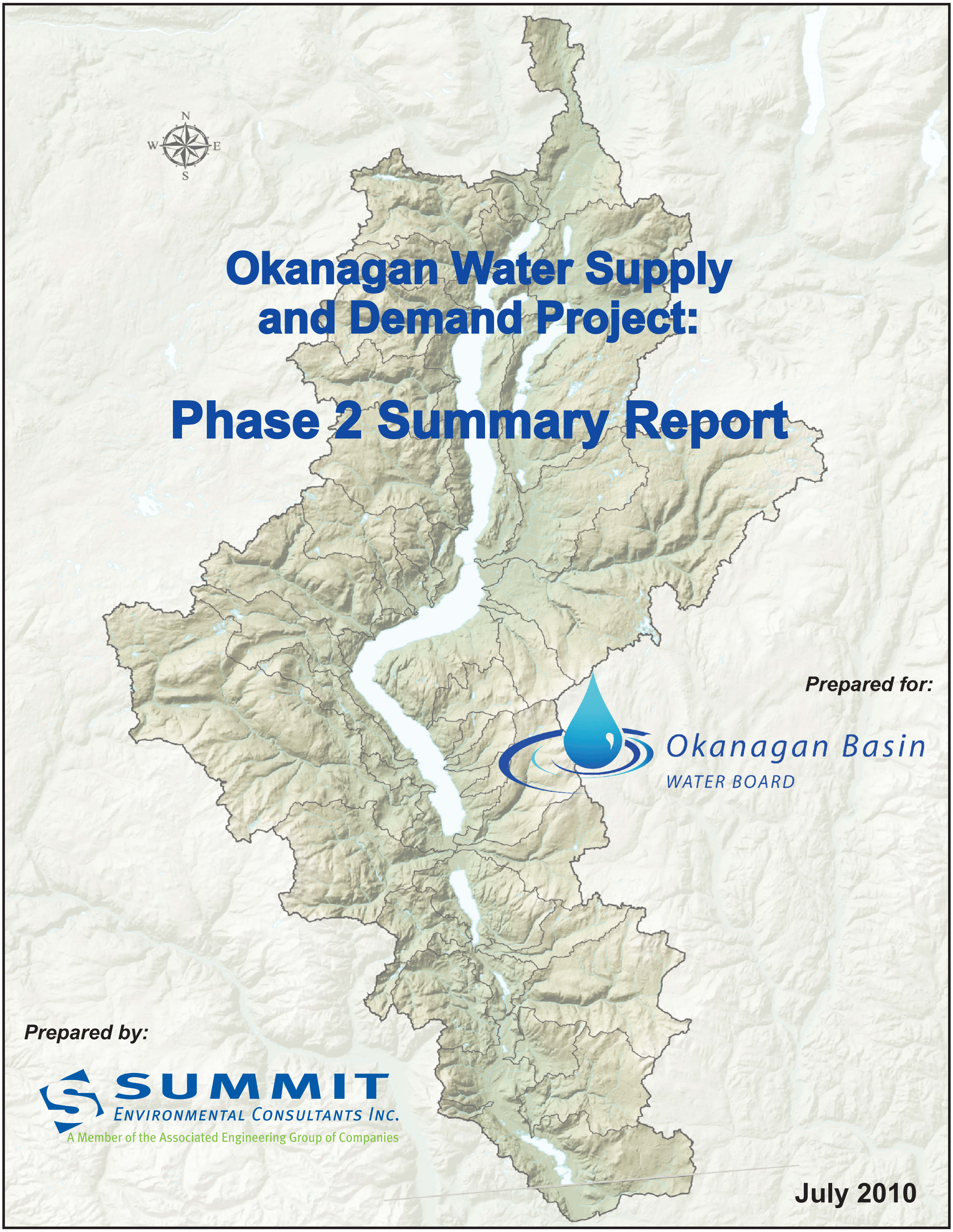

Okanagan Water Supply and Demand Project:

Phase 2 Summary Report

Prepared for:

Okanagan Basin
WATER BOARD

Prepared by:

SUMMIT
ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

July 2010

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SUMMIT
ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

July 30, 2010

Dr. Anna Warwick-Sears
Executive Director, Okanagan Basin Water Board
1450 KLO Road
Kelowna, B.C.
V1W 3Z4

Re: Okanagan Water Supply and Demand Project: Phase 2 Summary Report

Dear Dr. Warwick-Sears:

On behalf of the Phase 2 Okanagan Water Supply and Demand Project Working Group, I am pleased to provide a Summary Report of Phase 2 of the Project.

The Summary Report summarizes the studies, databases, and models developed and used during Phase 2, and lists key findings and recommendations. Supporting reports are provided as Appendices.

I believe that Phase 2 has provided a firm foundation for continuing to improve water management throughout the Okanagan Basin, and hope that it will continue to inform future work in this area.

Yours truly,

Summit Environmental Consultants Inc.

Brian T. Guy, Ph.D., P.Geo., P.H.
Project Manager, Phase 2 - Okanagan Water Supply and Demand Project

ERRATA

January 27, 2011:

The following revisions have been made to the original Summary Report published by Summit Environmental Consultants Inc. in July 2010:

1. Page 5: a reference to Section 12.0 in the last bullet has been changed to a reference to Section 10.0.
2. Page 6: a reference to Environment Canada in the seventh bullet has been removed.
3. Page 8: in Table 2.1, "MAL" has been changed to "MAL/AAFC".
4. Page 11: "Environment Canada" has been amended to "Environment Canada (EC), AAFC, and the University of Lethbridge (U. Leth.)".
5. Page 12: "Environment Canada" has been amended to "EC, AAFC, and U. Leth.".
6. Page 12: a reference to Environment Canada in the first paragraph of Section 5.0 has been removed.
7. Page 70: "Figure 19.1" has been changed to "Figure 6.1".
8. Other minor typographical errors have been corrected.
9. Appendix N: the following reference:

Neilsen, D., G. Duke, B. Taylor, J. Byrne, S. Kienzle, and T. Van Der Gulik (2010), Development and verification of daily gridded climate surfaces in the Okanagan Basin of British Columbia, *Can. Water Res. J., .XX, xx-xx*

has been updated to:

Neilsen, D., G. Duke, W. Taylor, J. Byrne, S. Kienzle, and T. Van der Gulik (2010), Development and verification of daily gridded climate surfaces in the Okanagan Basin of British Columbia. *Can. Water Resources J. 35(2), 131-154.*

EXECUTIVE SUMMARY

OVERVIEW

The Canadian Okanagan Basin (the Basin), in the southern interior of British Columbia, is the subject of the Okanagan Water Supply and Demand Project. Because of relatively high rates of water use, variable water supply, and the understanding that population growth and climate change could impact water supply and demand and the sustainability of aquatic ecosystems, in 2004 the Province initiated a project to investigate the supply of and demand for water in the Basin. The first Phase of the Project identified the information that could be used, and prepared a plan to complete the investigation. Phase 2 of the Project was initiated in 2007 by the Okanagan Basin Water Board in partnership with the Province; and was completed in collaboration with a large number of federal and provincial agencies and the Okanagan Nation Alliance. This report is a summary of Phase 2 of the Project.

OBJECTIVES

The objectives of Phase 2 were achieved:

- Completion of comprehensive basin-wide scientific studies on water supply and demand, updating work last completed in the early 1970s;
- Development of three sophisticated computer models for simulating water movement in the Okanagan: the Okanagan Water Demand Model (OWDM) that is used to determine water needs for various human uses, the Okanagan Basin Hydrology Model (OBHM), and the Okanagan Basin Water Accounting Model (OBWAM) - used to estimate natural streamflows and the effects of water storage and extractions on streamflows, groundwater, and lake levels; and
- Examining a few scenarios using the models to illustrate how they can be used to examine water alternatives under a changing climate, a growing population, a changing agricultural land base, continuation of the Mountain Pine Beetle epidemic, and changing water use efficiency.

The most important result of Phase 2 is the successful development of these sophisticated Okanagan-custom computer models. They are powerful state-of-the-art tools that can be used to simulate future water conditions in the Okanagan, and estimate the influence of both climate change and human decisions on water use and streamflows. These models also provide a way to determine how a water use or management decision made in one area of the Basin can affect another area of the Basin. These models will be useful to researchers, water suppliers, local, provincial, and federal government agencies, First Nations, and others with an interest in investigating the potential influences of natural events and human decisions on water resources.

In examining scenarios, the Phase 2 Project has not thoroughly investigated the full range of possible water futures, but instead has concentrated on illustrating some likely potential futures based on a limited examination. The technical work and the scenario outcomes have highlighted data and knowledge gaps, the important role (and the limitations of) demand management in adapting to climate change, the challenges facing water suppliers as they work to continue to provide reliable water supplies into the future, and the importance of proactive decision-making in securing a sustainable water future for the Okanagan.

Phase 2 has made optimal use of the existing information base. However, the information used has strengths and weaknesses. Each component of the Phase 2 work encountered data limitations that restrict the conclusions that can be drawn from that information. The findings, conclusions, and recommendations expressed in this report are appropriate for the level of information available. However, as more and better data become available to further develop the models, the precision and accuracy of the findings will be improved. The report makes specific recommendations for obtaining such additional data.

DELIVERABLES

Deliverables of the Phase 2 Okanagan Water Supply and Demand Project are:

- A User Needs Assessment Report;
- Reports on specific aspects of water supply and demand in the Okanagan: surface water, groundwater, water use, lake evaporation, and instream flow needs - these studies are reproduced in the Appendices to this Summary Report;
- The Okanagan Water Demand Model (OWDM), the Okanagan Basin Hydrology Model (OBHM), and the Okanagan Basin Water Accounting Model (OBWAM);
- The OkWater database, the Water Demand GIS database, and a series of climate datasets;
- The Okanagan Water Information Reference Library database;
- A web-based reporting tool; and
- A communication program.

