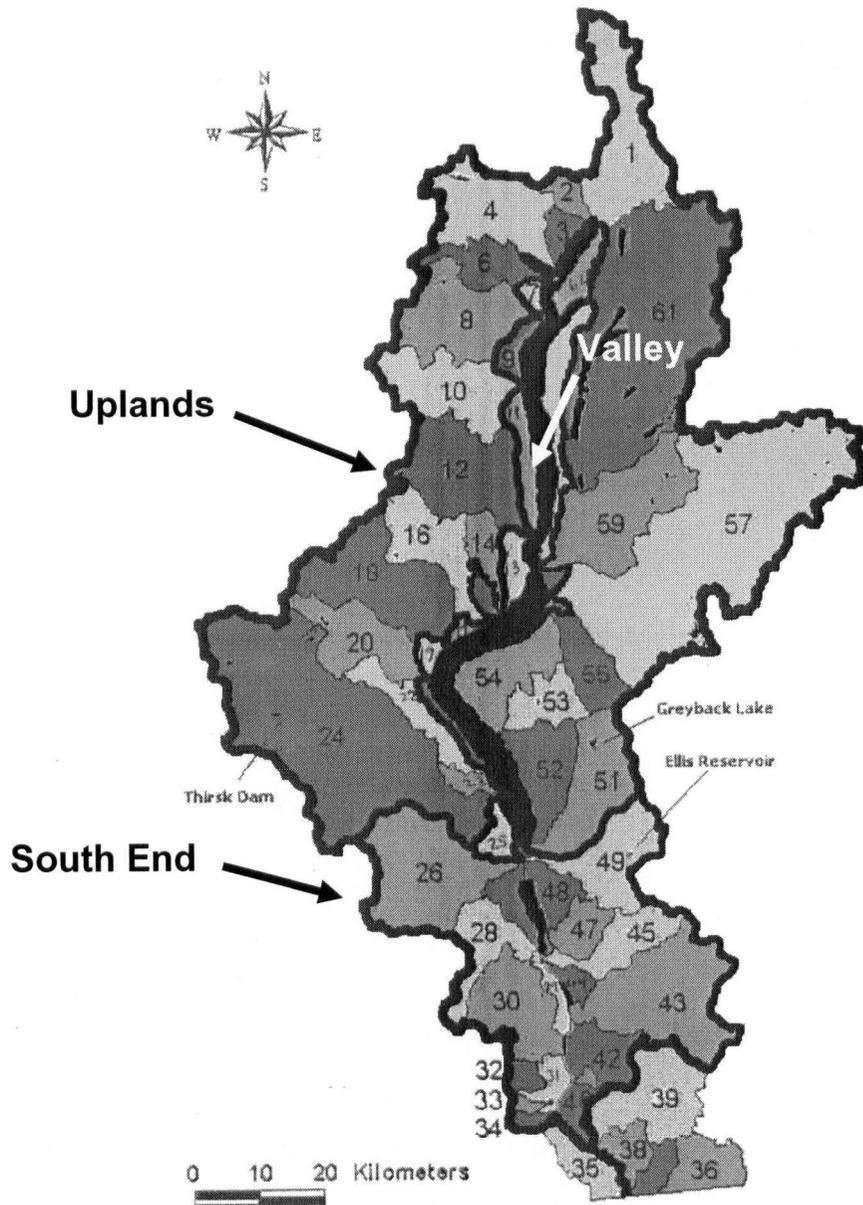
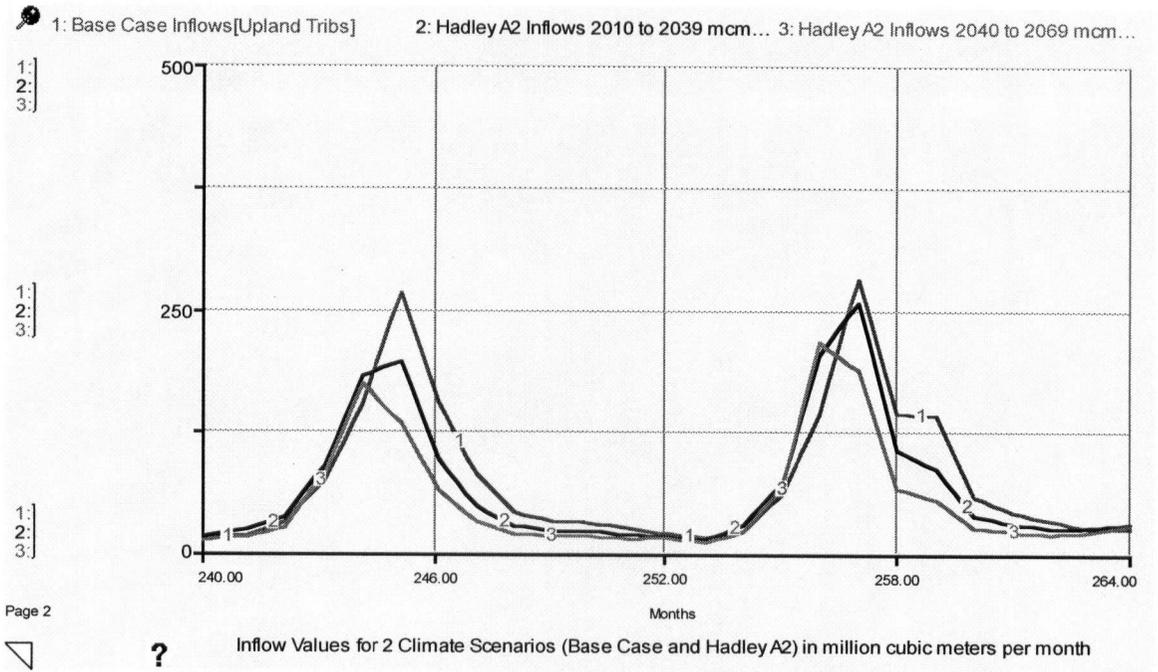


Table 1: List of watersheds in each model region.

Watershed Identification by Water Source Group					
Uplands		Valley		South End	
No.	Name	No.	Name	No.	Name
1	Deep Creek	5	--	26	Shingle Creek
2	Irish Creek	7	--	27	Skaha and Felis Creeks
3	Newport and Bradley Creeks	9	--	28	Marron River
4	Equesis Creek	11	--	29	--
6	Naswhito Creek	13	Faulkner and Keefe Creeks	30	Park Rill Creek
8	Whiteman Creek	15	Smith and Westbank Creeks	31	--
10	Shorts Creek	17	Drought Creek	32	Reed Creek
12	Lambly Creek	19	McCall Creek	33	Hester Creek
14	MacDonald Creek	21	--	34	Testalinden
16	Powers Creek	25	Madeleine Creek	40	--
18	Trepanier Creek	56	--	41	--
20	Peachland Creek	60	--	42	Wolf Cub Creek
22	Eneas Creek			43	Vaseaux Creek
23	Prairie Creek			44	Irrigation Creek
24	Trout Creek			45	Shuttleworth Creek
51	Penticton Creek			46	--
52	Strutt, Naramata, Robinson Creeks			47	McLean and Matheson Creeks
53	Chute Creek			48	Gillies Creek (and others)
54	--			49	Ellis Creek
55	Bellevue Creek			50	--
57	Mission Creek				
58	--				
59	Kelowna Creek				
61	Vernon Creek				
62	--				

Figure 4: Two year hydrograph of aggregated flow in upland streams, showing shift from base case (1981-82), to a decreased, earlier peak in Hadley A2 – 2020's (2030-31) and Hadley A2 – 2050's (2060-61).



Diversions from Adjacent Basins

There are at least three sources from which water is transferred to streams in the Okanagan – Kettle, Shuswap (from Duteax Creek) and Alocin (from the Nicola Basin). All of these are relatively minor. Kettle and Shuswap are captured in the model. Alocin is neglected because the participant/expert advisory committee suggested it was very minor. (The relative magnitudes of the three diversions were not compared, however.)

Kelowna has water rights to divert up to 3780 acre-feet (4.66 million cubic metres) of water per year from the Kettle River basin, and this water is taken during the spring and summer months. Information about the Kettle diversion was not available, so I approximated this diversion to provide 500 acre-feet (0.62 million cubic metres) per month to the Okanagan from May through October, matching the months of peak demand.

Diversions from the Shuswap River basin (taken from Duteax Creek) are not recorded, but I did have an estimate of the number of users on this source. Therefore, the model calculates the Shuswap diversion to be equal to the demand by the populations of residents who currently depend on the Shuswap as their water source. The Shuswap also supports some agricultural customers, so the estimate may be low. The diversion increases as the populations in these communities increase. The total water rights on the Shuswap are equal to 41,000 ac-ft or 50 million cubic meters. The maximum diversion simulated falls well below the total Shuswap water right.¹

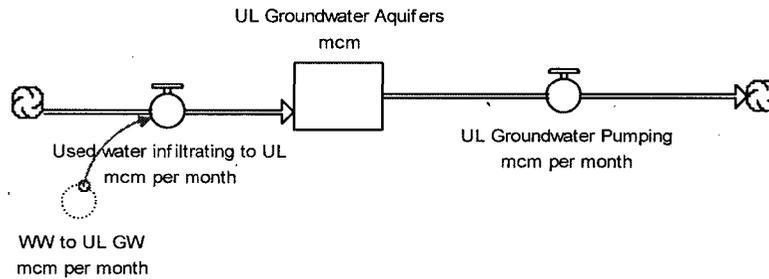
Groundwater

Groundwater contributes to the total water available in the Uplands. Since there is presently a lack of information about the interaction between groundwater and surface water, and about the sustainable yield of the aquifers, in the model I assume that groundwater supplies can meet present and future demand. In the same manner as the Shuswap diversion, future use is based on current use, with selected population growth rates applied. As with the Shuswap diversion, groundwater pumping increases as the populations of the communities that currently dependent upon this source grow.