ORGANIZATION OF THIS REPORT

This report is organized into five parts. Part One (Background) provides the context for the Phase 2 work. Part Two (Data and Databases) describes the datasets and databases developed during Phase 2, and summarizes the major technical studies completed during Phase 2. The technical studies provided the foundation for the models developed in Part Three, and are reproduced in their entirety in electronic form in the Appendices. Part Three (Models) summarizes the three models developed during Phase 2: the Okanagan Water

Demand Model (OWDM), the Okanagan Basin Hydrology Model (OBHM), and the Okanagan Basin Water Accounting Model (OBWAM). Part Four (Scenarios) describes the outcomes of the 15 Phase 2 scenarios. Part Five (Key Findings and Recommendations) lists the major findings and recommendations of Phase 2, and recommends next steps for subsequent phases of the Water Supply and Demand Project.

A glossary of key terms used in the text is provided in Section 21.0 and acronyms used are defined in Section 22.0.

KEY FINDINGS AND RECOMMENDATIONS

Key findings and recommendations of Phase 2 are described in Parts Two, Three, and Four of this report, and summarized in Sections 19.0 and 20.0. They are listed here.

- Climate change, population growth and other changes are likely to put increasing pressure on water supplies in the decades ahead. Future shortages are likely to occur in late summer when water supplies from surface sources are low and demands for water withdrawals and ecosystem needs are high.
- There is high seasonal and between-year variability in both water supply and water demand, and differences from place to place within the Basin; and robust decision-making must take into account this high variability.
- Groundwater is an increasingly important source of water for human needs, yet is under-regulated. Groundwater use should be regulated using the same system used to regulate surface water.
- Per capita water use in the Okanagan is relatively high, but there are opportunities to reduce water use through proven conservation measures.
- The Phase 2 results do not suggest an imminent widespread water crisis, rather that there is an opportunity to thoughtfully design and implement improved water management policies and practices within the Okanagan Basin. These policies and practices should include both supply-side and demand-side management strategies. Storing water in upland reservoirs will remain a key strategy for optimizing the use of tributary water sources.
- There is insufficient information available to optimize water management in the Basin. Additional data and information should be obtained on surface water, groundwater, climate, water withdrawals and distribution, aquatic ecosystem needs, lake evaporation, and evapotranspiration. Improved data on water supply and demand will enable improvements to the Project models.
- Additional scenarios should be examined to further explore the range of potential futures, and assist with the design of appropriate mitigation and adaptation measures.

- The key findings and recommendations contained within this report should be pursued in Phase 3 and potentially other future phases of the Okanagan Water Supply and Demand Project.

SUMMARY OF TECHNICAL COMPONENTS

Annual water balances

The overall annual water balance for the Basin, derived from information presented in several sections of the report, is shown in Figure 1. The values on the figure are annual totals, but they are averaged over time for the period 1996-2006, and across the entire area of the Basin. The figure does not indicate the variability which characterizes both water supply and demand. Decision-making must consider the seasonal variability in both supply and demand, the differences that exist from place to place within the Basin, and the annual variability of both supply and demand.

The annual average water balance for Okanagan Lake is shown in Figure 2.

Water Management and Use:

A summary of the water management and use studies completed in Phase 2 is provided in Section 6.0, and the key findings are summarized in Section 19.0. A total of 443,000 ML of water is licensed for withdrawal from surface sources for human use in the Basin. Of this total, 163,000 ML is supported by storage. Groundwater use does not require a licence. Although there are over 4,000 licences to store or use surface water in the Basin, about 95% of the withdrawal licences – by volume – are held by 57 of the largest water suppliers. Actual average annual water use in the Basin is 219,000 ML, derived from several sources (Figure 3).

The distribution of water used in the Basin is shown in Figure 4. Indoor domestic water use averages 150 L/person per day. Outdoor domestic water use averages 525 L/person per day year-round, i.e. more than 1,000 L/person per day during summer.

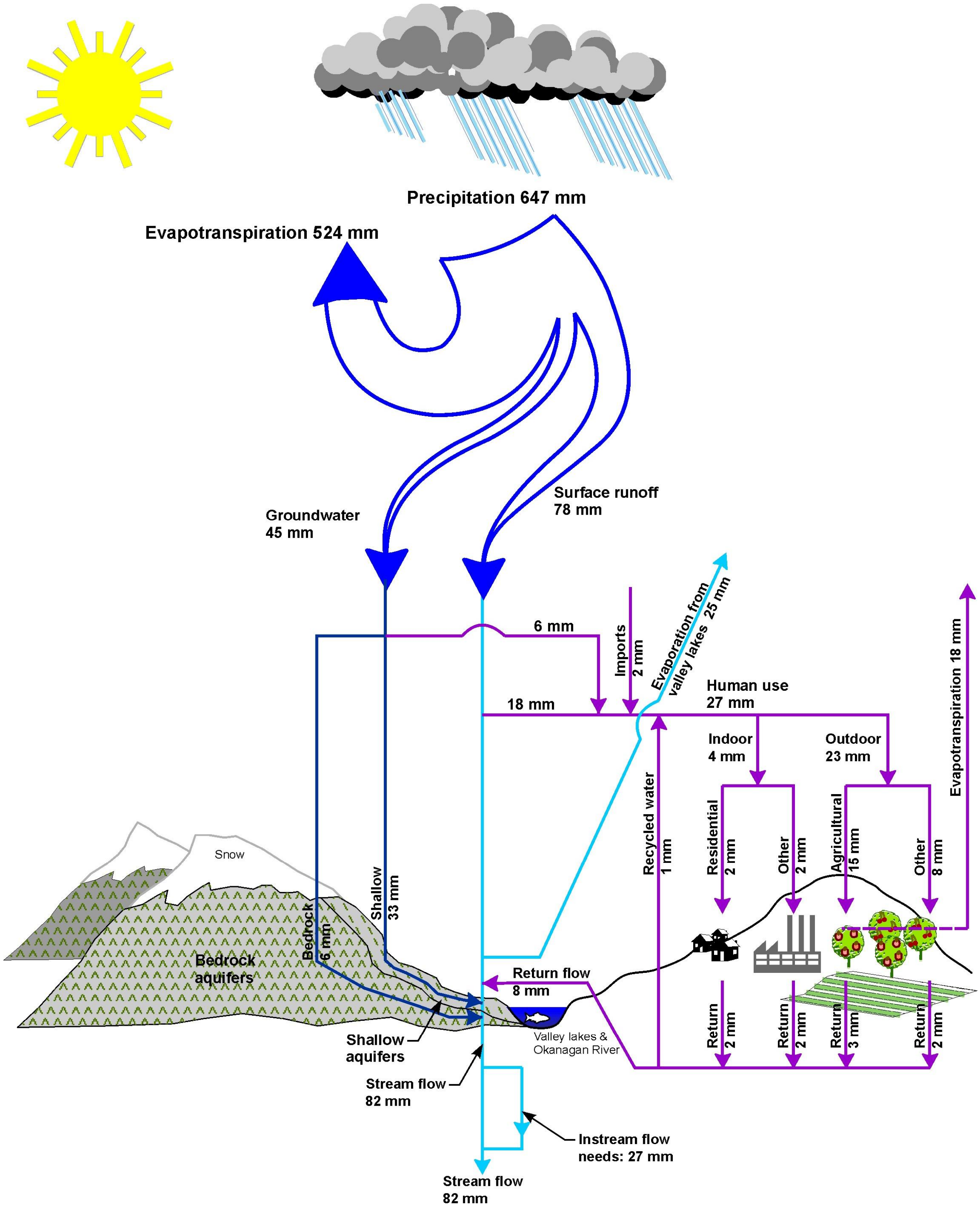

Figure 1 Average annual water balance for the Okanagan Basin.

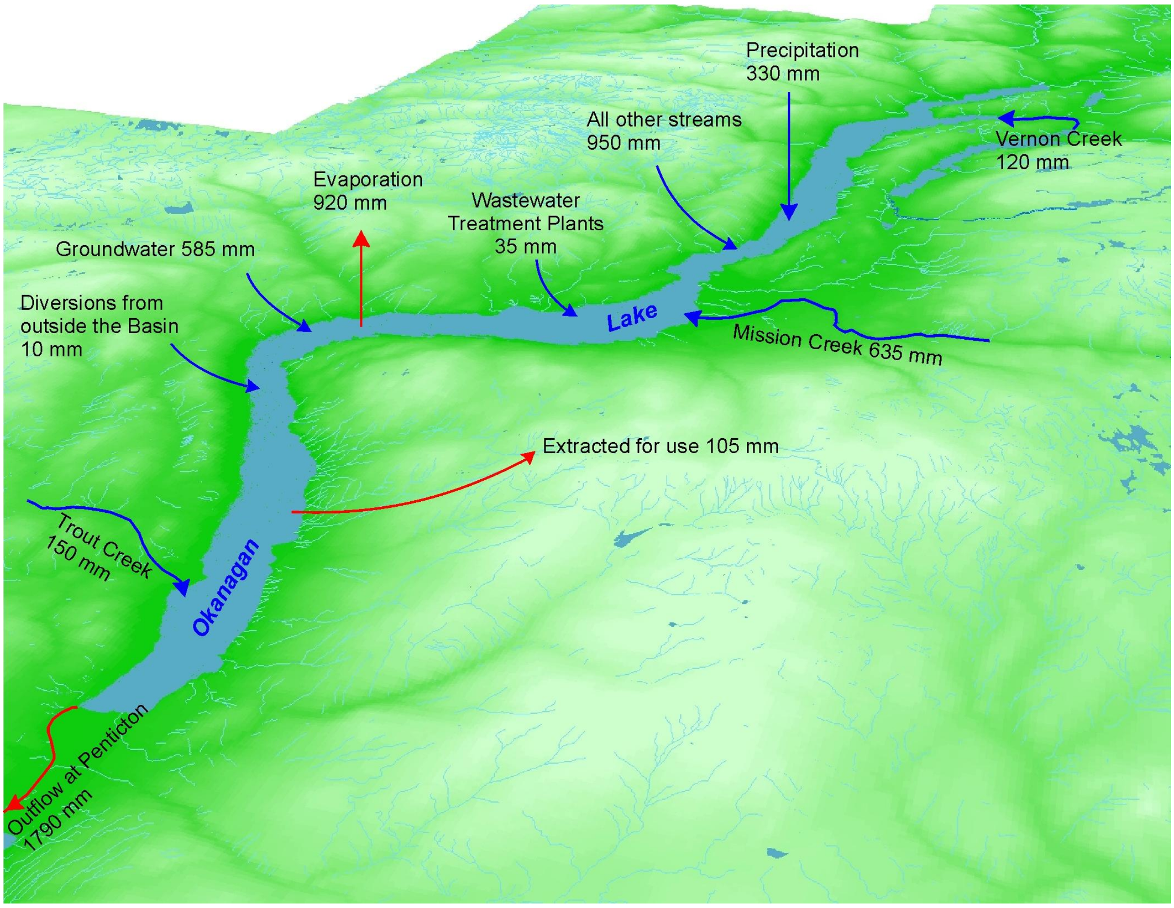

Figure 2 Average annual water balance for Okanagan Lake.

It is recommended that water suppliers measure and report their water extractions, and measure the water delivered to end-users. It is recommended that water conservation measures in all water use sectors continue to be expanded and adopted throughout the Basin, and that water suppliers should preserve their opportunities to expand storage in upland reservoirs.

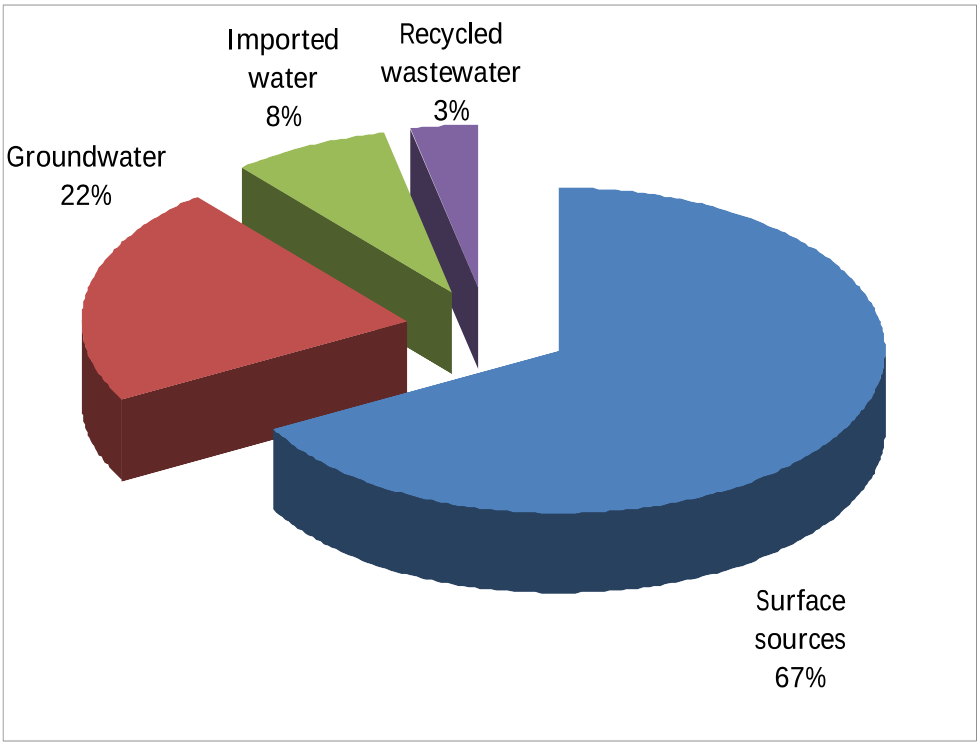

Figure 3 Distribution of total water use in the Okanagan Basin by source (based on data for 1996 to 2006).

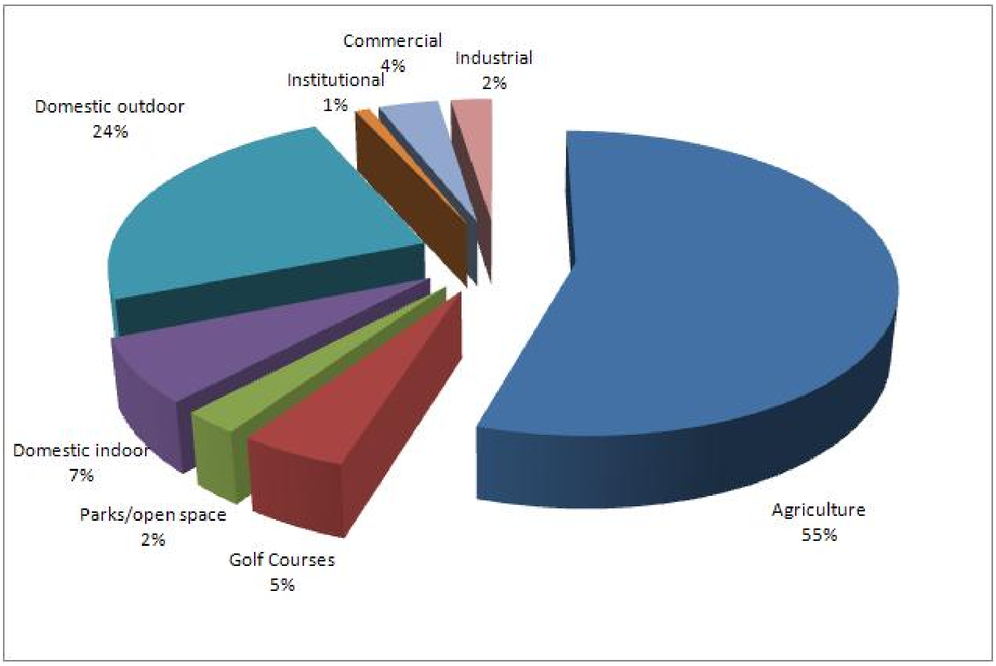

Figure 4 Distribution of water use amongst water users.

Groundwater

The groundwater studies undertaken during Phase 2 are summarized in Section 7.0. Because of minimal regulation of groundwater use, there is relatively little information on the hydrogeology and groundwater resources of the Okanagan Basin. A conceptual model of groundwater storage and flow was developed, in which most of the groundwater activity takes place in 79 distinct shallow unconsolidated aquifers, located primarily along the lower elevation valley bottoms. Estimates of groundwater discharge to Okanagan Lake vary over a wide range, which reflects the uncertainty and relative absence of information needed to make these estimates.

Additional hydrogeological characterization should be completed, and more data on groundwater extraction and on surface/groundwater interactions should be obtained. This information is needed to more adequately understand Okanagan groundwater resources. Groundwater use should be regulated using the same system used to regulate surface water.

Lake Evaporation

Section 8.0 of the report describes the investigation of lake evaporation conducted for Phase 2. The Penman-Monteith model was chosen for estimating evaporation from Okanagan Lakes, but due to a lack of direct measurements, the accuracy of the evaporation estimates is given within a fairly broad range. It is recommended that direct measurements of lake evaporation be obtained so that evaporation can be modelled with greater precision.

Surface Water Hydrology

Section 9.0 documents the studies of surface streamflow conducted during Phase 2. Several methods were used to estimate natural streamflows in tributary streams. The results were used to calibrate the Okanagan Basin Hydrology Model (OBHM). Runoff (the streamflow generated per unit of land surface area) increases from south to north, from west to east, and with elevation. About 83% of the total streamflow in the Basin enters Okanagan Lake, and areas downstream of the Lake (south of Penticton) generate only 17% of the total runoff in the Basin. Mission Creek is the largest tributary, producing 28% of the flow in the Basin, and Trout and Vernon Creeks each produce about 7% of the Basin flow. Streamflow is highly seasonal, with 86% of the streamflow generated from melting of the winter snowpack between March and July, and only 14% occurring in the other 7 months of the year.

It is recommended that additional streamflow monitoring stations be installed throughout the Basin, particularly downstream of the major storage reservoirs. Surface-groundwater interactions on the major alluvial fans in the valley bottom should be investigated to advance our understanding and improve our ability to model streamflow and groundwater discharges to the main valley lakes and Okanagan River, and our understanding of ecosystem needs during low flow periods of the year.

Instream Flow Assessment

Desk-top methods were used in this study to identify minimum instream flow regimes in Okanagan tributaries that provide (a) minimal and (b) optimal protection for aquatic populations (Section 10.0). However, these estimates are not accurate enough to describe actual instream flow needs in individual tributaries. The work demonstrated that such desk-top methods must be supported by field-based assessments to more reliably determine instream flows needed to protect aquatic ecosystems. It is recommended that an acceptable level of risk to aquatic populations be determined in advance, then site-specific studies be completed to identify the appropriate minimum instream flows.

Scenario Results

Three custom computer models for simulating water supply and demand in the Okanagan: the Okanagan Water Demand Model (OWDM), the Okanagan Basin Hydrology Model (OBHM), and the Okanagan Basin Water Accounting Model (OBWAM) were developed and used to examine 15 potential future water supply and demand conditions. The Phase 2 work did not attempt to examine all possible futures, but rather focussed on some reasonably possible outcomes to illustrate the usefulness of the models and the scenario-running process. The models are described in Part Three of the report (Sections 13.0 through 16.0). Part Four (Sections 17.0 and 18.0) summarizes the 15 scenarios examined during Phase 2.

The Phase 2 scenarios suggest that air temperatures across the Basin will increase in future. Snowpacks will decline and melt earlier, and spring snowmelt will generate smaller amounts of runoff. The summer low flow period will likely become extended, threatening both aquatic ecosystems and human demands for water. As noted earlier, water suppliers dependent on stored water in upland reservoirs for human and environmental use later in summer should protect their opportunities to expand storage. In successive drought years, Okanagan Lake could drop below its normal operating range, and threaten the ability to release water to Okanagan River. The scenarios suggest that a significant reduction in the impacts of climate change and population growth can be achieved through proven water conservation measures.

Additional scenarios should be examined to more fully explore the range of possible changes that could occur in response to the key drivers of change: climate, population, expansion of the agricultural land base, changes to the upland forest, and use of water conservation measures.

Despite the achievement of developing three custom computer models for simulating water supply and demand in the Okanagan Basin, there is substantial room for improvement in all three models using more and better scientific data (for all the water balance components, including climate), and more and better information on existing water management practices.