Groundwater is also an important water source in the South End. Here, however, the model does not merge groundwater and surface water. Because almost all residents are on groundwater and almost all other users depend on surface water, the sources are kept separate. This is not reflective of the physical reality of the system – in fact, I expect that there is groundwater/surface water interaction.

¹ A variation developed for Alexander and Hyatt for the Fish Water Management Tool increased the Shuswap diversion to supplement water shortages in the Uplands, up to the limit by the water right.

Figure 5: STELLA component for treatment of groundwater in the Upland sector.



Return Flows to Uplands

In the Okanagan, water is not only used once, but cycles through several uses before flowing south into Osoyoos Lake and across the international border. In the Uplands, water is returned in two ways, both actively and passively: (1) Domestic water is treated and re-distributed for irrigation of golf courses, (2) Outdoor irrigation (agricultural and residential applications) drains to Upland surface water sources. Additional information on return flows is provided in a following section.

IV. Water Demand Sectors

Residential Demand

Population Growth Calculations

All population data in the model is based on recent population statistics for each Regional District. Planning areas within each Regional District were considered because the political boundary lines are not aligned with the watershed boundary, and some residents do not depend on Okanagan water supplies. The identification of populations outside of the Okanagan was estimated using spatial maps as well as information provided by Al Cotworth. See

Table 2. Only populations served by Okanagan water sources were included in the model. Data was acquired through each Regional District's web sites.

The model calculates population for the initial simulation year using the historic or future selected growth rate between the data year and the initial simulation year. In the model, options for initial years are 1961, 2010, and 2040. Recent population data is used to calculate initial populations using:

$$P_n = P_o(1+r)^{n-o}$$

where P_x = population at time x
 n = year of interest
 o = year of known value
 r = annual growth rate between time n and o .

For historic simulations I did not simply define the initial starting populations because it was simpler to follow the same structure developed for the future simulations. Historic growth rates from 1961 to 2001-04 were calculated from BC Stats census data to be 1.98% for NORD; 4.22% for CORD; and 1.80% for RDOS. Determining these growth rates was complicated by the fact that I am only modeling portions of NORD and RDOS, and because the political boundaries for certain communities changed during this forty-year period. However, I think these are reasonable estimates for the purposes of the modeling exercise. Table 3 shows the small errors between the simulated and recorded populations for 1961.

Table 2: Current population data for Regional Districts, and the portion of the population served by Okanagan Basin water sources.

Recent Population Data			
	Reported Population	Portion on Modeled Sources	
		%	#
NORD, 2002 census data			
Vernon	33494	100	33494
Armstrong	4256	100	4256
Coldstream	9106	100	9106
Enderby	2818	0	0
Lumby	1618	0	0
Spallumcheen	5134	15	770
Elec Area B	5303	100	5303
Elec Area C	3627	100	3627
Elec Area D	2840	0	0
Elec Area E	938	0	0
Elec Area F	4093	0	0
TOTAL	73227		56556
CORD, 2004 census data			
Westside	37693	100	37693
Central OK East	4100	100	4100
City of Kelowna	105621	100	105621
Lake Country	10064	100	10064
Peachland	5077	100	5077
TOTAL	162555		162555
RDOS, 2001 census data			
	2001		
Penticton	30985	100	30985
Summerland	10713	100	10713
Oliver	4224	100	4224
Osoyoos	4295	100	4295
Princeton	2610	0	0
Keremeos	1197	0	0
Elec Area A	1897	100	1897
Elec Area B	1241	0	0
Elec Area C	4721	100	4721
Elec Area D	6604	100	6604
Elec Area E	1996	100	1996
Elec Area F	1989	100	1989
Elec Area G	2194	0	0
Elec Area H	1969	0	0
TOTAL	76635		67424

Table 3: Comparison of historic populations and those simulated by the model using calculated growth rates from the historic to the present.

	1961 Population Data		
	BC Stats	Simulated	Error
NORD	25694	25078	2.4%
CORD	27460	27485	-0.1%
RDOS	33486	33030	1.4%
BASIN TOTALS	86640	85593	1.2%

Annual population growth rates for future simulations are the same as those used by Neale (2005), and are based on BC Stats PEOPLE 27, Official Community Plans and other planning documents. These rates are shown in Table 4 with historic rates shown for comparison.

Table 4: Historic and Projected Annual Population Growth Rates [%] by Regional District.

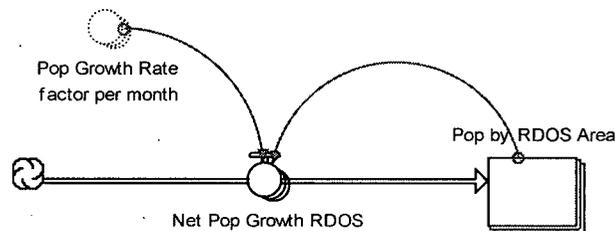
	Historic (1961-90)	Future Slow	Future Moderate	Future Rapid
NORD	2.0	1.0	1.4	2.0
CORD	4.2	1.0	1.7	2.4
RDOS	1.8	0.5	1.0	2.0

Because the model simulates in monthly timesteps, these annual rates (R_{annual}) are converted to monthly growth rates ($R_{monthly}$) using:

$$R_{monthly} = (1 + R_{annual})^{1/12} - 1$$

During simulations, populations increase according to the selected growth rate using a classic exponential growth relation. The relation is shown in the population growth equation, where n and o are in months rather than years, and $n - o = 1$. In STELLA™ language, population growth is expressed as shown in Figure 6.

Figure 6: Exponential growth in the STELLA™ language.



Converting RD populations to populations by water source

The Regional District boundaries are not the same as the three zones in the model. Population growth is calculated by RD to make use of the different growth rates. This sector reorganizes the populations according to their water source. Data regarding water sources for different communities was provided by local experts, particularly Al Cotsworth, Toby Pike and Andrew Reeder (Table 5).

Table 5: Division of residential water use according to water source.

	% Resid. Population on Each Water Source						% Pop on Source Area		
	Shuswap Tribes	Ground- water	Upland SW	Okanagan Lake	South End SW	Osoyoos Lake	Uplands Total	OK Lake Total	South End Total
NORD									
Vernon	10	0	90	0	0	0	100	0	0
Armstrong	95	5	0	0	0	0	100	0	0
Coldstream	40	0	60	0	0	0	100	0	0
Spallumcheen	10	90	0	0	0	0	100	0	0
Elec Area B	100	0	0	0	0	0	100	0	0
Elec Area C	75	0	25	0	0	0	100	0	0
CORD									
Westside	0	0	100	0	0	0	100	0	0
Central OK East	0	0	0	100	0	0	0	100	0
City of Kelowna	0	0	50	50	0	0	50	50	0
Lake Country	0	0	85	15	0	0	85	15	0
Peachland	0	0	100	0	0	0	100	0	0
RDOS									
Penticton	0	0	40	60	0	0	40	60	0
Summerland	0	0	100	0	0	0	100	0	0
Oliver	0	100	0	0	0	0	0	0	100
Osoyoos	0	100	0	0	0	0	0	0	100
Elec Area A	0	100	0	0	0	0	0	0	100
Elec Area C	0	100	0	0	0	0	0	0	100
Elec Area D	0	0	40	60	0	0	40	60	0
Elec Area E	0	0	100	0	0	0	100	0	0
Elec Area F	0	10	0	90	0	0	0	90	10

Calculating Residential Water Use

Residential water demand calculations are based on an analysis of water use records in the communities of Kelowna, Penticton, and Oliver by Neale (2005; 2006). The analysis assumed that indoor use is relatively constant throughout the year, while outdoor watering occurs primarily between April and October. Water use also increases in the summer due to a significant influx of tourists. This effect is not distinguished, but it is captured in the outdoor use peak since relations were developed from actual data.²

Indoor water use is calculated as a per capita rate. The historic and default rate used is 400 L/day/person which captures all residential, municipal and industrial use. The relation is simply:

$$\text{Indoor.Use} = \text{Population} \times \text{Use.Rate}$$

Neale showed that outdoor water use is a function of both housing type and maximum daily temperature. Assuming that the majority of residential outdoor water use is applied to lawns and landscape maintenance, residents of multiple unit dwellings have no significant outdoor water use. (Most apartment complexes do have some landscaping, but this is minor when divided by the large number of residents.) Linear correlations were developed between water use and daily maximum temperatures averaged monthly. These relationships were used to estimate increases in watering in the future associated with increasing temperatures due to global warming. I applied the relation for Kelowna to both the Uplands and Okanagan Lake water source areas, and applied the relation for Oliver to the South End. The relations varied widely between the three study areas, with use increasing substantially from the northernmost location (Kelowna) to the drier, southernmost location (Oliver). The central proximity of Kelowna and Oliver to their associated water source areas makes the extrapolations reasonable, however, the extrapolations from single communities to entire regions should be reassessed as more information becomes available.