NEXT STEPS

It is important to communicate Phase 2 results to stakeholders and the public within the Basin, and to extend the scientific and modelling work completed in Phase 2. Accordingly, a proposed Phase 3 work program has been developed, which can be subdivided into four components:

- Communication with stakeholders;
- Maintaining the databases and models, and using them to examine other scenarios;
- Turning results into specific policy recommendations; and
- Updating and improving the data and models.

These four programs are described in Section 20.0 of this Summary Report.

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LIST OF APPENDICES

The Summary Report includes electronic copies of each Appendix.

LIST OF ATTACHMENTS

The Summary Report includes electronic copies of each Attachment.

LIST OF TABLES

LIST OF FIGURES

PART ONE - BACKGROUND

1.0 INTRODUCTION

Overview of the Basin

The Okanagan Basin is located in south-central British Columbia. The Basin consists of a main north-south trending valley occupied by five major lakes, the Okanagan River, and several major population centres; and is surrounded on both sides by higher elevation plateaus. It is an arid region, with average annual precipitation of about 300 – 400 mm along the main valley bottom, and 800 – 1,000 mm at the highest elevations of the surrounding plateaus. In addition, there is high variation in the amount of precipitation received each year – some years are very dry and some are much wetter than average. Much of the incoming precipitation is lost to evapotranspiration (direct evaporation from lakes, and transpiration from plants and trees). The Basin had a population of 294,000 in 2006, according to the Canada Census, and is reported to have the highest ratio of population to water supply of any basin in Canada. The population continues to grow.

Much of the water used in the Basin by humans is provided by the melting of the winter snowpack that forms each year on the high elevation plateaus surrounding the main valley. Some of this annual spring snowmelt infiltrates into the ground to become groundwater, and some flows down tributary creeks into the main valley lakes. The flow in these tributary streams drops to low levels in summer (after the upper level snow has finished melting), and stays low until the following spring. Because the climate is arid, agricultural crops, golf courses, lawns, and other outdoor vegetation depend on irrigation to supplement natural precipitation. Humans require water for other uses as well (e.g. domestic and industrial). Accordingly, diversion structures have been constructed to extract water from creeks to supply water to distribution systems throughout the valley. However, irrigation continues well beyond the time when the high elevation winter snowpack has finished melting; and humans require water year-round for other purposes. Therefore, the development of communities and agriculture in the Basin has depended on capturing and storing a portion of the annual snowmelt in upper elevation reservoirs, and staging the release of that stored water to meet demands that are spread out over the year. The high elevation dams and reservoirs are owned and operated by a multitude of water suppliers, and are operated to serve the needs of the individual owners and operators. The main valley lakes are each controlled by dams which are operated by the B.C. Ministry of Environment (MOE) to serve multiple purposes - including flood prevention, aquatic ecosystem sustainability, intake submergence, navigation, and recreation. Water levels on these main lakes reflect the rate of water input to them by creeks and groundwater, and also reflect the rate of outflow and evaporation.

In addition to tributary creeks, other key water sources include the main valley lakes and groundwater.

The most recent Basin-wide analysis of water supply and demand took place in 1974 (the 1974 Okanagan Basin Study Report - Consultative Board, 1974). Since then there have been many local studies of water supply and forecasts of demand made by various water suppliers, but a Basin-wide assessment has not been repeated. Meanwhile, there is increasing concern about the sustainability of the water supply. Water shortages have recently occurred in some parts of the Basin (e.g. in 2003 in Trout Creek), which has led to conflicts between water users (e.g. between communities, fisheries interests, and irrigators). Previous studies in parts of the Basin have suggested that in future, continuing climate change will likely reduce water supply, but increase water use. Other studies have indicated that summers could become longer, hotter and drier, which would increase the demand for water to be supplied for irrigation, even as the climate makes those water supplies smaller and less reliable. If realized, lower and more variable streamflows will threaten aquatic ecosystems and species, and the ability to satisfy the needs of human water users. The MOE, which is responsible for the licensing of surface water in the Province of British Columbia (groundwater use is not licensed), has temporarily suspended the issuing of new surface water licences in the Basin, unless those licences are supported by upper elevation storage.

Uncertainty about the water remaining for allocation, combined with continuing population growth, the need to protect aquatic ecosystems and maintain a reliable water supply for a sustainable agricultural economy, and the potential for climate variability and climate change highlight the challenges to water management in the Okanagan Basin, and reinforce the need to update the 1974 Basin-wide water supply and demand estimates.

Overview of the Project

Against this backdrop, in 2004 the MOE initiated the Okanagan Water Supply and Demand Project. The Project is a multi-phase work program focussed on improving the state of knowledge of the water resources of the Okanagan Basin. In particular, MOE identified the need for a credible scientific study to establish current water availability, water use, and future potential influences on supply and demand. The “Basin” is defined as the watershed of the Okanagan River upstream of Zozel Dam near the outlet of Osoyoos Lake. Zozel Dam is located in Washington State, and controls the outflow from Osoyoos Lake. The lake is operated to maintain lake levels within certain ranges according to protocols established by the Osoyoos Lake Board of Control under the authority of the International Joint Commission, but is not operated to provide specified flows into the United States. The Basin covers 8,024 km^2, all but 73 km^2 of which is located in Canada.

Phase 1 of the Project was completed in 2005, and Phase 2 is now complete. Phase 2 was led by the Okanagan Basin Water Board in partnership with the MOE, and completed in collaboration with a large number of federal and provincial agencies and the Okanagan Nation Alliance.

The Phase 1 study (Summit 2005) identified and evaluated the information available for a comprehensive Basin-wide analysis of water supply and demand in the Basin, and identified data gaps. It also proposed a strategy for completing Phase 2. The Phase 1 report is available on the Okanagan Basin Water Board website: http://www.obwb.ca/104/.

The goals of Phase 2 of the Project were to:

- determine the **current** supply of and demand for water throughout the Okanagan Basin;
- develop or select a model (or models) that computes water demand, estimates natural hydrology and groundwater conditions, and routes water from tributaries into main valley lakes and downstream into Osoyoos Lake - that can be used to examine water management alternatives; and
- identify potential **future** changes in both supply and demand and run the model (or models) for several realistic future scenarios.

A Steering Committee with representation from the major funders and other agencies guided the Project. A technical Working Group of about 20 technical experts from various agencies was responsible for Project implementation. A Project Manager and Technical Advisor provided project management services to help the Working Group manage the Phase 2 work program.

A Communication Plan was developed and implemented during Phase 2 of the Project to ensure that First Nations, elected officials, local water managers, and the public were informed about the technical aspects of the study, the results, and the science used to support the recommendations.

Phase 2 was not designed to examine other aspects of water resource than supply and demand, except for a desktop examination of instream flow needs for aquatic species inhabiting tributary streams and lakes in the Basin. In addition, although the results are intended to support a variety of water management decisions, the Phase 2 work and this report are primarily technical in nature.

The Phase 2 work has made optimal use of the existing information base. However, the information used has strengths and weaknesses. Each component of Phase 2 encountered data limitations that restrict the reliability of the conclusions that can be drawn from that information. The findings, conclusions, and recommendations expressed in this report are appropriate for the level of information available. However, the reliability of those findings, conclusions and recommendations would be improved if more and better data were available - the report makes specific recommendations for obtaining such additional data.

Future phases of the Project will extend the Phase 2 work. The Phase 2 Working Group has recommended that Phase 3 focus on:

- Turning results into policy;
- Use and maintenance of the databases and models developed during Phase 2; and
- Updating and improving the Phase 2 data and models.

Specific recommendations for achieving these objectives are provided later in this report.

Organization of this Summary Report

This report summarizes the work completed during Phase 2 of the Project. It is organized into five parts. Part One (Background) provides information necessary to understand the work completed within Phase 2 of the Project. Part Two (Data and Databases) describes the datasets and databases developed during Phase 2, and summarizes the major technical studies. The major technical studies are reproduced in their entirety in electronic form in the Appendices which follow the main report text. Part Three (Models) summarizes the three main models developed during Phase 2: the Okanagan Water Demand Model, the Okanagan Basin Hydrology Model, and the Okanagan Basin Water Accounting Model. These models were developed and calibrated based on the technical studies summarized in Part Two. Part Four (Scenarios) describes the rationale for scenario selection, the 15 chosen scenarios, and scenario outputs. Part Five (Conclusions and Recommendations) lists the major findings of Phase 2 and recommends the next steps for subsequent phases of the Water Supply and Demand Project.

A glossary of technical terms used in the report is provided in Section 21.0, and a list of the acronyms used is provided in Section 22.0.

2.0 PHASE 2 OVERVIEW

This section of the Summary Report provides an overview of Phase 2.

Deliverables

Technical Reports

The core of Phase 2 is the data and information collected by component water supply and demand studies. The following technical reports were produced:

- A User Needs Assessment Report (Appendix A);
- A series of reports on specific aspects of water supply and demand in the Okanagan (these studies are reproduced in electronic form in the Appendices to this Summary Report); and
- A Summary Report (this report) that summarizes the Phase 2 work.

The User Needs Assessment (UNA) was one of the first tasks of Phase 2. It was completed early in the program to capture the input of key water users and reflect their wishes in the design of the work program. The report (ESSA 2007), reproduced in Appendix A, clarified and prioritized user needs, and identified 13 functional requirements for Phase 2. The UNA process also highlighted the challenges of managing the enormous amount of data to be generated; of finding a way to make different models "talk to each other"; and of ensuring ready access to and sharing of this data and knowledge with water authorities and the public, so that it can be easily incorporated into water decision-making.

Technical reports on several independent studies were published during Phase 2. These studies were undertaken to fill information gaps identified during Phase 1, and to provide information required to calibrate the models developed during Phase 2. The following studies were completed and are provided in the Appendices to this Summary Report:

- A groundwater assessment and development of a conceptual groundwater model for the Basin (Section 7.0 and Appendices D and E);
- A surface water study (Section 9.0 and Appendix G);
- An assessment of current water use within the Basin (Section 6.0 and Appendix C);
- A study of evaporation models useful for estimating evaporation from Okanagan Lakes (Section 8.0 and Appendix F); and
- An assessment of instream flow needs for aquatic and other organisms in the Okanagan Basin (Section 10.0 and Appendix H).