The linear correlations from Neale (2005) for outdoor water use per dwelling are:

$$Use_{dwelling} = a \cdot T_{max} + b \quad \text{[Equation 1]}$$

where $Use_{dwelling}$ = cubic metres of water use per month per detached dwelling,
 T_{max} = daily maximum temperature values averaged monthly, in degrees Celsius,
and the coefficients a and b are defined in Table 6.

² Because outdoor use includes tourism demand, simulations of outdoor use should not drop to zero. This result is possible with the scenario of 100% apartments and no single family dwellings.

Table 6: Correlation coefficients for the Outdoor water demand equation

Water Source Area	a [m³/month/°C/dwelling]	b [m³/month/dwelling]
Uplands & OK Lake (Kelowna)	3.0612	-34.465
South End (Oliver)	10.979	-145.35

Next, total outdoor water use for each area of interest [cubic metres per month] is determined by:

$$WaterUse_{outdoor} = Use_{dwelling} \cdot Population \cdot (SDD.Ratio) \cdot \left(\frac{1}{Occupancy.Rate} \right),$$

where *SDD.Ratio* = the ratio of ground-oriented, single detached dwellings to total dwellings,

Occupancy.Rate = the average number of people per household.

At present, Regional Districts in the Okanagan have reported between 2.3 and 2.5 occupants per household and 31% apartments (69% ground-oriented dwellings). Due to changing population demographics, these values are expected to change to 2.1-2.2 occupants per dwelling in 2031, and apartments are expected to increase to 34%, decreasing SDDs to 66% by 2069.

Residential Demand Side Management Strategies

Neale (2005) reviewed case studies in the literature to estimate the efficacy of a variety of demand side management strategies. The strategies evaluated and included in the model are listed in Table 7 with the expected reduction in water use.

Table 7: Average water savings from demand side management options (from Neale et al. 2007; Neale 2007; 2005)

DSM Option	Water Savings	
	Indoor	Outdoor
DSM Option 1: PUBLIC EDUCATION		
Sustained public awareness program including a part-time staff person and printed brochures etc. (source: Hrasko 2003)	10%	10%
DSM Option 2: METERING WITH CUC		
Water meter installation and volume-based billing. Water rate is a constant unit charge (CUC), or the same charge for each additional unit of water consumed. (sources Stephens et al. 1992; Mayer et al. 2004)	20%	20%
DSM Option 3: METERING WITH IBR		
Water meter installation and billing with an increasing block rate structure (IBR). Volume-based water charges increase when water use exceeds pre-defined thresholds. (sources: Gleick et al. 2003; Herrington 2001)	32%	32%
DSM Option 4: XERISCAPING		
Xeriscaping bylaws are implemented, similar to the landscape ordinances used in several US jurisdictions, requiring all new and renovated landscaping to conform to xeriscaping principles. (sources: Richard 1993; Brandes and Fergasun 2003; Gleick et al. 2003; Kunzler 2004; Xeriscape Colorado 2005)	0%	50%
DSM Option 5: HIGH EFFICIENCY FIXTURES & APPLIANCES		
Bylaws are implemented requiring water efficient appliances and fixtures to be installed in all new and renovated dwellings. (sources: DeOreo et al. 2001; Gleick et al. 2003; Mayer et al. 2004)	40%	0%
DSM Option 6: COMBINED METERING WITH IBR, XERISCAPING AND HIGH EFFICIENCY APPLIANCES & FIXTURES		
Options 3-5 are implemented. Water savings for Xeriscaping and High Efficiency are reduced by the percentage water savings for Metering with IBR to account for voluntary adoption of these mechanisms under the metering program.	59%	66%

Agricultural Demand

Agricultural water demand is based on scenarios developed by the Crop Water Demand (CWD) model by Neilsen et al. (2006; 2004). Neilsen correlated crop water demand to a number of factors:

- Crop type
- Solar radiation (function of latitude)
- Canopy development
- Length of growing season
- Maximum daily temperature
- Growing degree days (GDD)

The CWD model generated scenarios that correspond to the climate change scenarios. Output is given in terms of total water required by each major water purveyor per unit of time. Total land in production and the crop type mix were based on current conditions and assumed to be constant in both the historic and the future simulations (Cohen et al. 2004, p 91).

To provide the option for varying the total land in production and the mix of crop types in OWSRM, I converted the CWD volumes to rates of application per land area and per crop type (Pasture, Vineyard, Tree Fruits, and Other Crops). Rates were calculated for the major water purveyors and extrapolated to the total land in production by water source (Upland tribs, Okanagan Lake, South End). The variation of crop water demand rates between purveyors is illustrated in Figure 7. Note the rates are relatively consistent. A sub-set of the 50+ major water purveyors were carefully selected to ensure diversity in geographic location and to ensure adequate representation of each crop type. Because the variation between major water purveyors in each area was relatively minor, the additional effort of testing each and every purveyor would not have changed the value of the average significantly, particularly relative to the accuracy required for this modeling exercise.

Crop water demand does vary somewhat between locations (Figure 8) and varies considerably between crop types (Figure 9). Although the timing and magnitudes of "Pasture" and "Cropland" are nearly identical, "Tree Fruits" and "Vineyard" show very different requirements. The lower water requirement of wine grapes has stimulated considerable discussion among the community. However, this option may not be socially or economically viable.

Figure 7: Comparison of crop water demand [m] for seven major water purveyors in the Uplands during the first two years of the historic scenario (1961-62)

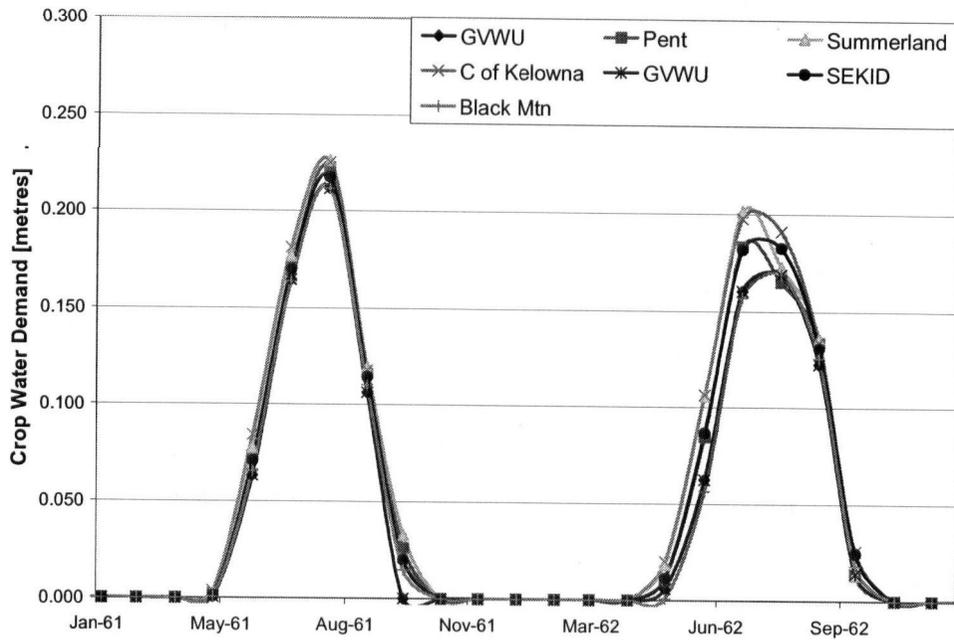


Figure 8: Comparison of crop water demand [m] for the three different water source types. Note the increasing trend from Uplands down to the warmer South End.

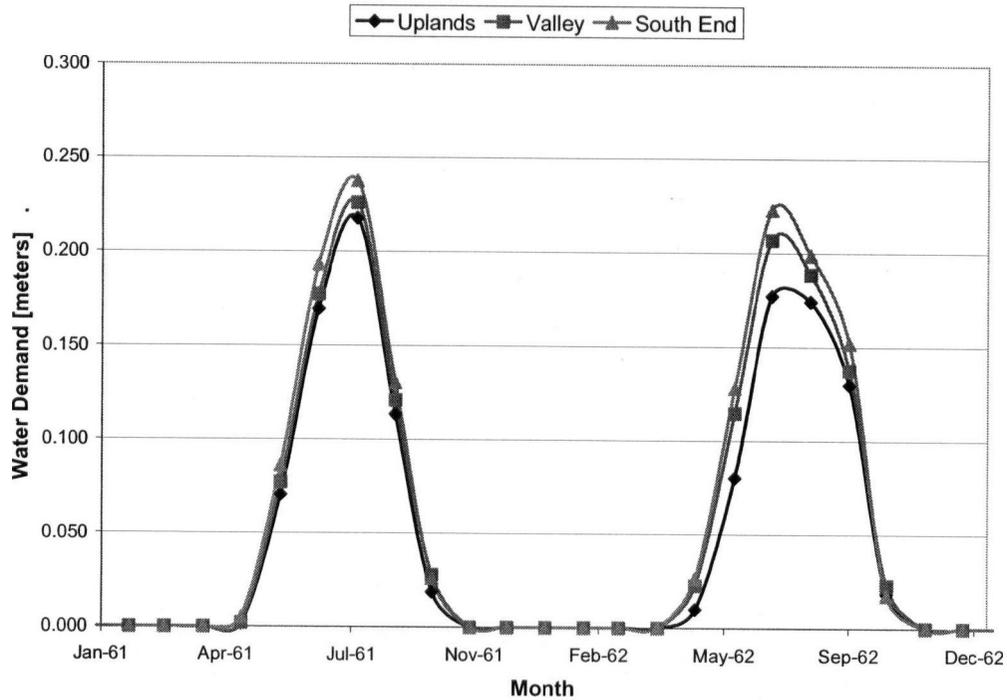


Figure 9: Comparison of crop water demand rates [m] for the four categories of crops in the Uplands.

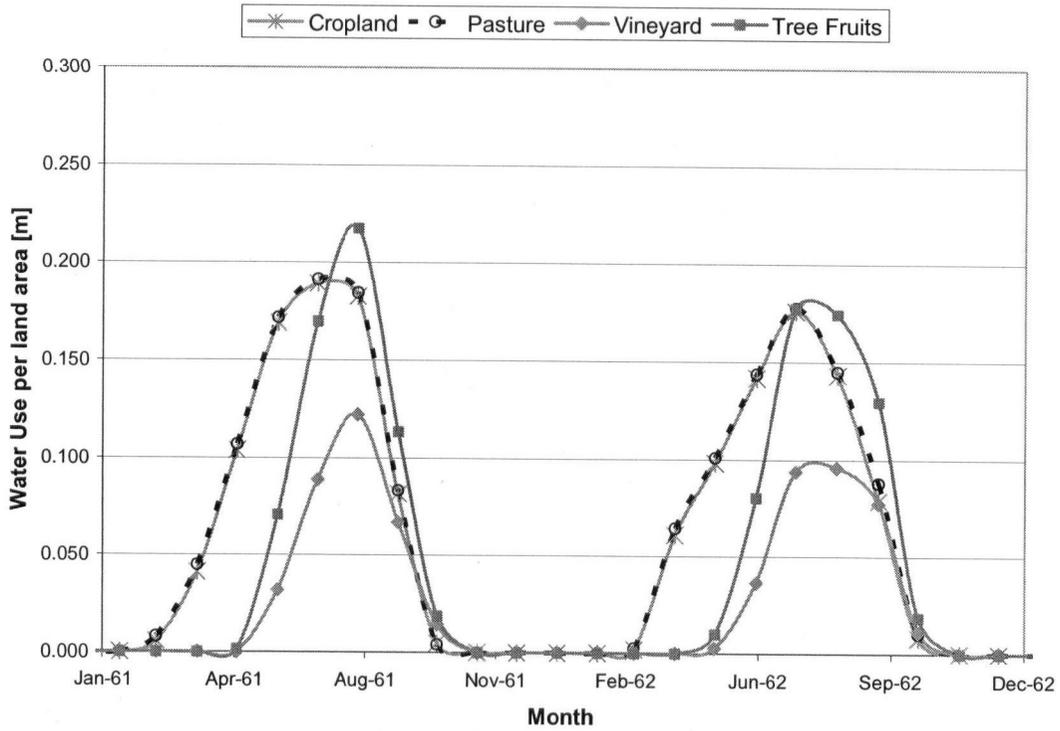
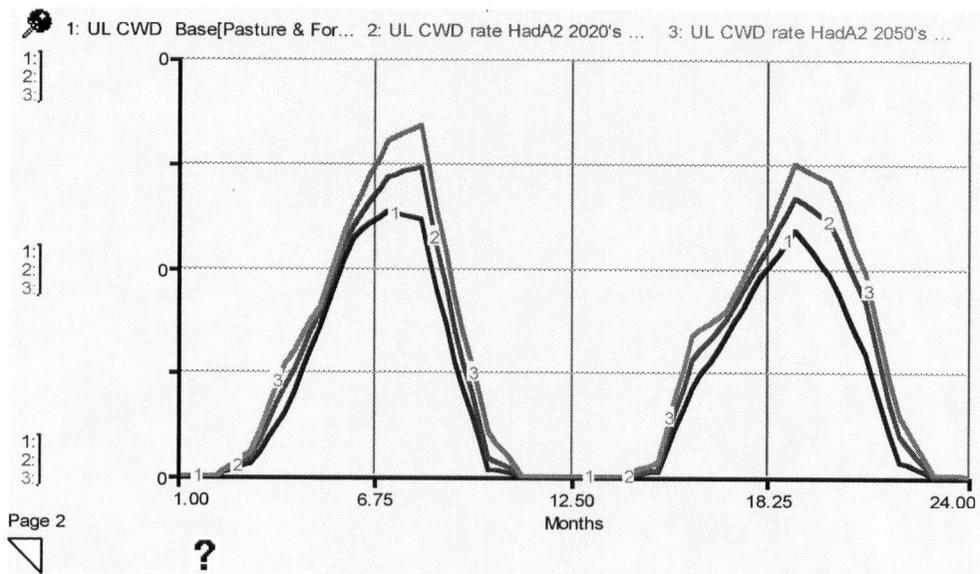


Figure 10: Comparison of Pasture crop water demand scenarios. Note increasing trend from historic base case to 2020's and 2050's.



In OSWRM, the appropriate crop water demand scenario is selected according to the simulation settings. Next, these values are used to estimate the agricultural water

demand in each month. Multiplying the crop water demand rate [m] by the area of land dedicated to that crop gives the total crop water demand in m³/month. However, this rate is the minimum required with 100% irrigation efficiency. Actual irrigation also includes watering for frost protection and evaporative cooling. In the South East Kelowna Irrigation District (SEKID) between 1976 and 1990, which was prior to metering, actual agricultural use was 30% higher than crop water demand. This value is in agreement with expert judgment (van der Gulik, Jan 2006 meeting) and estimates for Oliver. This factor, labeled "Ag demand above CWD" in the model, is applied to all four crops and all three water source areas.

To summarize, values from Neilsen include a 30% increase over what the crop requires, which covers delivery needs (moisture absorbed by soil surrounding plants, for example). The values I input in the model include an additional ~30% for inefficiencies in the irrigation systems.

Instream Flow/Conservation/Fish Demand

Conservation Flow Requirements in Tributaries to Okanagan Lake

In the Okanagan, instream flow recommendations to support aquatic life have been made since the early 1970's, however, targets have not been enforced. Trout Creek, as a result of the 2003 drought, is one exception.

In 2001, B.C. Fisheries released a report that outlined "Conservation Flow Targets" for twenty-one³ tributaries to Okanagan Lake that support rainbow trout or Kokanee salmon. These targets vary each month, and are based on a percent of Mean Annual Discharge (MAD). The MAD is calculated for each stream, based on long-term average historic data. The target varies each month according to the percentages shown in Table 8. The percentages are the same for each of the 21 streams.

"Conservation flows" are intended to be sufficient to support aquatic life. This is in contrast to "minimum flows" which are only the lower threshold of what is needed to support aquatic life, and are in the order of 10% of MAD.

In OSWRM, all of the upland tributaries are aggregated into one parameter. I calculated the MAD for this aggregated flow using the 30 years of historic (1961-90) monthly data (with data gaps patched). The long term average flow worked out to be 65.1 million cubic metres per month, or 24.77 cubic metres per second. (I checked this by calculating the MAD for individual creeks and comparing with those reported in the NHC report.)

³ There are forty-six named tributaries of Okanagan Lake.

Table 8: Conservation flow target structure. (NHC, 2001, page 17)

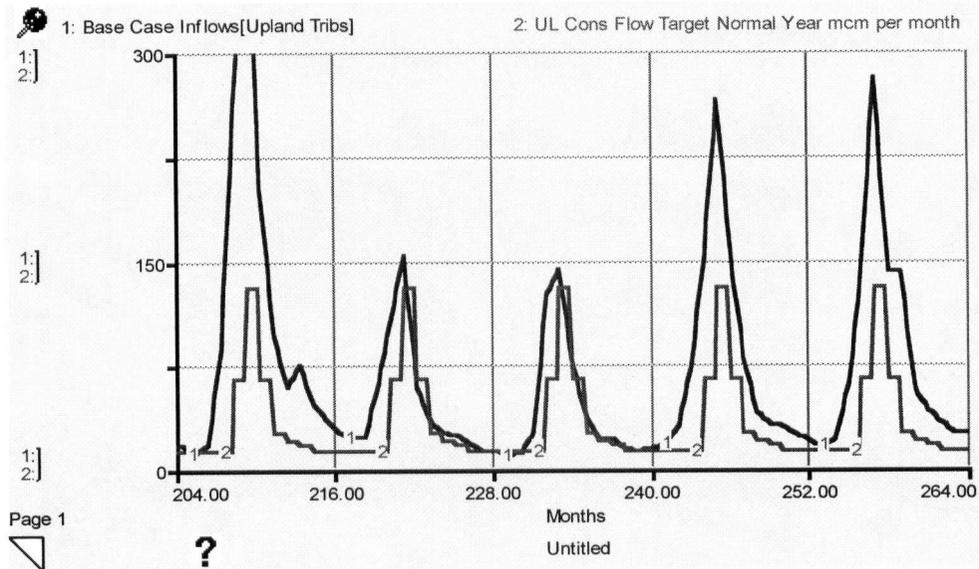
Month(s)	Percent of MAD
January – March	20
April	100
May	200
June	100
July	40
August	30
September	25
October - December	20

Note that if aquatic ecosystem requirements are only applicable to 21 of the tributaries, then instream flow needs are overestimated in the OSWRM. However, even if this were true, then the current structure captures the relative balance of demands present in each of the critical streams. Future model revisions should further explore this issue.