New Demand, Supply, and Water Balance Models

Three models were developed during Phase 2:

- The Okanagan Water Demand Model (Section 14.0 and Appendix I);
- The Okanagan Basin Hydrology Model (Section 15.0 and Appendix J); and
- The Okanagan Basin Water Accounting Model (Section 16.0 and Appendix J).

Datasets and Databases

Three databases and a series of climate datasets were developed to support the Phase 2 work:

- The OkWater database (Section 11.0 and Appendix K);
- The Water Demand GIS database (Section 14.0);
- The Okanagan Water Information Reference Library database (Section 12.0 and Appendix L); and
- Gridded climate datasets (Section 5.0 and Appendix N).

The OkWater database is the repository and management tool for technical Project data. It is the bridge between the Project models, and hosts data required by a web-based reporting tool, which is being developed to display results of the Phase 2 work to interested parties over the Internet. Its first function was to host the time series outputs and other data produced by the Project's technical studies, and provide that information to the Okanagan Basin Hydrology Model, which was calibrated using that information. The OkWater database also hosts the output from the Okanagan Water Demand Model, which is used to estimate water use throughout the Basin. That data is delivered from the OkWater database to the Okanagan Basin Water Accounting Model, which calculates the effects of water management on natural flows and lake levels. The Accounting Model results are delivered back to the OkWater database, where they can be viewed by users over the Internet through the web-based reporting tool.

The Water Demand GIS database was developed by the Ministry of Agriculture and Lands (MAL) and Agriculture and Agri-Food Canada (AAFC), and houses all the information needed by the Okanagan Water Demand Model. It contains detailed cadastral maps, as well as maps of soil, irrigation systems, and crop types throughout the developed areas of the Okanagan Basin (areas where irrigation is used). The Demand database also has detailed topographical information (elevation, slope, and aspect) and climate data (daily maximum and minimum temperature and daily precipitation). With this data, the model is able to compute daily irrigation requirements for field-sized parcels of land throughout the developed area of the Basin.

The Okanagan Water Information Reference Library database includes summary information on all the source documents used in Phases 1 and 2 of the Project. A user can search the database for relevant documents using several different information classifications (e.g. subject matter or geographic location). Once identified, summary information on the source document is displayed, and a user can obtain the original document through a hyperlink.

Communication with Stakeholders

The Phase 2 work is scientifically specialized, but the results are intended for use by planners, developers, decision-makers, and others. The Project team has undertaken to provide results in a form that can be understood by a broad audience. Communication has taken the form of:

- A series of presentations to local governments, First Nations, and stakeholders explaining the Project and its results;
- Media releases;
- Presentations at conferences; and
- Development of a web-based reporting tool to provide model output and other information on the current state of water supply and demand at multiple locations within the Okanagan, and on the likely future influences of population growth, climate change, land use change, and other factors.

Project Management and Work Program

The Phase 2 Project Management team included several committees and individuals, each with well-defined roles and responsibilities (Figure 2.1). The individuals who served on the Project team are listed in Appendix M. The Phase 2 work program and schedule is outlined in Table 2.1.

Funding for Phase 2 was obtained from a number of sources:

- Province of British Columbia;
- Okanagan Basin Water Board; and
- Government of Canada (Gas Tax rebate program, Natural Resources Canada, the Canada-B.C. Water Supply Expansion Program).

In-kind contributions of time and expenses were made by all the agencies and organizations listed in Appendix M.

Table 2.1 Phase 2 work program and schedule

Activity	Dates
Establish Steering Committee and Working Group, and complete initial strategic discussions	June - July 2006
Hire a Project Manager and develop detailed work plan and cost estimate	January - April 2007
Conduct a User Needs Assessment	February - April 2007
Conduct technical studies of groundwater, water use, hydrology, lake evaporation, and instream flow needs – needed to calibrate the demand model and the supply model.	May 2007 – October 2009
Update and maintain the Information Database created in Phase 1.	May 2007 – March 2010
Develop a data warehouse (the OkWater database) to house data provided by the technical studies, and results generated by the Project models.	March - August 2007
Extend the MAL/AAFC Agricultural Demand Model by adding non-crop irrigation and indoor water use to create the Okanagan Water Demand Model.	May 2007 – August 2009
Choose an appropriate supply model – the MikeSHE-based Okanagan Basin Water Accounting Model (and its main sub-model, the Okanagan Basin Hydrology Model).	April 2008
Calibrate the chosen models.	April 2008 – November 2009
Choose and run scenarios to illustrate the effects of different future conditions on water supply and demand.	June 2008 – February 2010
Communicate to public and stakeholders.	February 2007 – March 2010
Study Reporting: create stand-alone reports for each major study component; a Summary Report document, and a web-based reporting tool.	December 2007 – June 2010

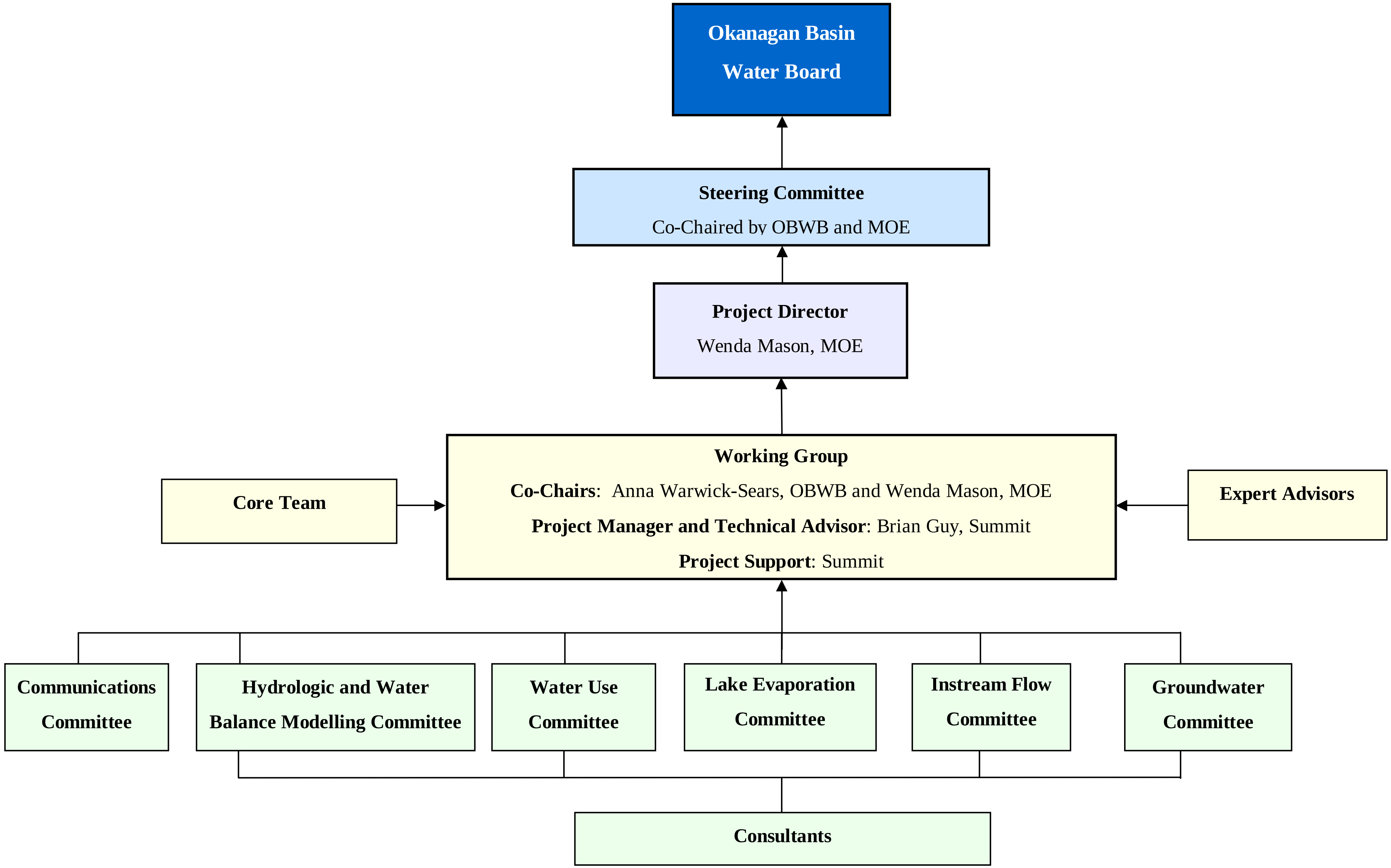

Figure 2.1 Phase 2 organization chart.

PART TWO – DATA AND DATABASES

3.0 PART TWO OVERVIEW

Part Two of the Summary Report summarizes the various datasets, databases, and technical studies completed during Phase 2 of the Okanagan Water Supply and Demand Project. Figure 3.1 is a schematic diagram that illustrates the various studies and the links between them.