Applying the percentages to the MAD of 65.1 million cubic metres per month gives us the target values as shown in Figure 11. **In model simulations, the MAD value is held constant, even if climate change impacts the hydrologic regime.** This reflects the reality that recalculating the MAD will be a result of a policy decision, not an automatic, annual effort. The figure shows conservation targets compared to upland stream inflows in five years (1978-82) with varying hydrologic conditions. As you can see, it may not be possible for water managers to meet conservation targets in dry years. When the ideal target cannot be met, "dry year" targets are calculated based on current flows as an alternative to the standard targets. Default values are set at 50% of current monthly inflow for all months, however, model users may adjust this percentage for both the peak flow months (April – June) and the low flow months (July – March). In practice, as these targets are not enforced (except on Trout Creek), the magnitude of the reduced targets is up to the discretion of water managers.

Early model versions automatically adjusted the conservation target during dry years, and showed a reduced target in the total demand (Figure 12). However, updates in fall 2006 revised this such that the normal year conservation target is used for showing total demand.

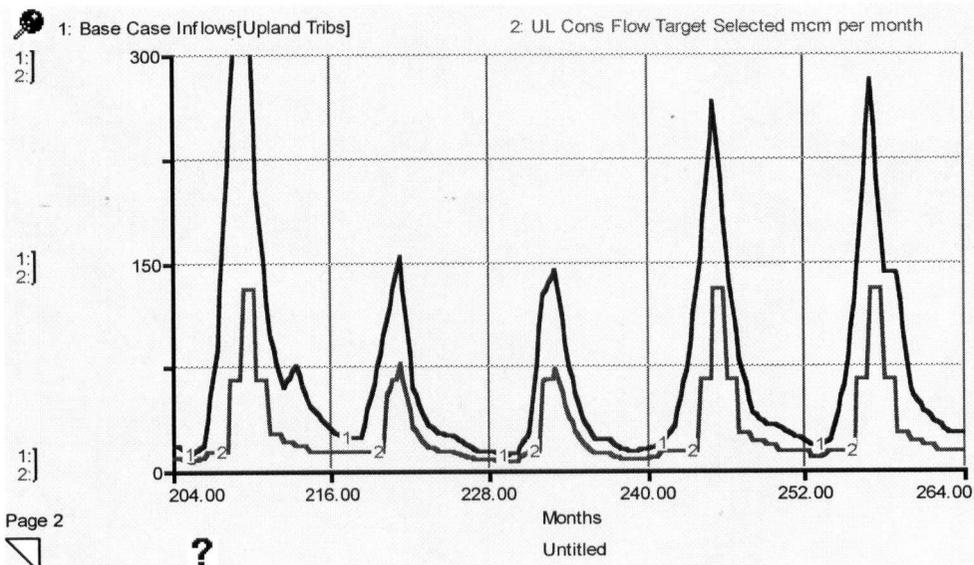
Figure 11: Modeled standard conservation targets shown with five years of varying hydrologic conditions (1978 – flood; 1979-80 – drought; 1981-82 – average).



Page 1



Figure 12: Conservation targets with modifications. Conservation target is no more than 50% of inflows. Greatest reductions are in drought years (1979-80).



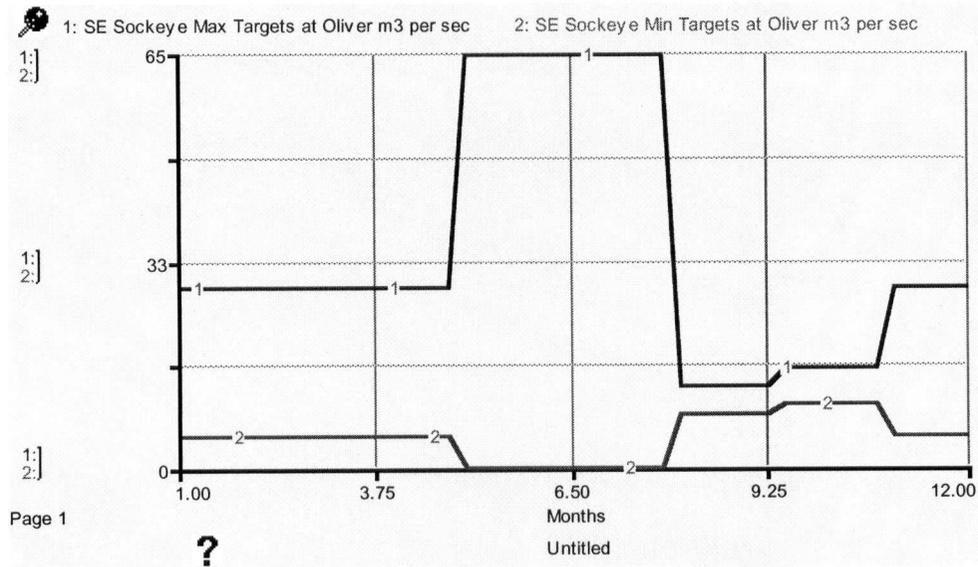
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Fish Flow Requirements in South End

Fish flow requirements included in the model are defined by the operational rules for management of Okanagan Lake, as spelled out in the Fish Water Management Tools Documentation (Alexander et al. 2005). The targets ranges are specified and are most restrictive between August and mid-October, as shown in Figure 13.

Figure 13: Instream flow targets for Sockeye in Okanagan River near Oliver over a 12-month period (Jan – Dec)



V. Wastewater/Return Flow Pathways

Water that has been used for irrigation (both agricultural and residential outdoor) evaporates, transpires and infiltrates into the soil and groundwater. For residents on sewers, only a fraction is lost through evaporation (assumed 5%); the remainder flows to a wastewater treatment plant (WWTP). There are several WWTPs in the Okanagan, and each “disposes” of the treated water in different ways. Current populations in each of these communities were used to determine, for the basin as a whole, what percentage of water from residential indoor use goes where. Table 9 shows the return flow pathways for each community, and the percentages of total indoor water use that takes this pathway. The model assumes all residents are on sewer, but this is not the reality. Residents on septic release to groundwater.

Table 9: List of wastewater pathways by community (information provided by Phil Epp and treatment plant web sites).

Residential return flow pathway	Communities served	Population represented (% of all modeled region)
Uplands groundwater (ex: infiltration ponds)	Coldstream (50%); Spallumcheen; NORD Electoral Areas B & C; Lake Country; RDOS Electoral Areas E & F	15%
Okanagan Lake	Vernon (10%); Westside and Central Okanagan East Electoral Areas, including Native Reserves; City of Kelowna; Peachland; Summerland	60%
South End surface water	Penticton (90%)	5%
Reclaimed for irrigation / Reuse	Vernon (90%); Armstrong; Coldstream (50%); Penticton (10%); Oliver; Osoyoos	20%

VI. Water Balance Calculations

Uplands Hydrology Sector

UL Reservoirs stock represents the aggregate of the live storage of all upland storage reservoirs and lakes, as well as supplementary sources. The stock behaves like a single reservoir for the whole region, regardless of the fact that in the real system, many of these sources do not combine. The major relations in the sector are shown in Figure 14.

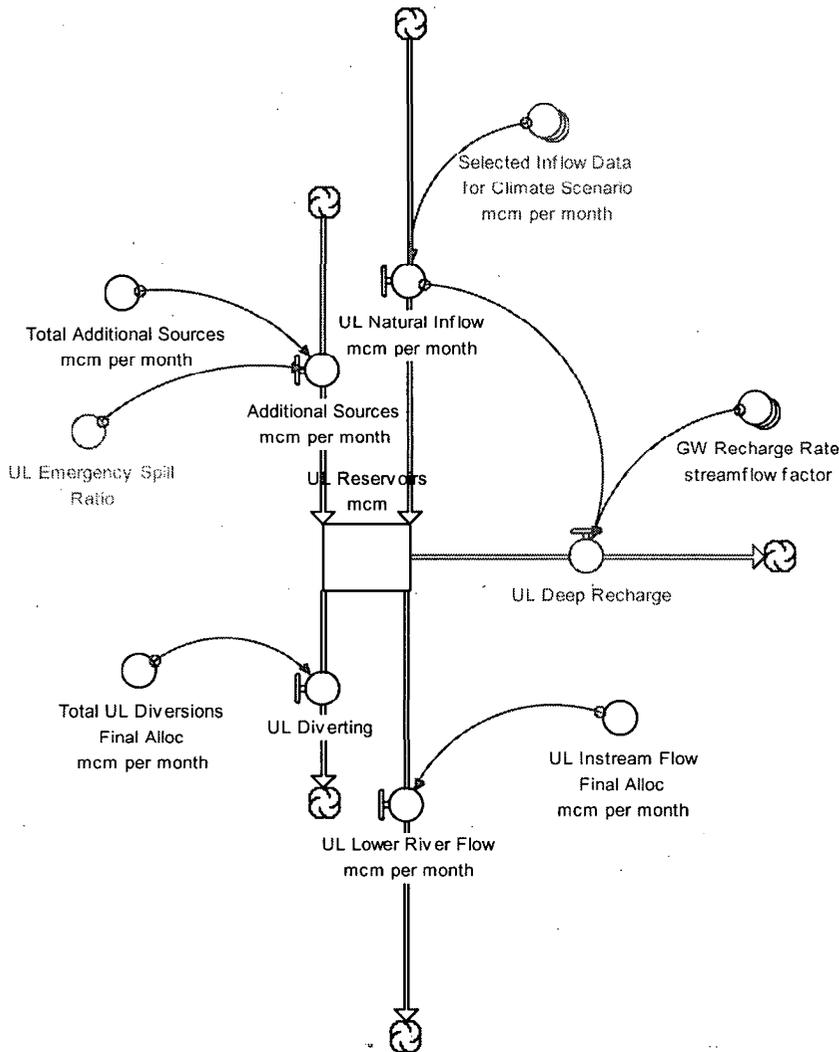
Inflows to the UL Reservoirs stock, which are detailed above, include the natural stream flow scenario (either the base case or a climate scenario), labeled "UL Natural Inflow," and the total additional flows (groundwater, Kettle and Shuswap), labeled "Additional Sources." The net inflow describes the stream flow after land cover processes take effect, such as forest evapotranspiration. Here, a rule is applied that the additional sources are cut off when the reservoirs are full, or more specifically, when UL Emergency Spill Ratio > 1. This is an actual policy for the diversions.