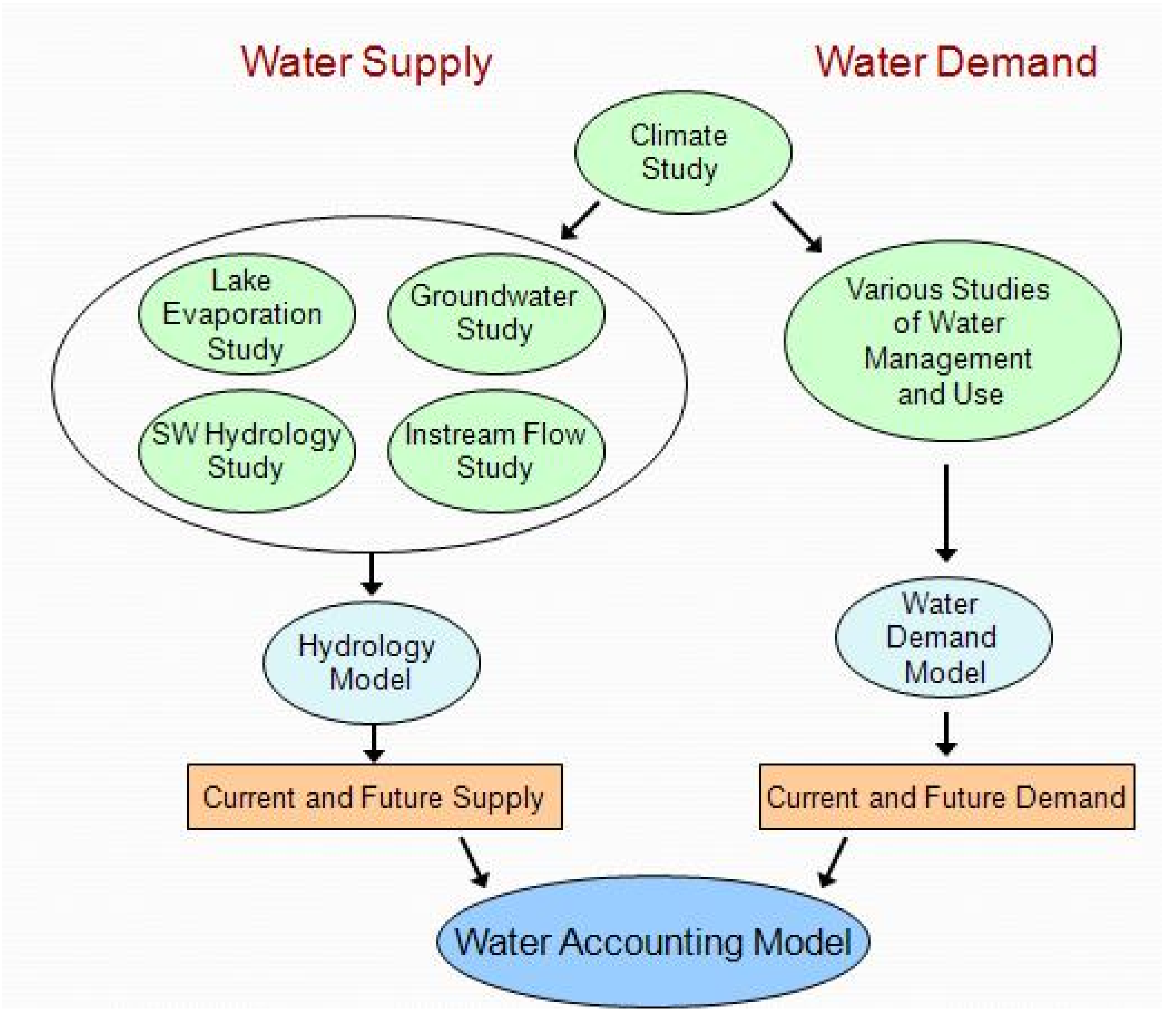

Figure 3.1 Interactions between the various Phase 2 technical studies and models.

4.0 BASIC TECHNICAL CONCEPTS

Three map layers were developed during Phase 2:

- A surface water layer (Attachment 1);
- A groundwater layer (Attachment 2) ; and
- A water use area layer (Attachment 3).

A separate climate layer consisting of a 500 m by 500 m grid was developed by Environment Canada (EC), AAFC, and the University of Lethbridge (U. Leth.) prior to the start of Phase 2 for water demand modelling and other applications. The development of the climate datasets is explained in Section 5.0. In addition to these layers, the Okanagan Water Demand Model has used several other data layers covering the developed areas of the Basin, including soil, cadastral, irrigation systems, and crop types. These layers are described in Section 14.0.

The surface water layer consists of 81 nodes (i.e. "points-of-interest) which are tributaries, residual land areas, mainstem lakes (i.e. Kalamalka, Okanagan, Skaha, Vaseaux, and Osoyoos), and mainstem Okanagan River locations.

The groundwater layer consists of 324 aquifers underlying the Okanagan Basin - 245 bedrock aquifers and 79 alluvial aquifers. The bedrock aquifers are found in the upper elevation areas of the Basin, and the alluvial aquifers are found along the main valley, and along the larger tributary valleys.

Water extracted from surface sources and groundwater wells is used for many purposes. Attachment 3 is a map of water use areas in the Basin. Each of these areas is linked to one or more water sources (surface or groundwater). After calculating the water used on each water use area, the Okanagan Water Demand Model calculates the required withdrawal from each water source to satisfy that demand.

The various possible ways in which water can move on the surface and below ground surface within the Basin are illustrated schematically on Figure 2.1 in Appendix B.

The scientific studies undertaken in support of the Project were designed to:

- Provide the current (1996-2006) and best available information on water resources in the Basin; and
- Provide relevant information to calibrate the Okanagan Basin Hydrology Model and the Okanagan Basin Water Accounting Model.

The 1996-2006 (11-year) period was selected as the “base case” for three reasons:

- It reasonably reflects the current population, climate, land use, irrigation practices, and water distribution systems;
- It includes three Canada Census years (1996, 2001, and 2006); and
- It specifically includes the year 2006, which represents a reasonably average year for water supply and use for which data from water suppliers was available.

The Census data facilitated analyses of per capita water use during the water use studies.

The Okanagan Basin Hydrology Model and the Okanagan Basin Water Accounting Model were calibrated using 1996 – 2006 data. Since this period includes a mix of average years, drier than average years, and wetter than average years, it is ideal for model calibration over a wide range of natural conditions.

5.0 DEVELOPMENT OF CLIMATE DATA SETS

A climate layer consisting of a 500 m by 500 m grid was developed by EC, AAFC, and U. Leth. for use in water demand modelling and other applications (Appendix N). Estimates of daily maximum and minimum temperature and daily precipitation have been generated for each cell in this climate grid using a number of methods. First, for the 1996-2006 calibration period, a network of 154 climate stations provided observed information to allow Environment Canada to populate the grid with daily maximum temperature, daily minimum temperature, and daily precipitation values. This dataset contains the best estimates of actual climate data available, and was used to calibrate both the Okanagan Water Demand Model and the Okanagan Basin Hydrology Model for the 1996 – 2006 period. Second, using the outputs of six General Circulation Models (GCMs), with outputs downscaled to the Okanagan climate grid, daily values of temperature and precipitation for each day from 1961 to 2100 were estimated.

The Working Group chose to use the Canadian General Circulation Model Version 2 (CGCM2) model (with the A2 CO_2 emission scenario) for examining the impact of future climates on Okanagan water resources (Sections 17.0 and 18.0). To ensure a clear comparison between future climates and the 1996-2006 calibration period climate, precipitation and temperature in the 1996-2006 “observed” dataset were compared with the 1996-2006 CGCM2A2-generated dataset. Differences in means and variances were corrected (see Appendix N), so that clear comparisons can be made between scenario results and 1996-2006 results.

6.0 WATER MANAGEMENT AND USE

Overview

In the Okanagan Basin water is extracted from many streams, lakes, and groundwater aquifers to support a growing population (approximately 294,000 in 2006) and a multitude of water-reliant activities. A number of investigations were completed during Phase 2 to understand how water is used and managed throughout the Basin. These investigations (which are documented in Appendix C), supported the development of the Okanagan Water Demand Model (the model is described Section 14.0). The output of that model provides an updated picture of how much water is presently[1] extracted from water sources and used in the Basin. A summary of the key technical findings is provided in this section.

Annual water balances

The overall water balance for the Basin is shown in Figure 6.1. This figure summarizes the information presented in the present section of the report, as well as information presented in subsequent sections. The values on the figure are annual totals, but they are averaged over time for the period 1996-2006, and across the entire area of the Basin. The figure does not indicate the variability which characterizes both water supply and water demand. Decision-making must consider the seasonal variability in both supply and demand, the differences that exist from place to place within the Basin, and the annual variability in both supply and demand.

The average annual water balance for Okanagan Lake is shown in Figure 6.2. As for Figure 6.1, this figure summarizes information presented in the present section of the report, as well as information presented in later sections.

Water rights for extraction and use of water in the Okanagan Basin

Within the Basin there are 101 known water suppliers and a total of nearly 4,000 active water licences[2] which have been issued by the Province to store or use surface water[3]. Approximately 443,000 megalitres[4] (ML) of surface water is licensed annually for offstream use while 351,000 ML is licensed for in-stream (conservation) and other "non-consumptive"

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[1] A period between 1996 and 2006 was analyzed to define current conditions.

[2] Water licences issued by the Province identify the volume of water that suppliers or users are legally entitled to extract from surface water sources for beneficial use. The volume of water allocated with water licences does not necessarily indicate the volume of water *actually* extracted and used.

[3] Surface water includes water from streams, lakes, and springs. It does not include groundwater, which currently does not require licensing.

[4] 1 megalitre (ML) is equal to 1 dam^3 (cubic decametre) or 1,000,000 litres. For reference, the volume of an Olympic-sized swimming pool is 2.5 ML, while the approximate volumes for the main lakes in the Okanagan Basin are as follows: Ellison (Duck) Lake (5,400 ML), Vaseux Lake (18,000 ML), Wood Lake (157,000 ML), Osoyoos Lake (325,000 ML), Skaha Lake (500,000 ML), Kalamalka Lake (1,560,000 ML), and Okanagan Lake (24,600,000 ML).

uses[5]. These uses are supported by 163,000 ML of water licensed for storage, typically within upland reservoirs. The operation of storage reservoirs is critical to the management of surface water in the Basin since most surface runoff occurs during a short period each spring when snowmelt occurs. However, most demand for water occurs later in the summer. The 36 major storage reservoirs in the Basin have a combined capacity of 133,000 ML, or about 82% of the total volume licensed for storage.

Volume of water actually used in the Okanagan Basin

Based on the technical studies and on the Okanagan Water Demand Model, the average annual water use in the Basin totals an estimated 219,000 ML. However, between 1996 and 2006, total annual water use has ranged from about 187,000 ML in 1997 (a relatively wet year) to 247,000 ML in 2003 (an extremely dry year) (Figure 6.3).