Outflows from the UL Reservoirs stock include infiltration to the aquifer, the sum of out of stream diversions, and water that remains instream and flows to Okanagan Lake. Each of these components is defined in other sectors, and described above.

There are several assumptions related to this sector:

- Streamflow losses can be significant, particularly in dry years, such that what is released from storage is not equal to what arrives at a destination point downstream. Loss rates vary between stream reaches, and with the current and pre-existing hydrologic condition. As stream reaches can be both losing and gaining, not enough information was available to aggregate this phenomenon to the scale of the Uplands region, so it was neglected in this version of the model. As additional information becomes available, it could be added.
- Evaporation from storage areas is neglected, on Bob Hraske's recommendation, because the surface area of the lakes is relatively small, and they are located in higher elevations at lower temperatures.
- The total capacity of storage reservoirs on the tributaries to Okanagan Lake was calculated by information provided by Don McKee. Assuming 85% of licensed storage is actually built, there is 280,000 ac-ft of storage in the tributaries.
- Instream flow requirements apply to the entire stream reach, which includes areas downstream of diversion points. Return flows may supplement instream flow in the lower reaches of some streams, however this study did not examine the system at this level of detail, so I simply assume that instream flow needs cannot be met by any of the water that is diverted for agricultural and domestic uses.

Figure 14: Main components of the Uplands Hydrology Sector, where the water balance for this region is calculated.



Upland Storage Outflow Calculations Sector

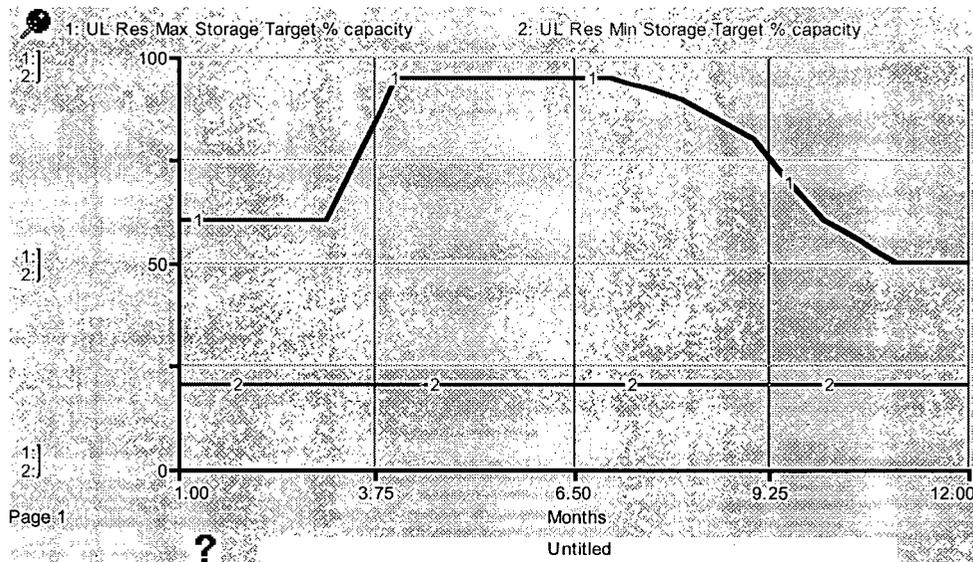
Calculations for releases from the Upland Reservoir stock are based on operations for the upland reservoirs. Inflows and total demands are considered to determine what amount of water the managers would like to release. Next, the state of the reservoir is considered. The upland reservoirs are not mandated to operate for flood control. Through the late fall and winter, storage may be low, and releases are approximately equal to the rate of inflow, maintaining instream flow. The reservoirs may fill very gradually through these months, but do not fill significantly until the spring during the freshet. At this time, all demands can be easily satisfied, and the remainder is

captured in the reservoirs. Water is stored in the reservoirs until required late in the irrigation season, to supplement the diminishing surface water supplies.

The amount requested from the reservoirs is the "UL Pre-release." Between the months of November through April, the pre-release is equal to the total amount of water requested by agricultural, residential, and instream users. In the remaining months, the pre-release is equal to the maximum of the total amount requested and the natural inflows.

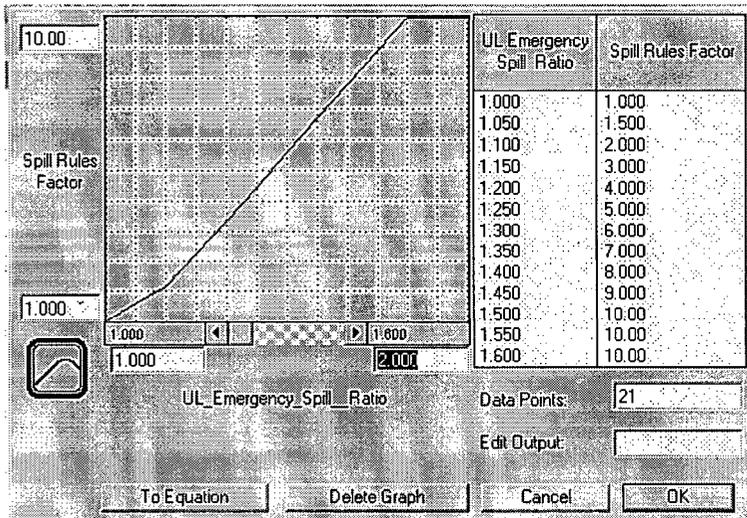
The condition of the reservoir is defined by the max and min storage targets shown in Figure 15. Here, they are shown expressed as percentages, but are converted to units of volume by using the value of the total storage capacity. The extra step permits the user to easily simulate a change in storage volume while maintaining the operational rules. These storage targets are not absolute limits, but act as guides to help the model to operate in a more realistic manner. During the simulations, the stock may surpass these targets.

Figure 15: UL Reservoir Storage Target ranges as a percentage of the total capacity. These targets help direct management decisions for releasing (summer) and filling (during spring freshet).



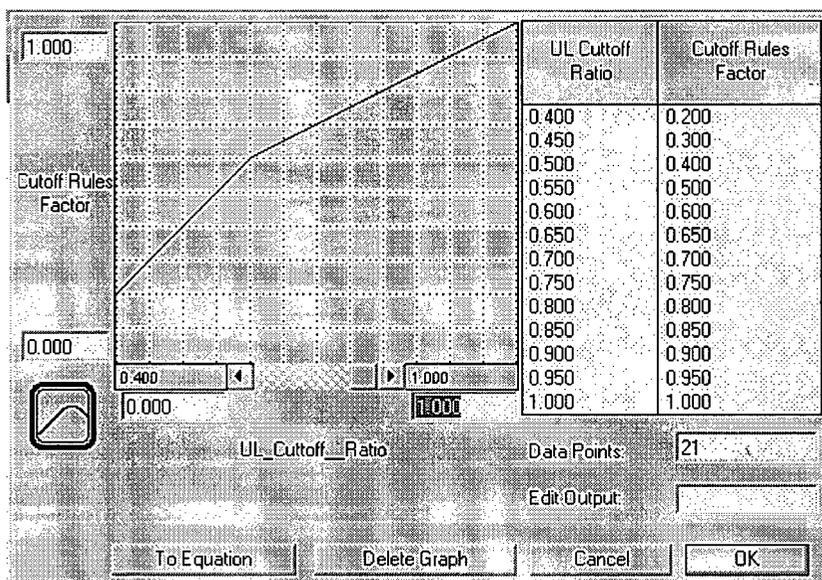
The actual value of the reservoir stock is then compared with the values of the max and min targets (as units of volume) to determine if the reservoir needs to hold back water and fill or to release excess water. First the "UL Emergency Spill Ratio" is calculated by dividing the actual volume of the reservoir by the maximum reservoir target. The ratio is limited to a minimum value of 1. If the value exceeds 1, then additional water must be spilled. Rules for spilling are defined in the "Spill Rules Factor," as shown in Figure 16. As the ratio increases, the intensity of spilling also increases.