Sources of Water in the Okanagan Basin

Of the 219,000 ML of water actually used annually in the Basin, an estimated 147,000 ML (67%) is obtained from surface sources in the Basin (Figure 6.4). The rate of surface water extraction varies throughout the year in response to demands by water users. During the late fall and winter, when irrigation is not occurring, surface water extraction in the Basin is steady at about 500 ML/week. However, with the onset of irrigation in spring, water extraction rates increase until they peak in late July to mid-August at about 8,500 to 10,000 ML/week. While water is extracted from many locations in the Basin, about 32% of the total surface water used is obtained from the three (3) largest sources: Okanagan Lake, Mission Creek and Kalamalka/Wood Lake (Table 9.2 in Appendix C).

Although less groundwater than surface water is used, groundwater is becoming an increasingly important source of water. There are now 23 known water suppliers (with 74 active wells) that pump a combined total of 49,000 ML of groundwater each year in the Basin. This represents 22% of the total water use in the Basin (Figure 6.4). As with surface water, the rates of groundwater extraction vary with demand through the year, from about 100 ML/week in late fall and winter to about 3,000 to 4,000 ML/week in late-summer.

There are eight (8) known water suppliers that import water from outside the Basin to supplement existing water supplies (Table 7.1 in Appendix C). On average, the volume of water imported annually is approximately 17,000 ML, or 8% of the total use in the Basin (Figure 6.4).

[5] See Table 5.2 in Appendix C for a complete description of licensed end-uses.

Several water suppliers (including Greater Vernon Water, Town of Oliver, City of Armstrong, and Town of Osoyoos) are supplementing their water supply by using WTP effluent to irrigate agricultural lands. On average between 1996 and 2006, 7,000 ML of this “recycled” wastewater was used for this purpose each year, which represents 3% of the total water use in the Basin.

The study evaluated two means by which humans “return” water to groundwater: the operation of septic systems and over-irrigation. The latter is also known as *deep percolation*, and represents a volume of water that is not used by vegetation but rather infiltrates beyond the root zone to groundwater. On average, septic systems in the Basin “return” about 10,000 ML of water per year to groundwater, while deep percolation supplies about 25,000 ML per year.

Four (4) of the ten (10) known wastewater treatment plants (WTPs) in the Basin (namely City of Kelowna, City of Penticton, District of West Kelowna, and District of Summerland) discharge or “return” water to surface waterbodies, namely Okanagan Lake and Okanagan River. Combined, these four (4) WTPs discharge a total of 17,000 ML of effluent on average each year. Approximately 75% of this volume is discharged to Okanagan Lake while 25% is discharged to Okanagan River near Penticton.

Distribution of water between end-uses in the Okanagan Basin

Year-to-year distribution of water use among the end-uses is relatively consistent, with the greatest proportion (55%) typically used for agriculture (Figure 6.5). This is followed by domestic outdoor (24%), domestic indoor (7%), golf courses (5%), commercial (4%), parks and open spaces (2%), industrial (2%) and institutional (1%) water use.

On average, 120,000 ML (or 55% of the total Basin water use) is used to irrigate an agricultural area in the Basin of approximately 18,300 ha. This represents a Basin-wide average application of 660 mm of water over the irrigation season. Locally, however water application rates vary by crop, irrigation system, soil and climate.

Within the Basin there are 41 known golf courses that irrigate an estimated 1,060 ha of land. An estimated total of 10,000 ML of water is typically used by golf courses during the irrigation season. This represents an average application of 960 mm per season. Irrigated park lands and other “green” spaces in the Basin, totalling approximately 590 ha require an additional 5,000 ML each irrigation season. This equates to an average application of 920 mm per season.

In the Basin, total domestic water use averages 68,000 ML per year, or 31% of the total water use in the Basin (Figure 6.5). Approximately 22% of this total is used indoors, while 78% is used outdoors. Between 1996 and 2006, the average year-round combined indoor and outdoor water use in the Basin was 675 L/person/day. Indoor use is relatively constant throughout the year at 150 L/person/day. Outdoor use is nearly zero for 6 months of the year, but averages over 1,000 L/person/day in the other 6 months.

Institutional, commercial, and industrial (ICI) water users include schools, hospitals, care facilities, businesses, and industry. In most cases, the main use of water is for indoor domestic-type purposes (e.g. drinking, toilet flushing, and washing). Over 5,000 ICI users were identified in the Basin, together using an average of 15,000 ML (or 7% of the Basin total) annually. Of this total, approximately 2,000 ML is associated with institutional users, 8,000 ML is associated with commercial users, and 5,000 ML is associated with industry (Figure 6.5).

Losses from the managed system and "unaccounted for water" (UFW) include water lost to deep percolation through over-watering, irrigation system inefficiencies, leakage in the water suppliers' distribution systems or at the point-of-use, and water theft. The term "loss" is used relative to the managed system – the water is not lost from the groundwater system or the Basin as a whole. Based on limited records, distribution system losses for all end-use categories were assumed to be 5% of the total volumes conveyed through water supplier systems. Losses are included in all the quoted water use values above. Total losses from all end-uses average an estimated 51,000 ML.

Summary

These investigations of water use and management are the result of a major effort to understand current water management and use patterns throughout the Basin. This summary provides Basin-wide information, and information for specific areas is provided in Appendix C.

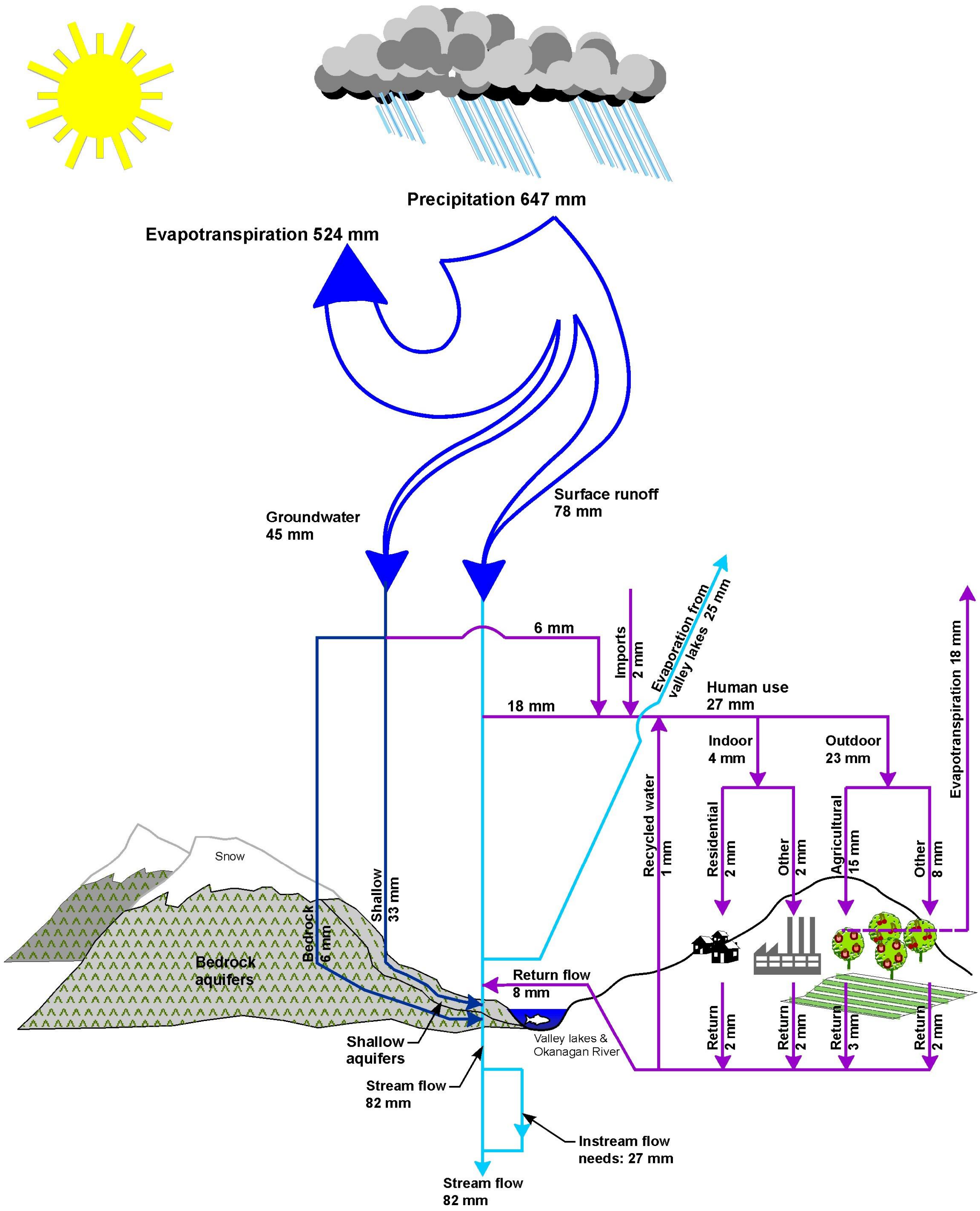

Figure 6.1 Average annual water balance for the Okanagan Basin.