Figure 16: Spill Rules Factor Rule curve



Similarly, the "UL Cutoff Ratio" is defined as the ratio of the actual volume of the reservoir to the minimum target volume. This parameter is limited to a minimum value of 1. If the value falls below 1, then the reservoir volume is low, and the amount of the water requested for release may be adjusted, according to the Cutoff Rules Factor, as illustrated by the graph in Figure 17. As values fall below 1, the cutoff rules factor also decreases. When the ratio is zero, then the cutoff rules factor is also zero, such that no water will be released from the reservoir when it is empty.

Figure 17: UL Cutoff Rules Factor, as a function of the UL Cutoff Ratio.



Finally, the value of the "UL Managed Outflow" is calculated simply as the UL Pre-release multiplied by the two Rules Factors.

Also in this sector, the model calculates the value of the "UL Supply Demand Balance," as:

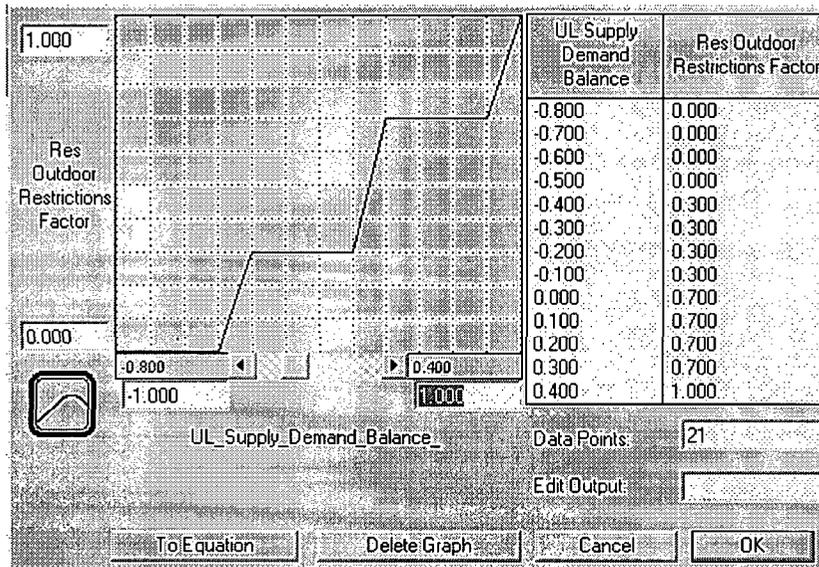
$$UL.Supply.Demand.Balance = \frac{UL.Managed.Outflow - UL.Total.Demand}{UL.Total.Demand}$$

By this definition, when the calculated ratio is equal to zero, then only enough water to satisfy all demands is available. Positive values indicate more than the minimum amount of water is available to satisfy demands, while negative values represent deficit conditions. This value is the important indicator for determining if allocations will be short of demands, and if restrictions must be implemented.

Uplands Demand Reductions for Shortages Sector

The main purpose of this sector is to implement established policies for reducing use during periods of water shortage. For example, today there are established policies for reducing residential use during periods of drought. This is a tiered structure, where watering is restricted to a certain number of days per week. As shortages become more severe, the watering restrictions become more intense; watering is permitted on a fewer number of days per week. This policy mechanism is captured in the Residential Outdoor Restrictions Factor as shown in Figure 18. When the UL Supply Demand Ratio is low, the Restrictions Factor takes a value greater less than one. The factor is multiplied directly against the original amount of residential outdoor water demanded, providing the value for "Res Outdoor Restricted." More specifically, outdoor water restrictions are implemented when supplies are only 30% above demands. This is more prudent than waiting until you already have shortages (when the ratio = 0.0) to implement restrictions.

Figure 18: Residential Outdoor Restrictions Factor defined as a function of the UL Supply Demand Balance Ratio.



Residential Indoor Demand and Agricultural Demand have parallel mechanisms for managing drought. The thresholds and intensities of restrictions vary for each use. Residential Indoor restrictions are implemented last, as shown in Figure 19. Agricultural restrictions are not implemented until the ratio is at -0.2, however, water is entirely cut off if the value drops as low as -0.8

Figure 19: Residential Indoor Restrictions Factor defined as a function of the UL Supply Demand Balance Ratio.

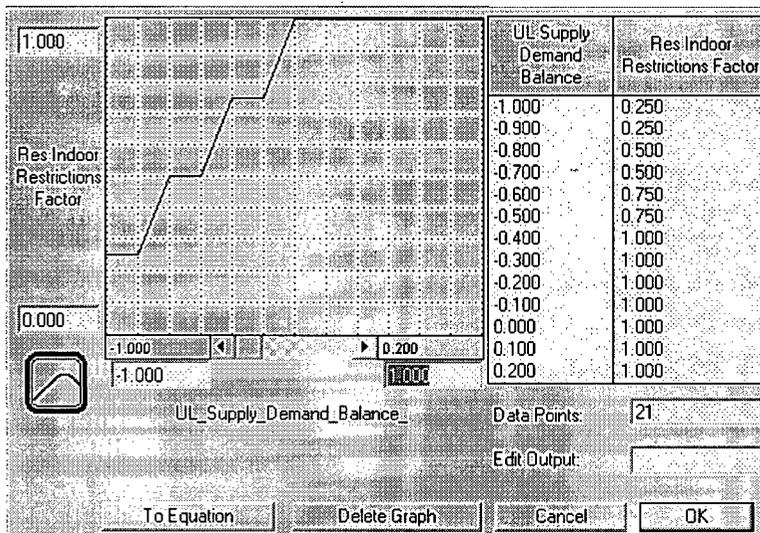
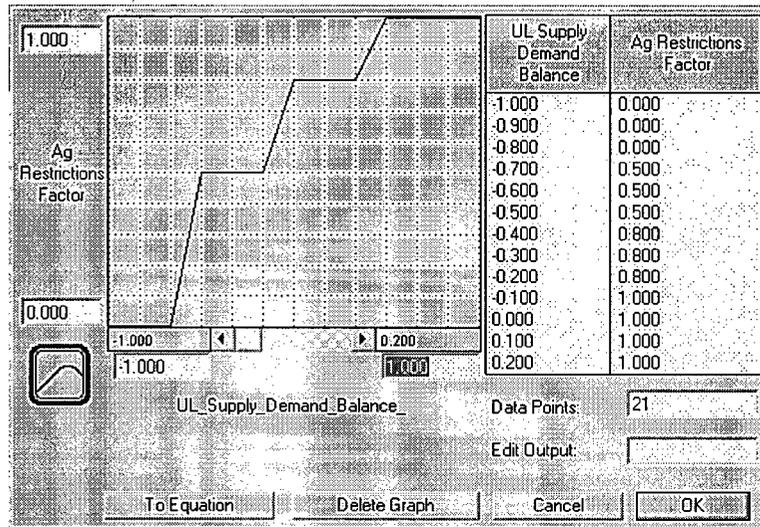


Figure 20: Agriculture Restrictions Factor defined as a function of the UL Supply Demand Balance Ratio.



The last step in this sector is to total the new reduced demand. The restricted levels for agriculture and residential uses are summed with the conservation flow target that has already adjusted for drought periods. This new level of demand that includes adjustments from drought policies is represented in the converter, "UL Total Reduced Demand."

Note that there is an alternative management option included in the model where, instead of restricting use during low flow periods, all diversion demands can be satisfied by pumping water from Okanagan Lake. This mechanism appears in the last Upland Sector, named, "UPLANDS ALLOCATION SUMMARY."

Uplands Demand Allocations Sector

The purpose of this sector is to allocate water to the various users. The first step in this process is to determine if the water shortage policies implemented in the previous sector were sufficient to reduce the total demand level to the amount of supply available. In a formula that is very similar to the first supply demand ratio calculated, we determine the new supply demand balance as:

$$UL.Adjusted.Supply.Demand.Balance = \frac{UL.Managed.Outflow - UL.Total.Reduced.Demand}{UL.Total.Reduced.Demand}$$

Keep in mind that these reductions are only relevant for months when there are shortages. For the timesteps that had sufficient water supplies to meet all demands from the start, these adjustments will have no effect.

If the Adjusted Supply Demand Balance is negative (meaning that we still cannot satisfy all demands) then we have two options. The model user chooses to either have the simulation stop, at which point they adjust the drought policies, or have the model automatically reduce all demands by the percentage that the system is short of meeting them. The default value is for the model to reduce all demands. The "Drought Management Auto or Manual Mode Switch" is where the model user controls this setting. If manual mode is selected, the "UL Shortages Messenger" will be active. Otherwise, the model will continue on its merry way cutting the allocation to the required level. This is done through the "UL Auto Demand Adjuster." This converter simply takes a value of the managed supply divided by the reduced demand, but is restricted to a maximum value of 1. This adjuster is used to determine the allocation levels of all of the uses, including conservation demand.

A final step conducted in this sector is to calculate the "UL Instream Flow Allocated." In cases of shortages, this instream flow will be equal to the "UL Cons Flow" so this step appears to be unnecessary at first glance. However, in all of the timesteps with more than sufficient water available, the actual amount of water retained in the stream will be greater than the conservation flow allocation. The formula is simply:

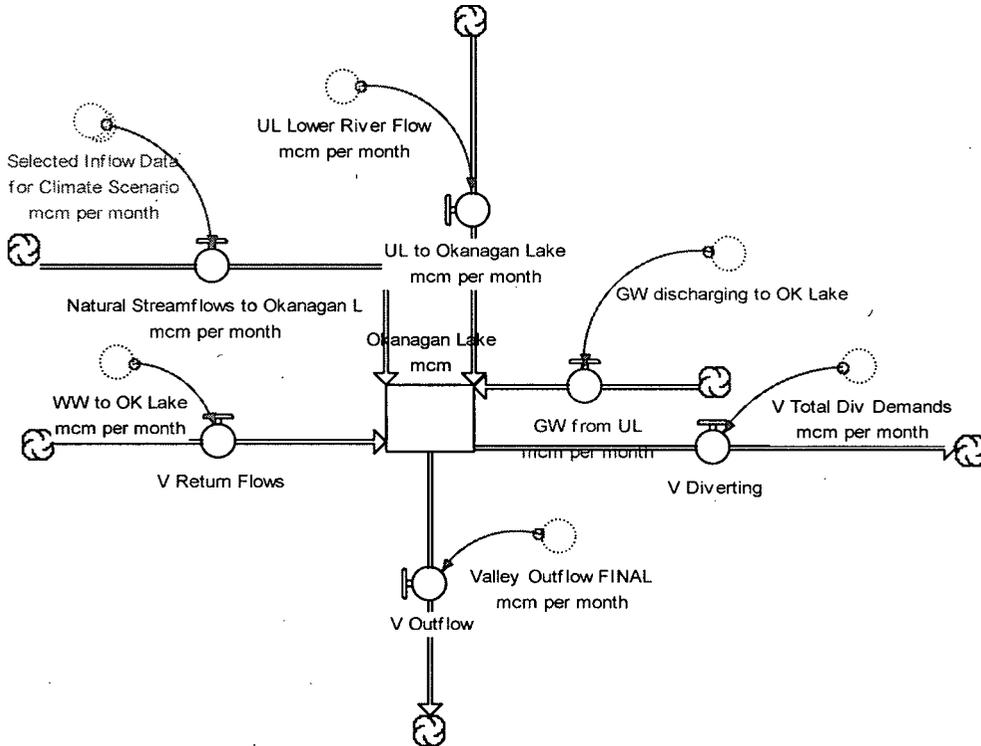
$$\text{UL Instream Flow Allocated} = \text{UL Managed Outflow} - \text{UL Total Div Allocated}$$

UPLANDS ALLOCATION SUMMARY Sector

In this sector, final decisions are made regarding allocations. If the default setting is used, such that water diversions are reduced during deficit situations, then the allocations are equal to those calculated in the previous sector. However, there is a user option where any deficit in the Uplands can be satisfied with water from Okanagan Lake. In this case, there are no reductions, and allocations are equal to what was originally demanded. Converters with names that include "Final Alloc" are used to include any and all of the reductions and policies described in other sectors.

Valley Hydrology Sector

Figure 21: Supply and Demand balance calculation for the Valley Sector.



Okanagan Lake is the water source labeled as "Valley." Sources for Okanagan Lake include flows from the Uplands region, additional natural inflows for the minor, unmanaged tributaries, some return flows from residential use, and groundwater recharge from the Uplands.. The value for inflows from the Uplands is equal to the instream flow allocated for the Uplands.

Lake outflows include simply diverted flows for residential and agricultural use, and outflow downstream to Okanagan River, representing releases from Penticton dam.

Okanagan Lake Condition Sector

The purpose of this sector is to convert the volume of Okanagan Lake into terms of stage. We assume that the surface area of the lake remains at a constant 341 msm, and that at a volume of 26,000 mcm, the stage is at 341.9 m.

Valley Diversion Tracker Sector

In this sector, we make a significant assumption that all demands can be met. The justification is that current diversions from Okanagan Lake for agricultural and residential purposes are quite small, as compared with the other regions. Furthermore, I assume that the diversions can be compensated through lake management.

Okanagan Lake Dam Operation Sector

The information for this sector is based on information provided in The Okanagan Fish Water Management Tool: Guidelines for Apprentice Water Managers (Alexander et al., 2005: p. 32). The lake is managed for a number of different purposes throughout the chain of lakes and rivers that connect them, with requirements that vary throughout the year. Purposes include flood control, kokanee shore spawning and incubation, sockeye incubation, mitigation of the temperature-oxygen squeeze on sockeye juveniles, agricultural and domestic water intakes, recreational navigation and river recreation.

Many of these needs can be accommodated by stage targets. In the real system, forecasting plays a significant role, particularly related to the snowpack and the expected volume and timing of the spring freshet. This version of the model does not have a forecasting component. The monthly timestep also creates challenges for imitating lake management, which in reality may be adjusted on an hourly basis.

Four things are considered to determine how much water to release from the lake each timestep. First, net inflows are determined. Theoretically, releasing the same volume would maintain lake levels. Next, lake stage and monthly targets are considered, and the model calculates how much water needs to be released to achieve the target. Third, the minimum and maximum outflow thresholds are incorporated and adjust the outflow value if needed. Fourth, flow for sockeye is considered. Finally, the user must decide whether the model will aim to meet the lake level targets or meet the sockeye flow targets. The user setting will determine which value the model uses to calculate releases from the lake, labeled, "Valley Outflow FINAL."

VII. Adaptation Strategies

The following table summarizes the adaptation strategies and policies available to the user on the user interface. The “Basic Options” are available in the standard interface, while the “Advanced Options” can be found by navigating to the Programmer’s Interface.

Table 10: Adaptation and policy options included in the model on the user interface

Description of option	Default value	Range
<i>I. Basic Options</i>		
Agricultural use in the Uplands Implement ag conservation? How effective will ag conservation be at reducing water use?	No 50%	Yes/No 0-100% (max)
Agricultural use in the Valley (Okanagan Lake source) Implement ag conservation? How effective will ag conservation be at reducing water use?	No 50%	Yes/No 0-100% (max)
Agricultural use in the South End Implement ag conservation? How effective will ag conservation be at reducing water use?	No 50%	Yes/No 0-100% (max)
Residential conservation for whole basin Public education Xeriscaping Plumbing retrofit Metering with constant unit charge (CUC) or increasing block rate (IBR)	Off Off Off None	On/Off On/Off On/Off None, CUC, or IBR
Residential development patterns across the basin Housing occupancy rate (average people per dwelling) Ratio of apartments (multiple-unit dwellings) in the housing stock	2.3 0.31	1.0 – 5.0 people 0.00 – 1.00
Instream flow needs at Oliver (sockeye as an indicator species) Operate lake outflow to optimize for sockeye instead of optimizing for Okanagan lake level?	No	Yes/No
Drought policies regarding allocation to user groups. Graphs define appropriate levels of restrictions for the full range of values of water deficit. Ag restrictions Res outdoor restrictions Res indoor restrictions	1.00 – 0.00 1.00 – 0.00 1.00 – 0.25	Graph Graph Graph
Drought policies for conservation flow targets – these targets are active only when the standard target cannot be met % of inflow in peak flow months (Apr.– Jun) % of inflow in low flow months (Jul – Mar)	50% 50%	25 – 75% 50 – 100%
Drought management simulation mode When shortages occur, either the model will allocate water according to the restriction graphs, or the user can be alerted and asked to reduce allocations manually.	Auto	Auto or Manual
Water recycling and reuse Recycling and reuse presently occurring in the Okanagan can be omitted to test the effects of this practice on the system.	On (Re-use)	Re-use/No re-use
Supplementation from Okanagan Lake for Upland users Anytime shortages in the Uplands occur, the Ag and Res demands are supplemented with water from Okanagan Lake	Off (not supplemented)	On/Off
<i>II. Advanced Options (in Programmer's Interface)</i>		
Hydrology Upland Storage – total capacity (mcm) Uplands groundwater recharge – transit time (months) Uplands groundwater recharge – streamflow factor (how much of natural flow enters aquifer)	350 6 0.00	200 – 500 1 – 36 0.00 – 1.00
Population growth In the basic user options, population growth scenarios have preset rates for each Regional District. Here, the user can change the	multiple values	varies from 0.0 to 5.0%

Description of option	Default value	Range
definitions of the rapid, moderate and slow growth rates for the three Regional Districts.		
Agricultural land use by crop type in the Uplands. Note that the initial total is 215 million square metres. Changing values will change the total land in production, unless user maintains this total.		
Pasture and Forage	32	0 - 100
Tree Fruits	59	0 - 100
Wine Grapes	9	0 - 50
Other	115	0 - 150
Indoor water use in the Uplands		
Loss from indoor use	5%	0 - 10%
Indoor water use return flow pathways in the Uplands. Where does water go after indoor use?		
Okanagan Lake	60%	0 - 100%
Recycled	20%	0 - 100%
Groundwater	15%	0 - 100%
South End surface water (Rivers downstream of Okanagan Lake)	5%	0 - 100%
Outdoor water use return flow pathways in the Uplands. Where does the water go after ag or residential irrigation?		
Evapotranspiration losses	50%	0 - 100%
Groundwater recharge	17%	0 - 100%
Surface water recharge	33%	0 - 100%

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