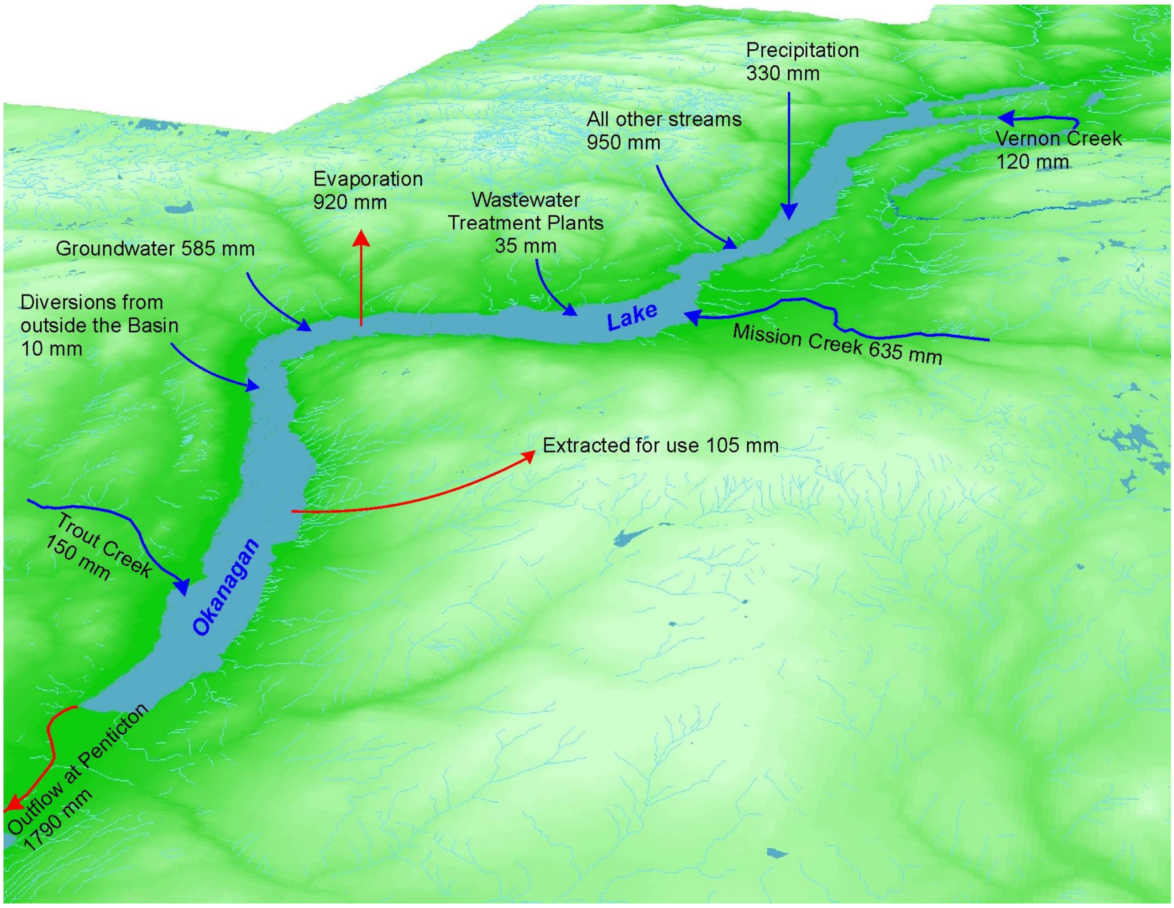

Figure 6.2 Average annual water balance for Okanagan Lake.

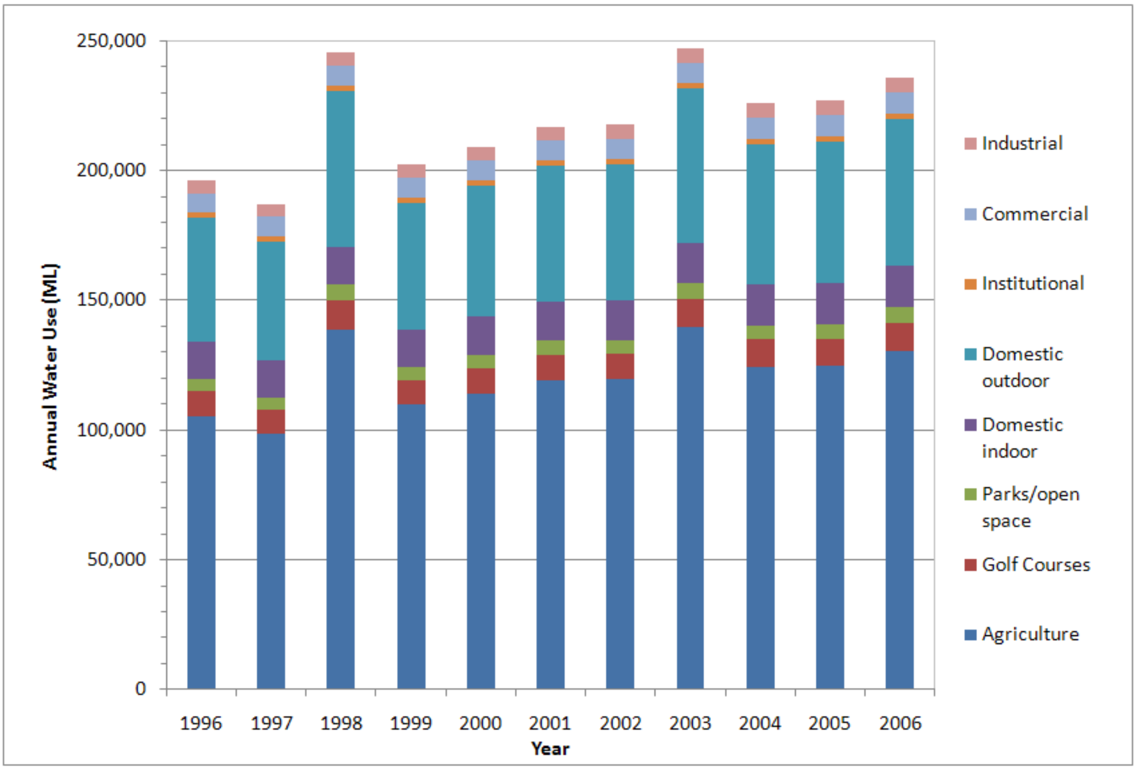

Figure 6.3 Estimated volume of water used in the Okanagan Basin between 1996 and 2006 by end-use.

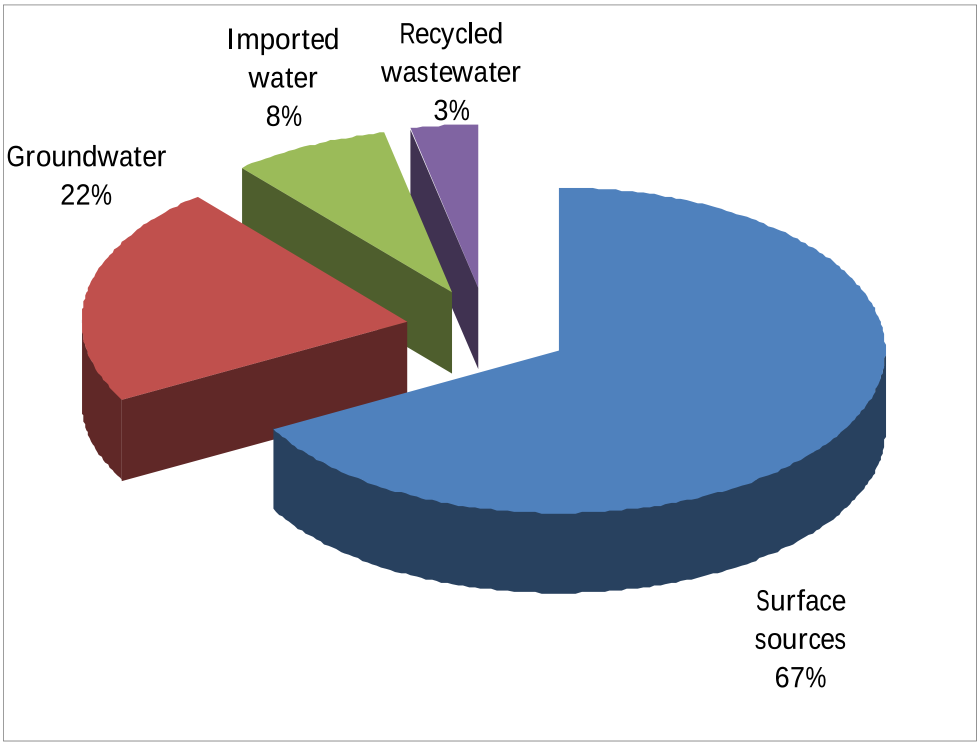

Figure 6.4 Typical distribution of total water use in the Okanagan Basin by source (based on data for 1996 to 2006).

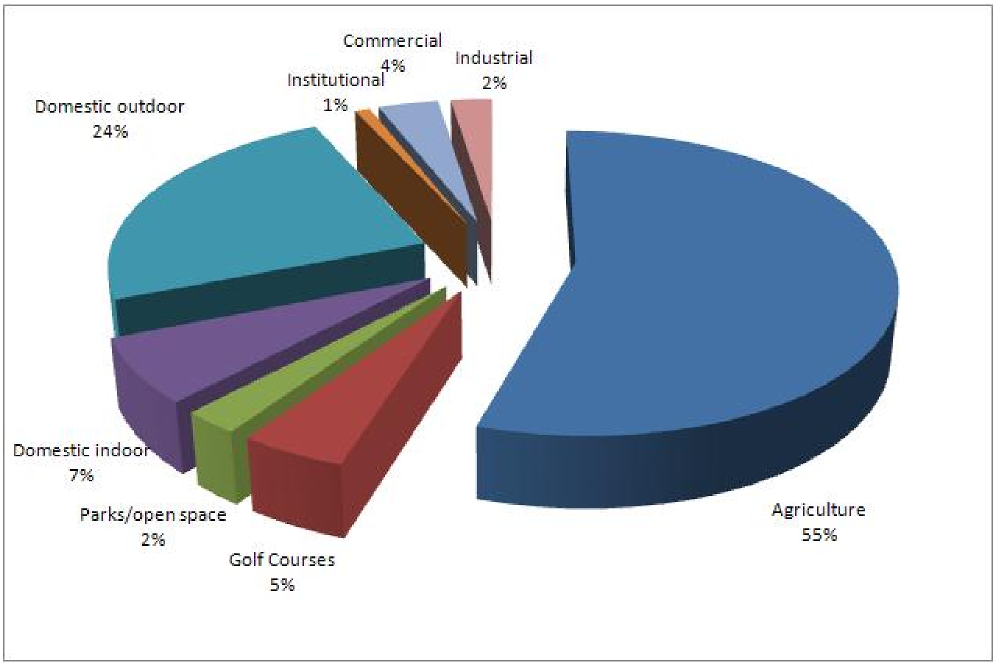

Figure 6.5 Typical distribution of water use amongst water users.

7.0 GROUNDWATER RESOURCES

Introduction

Three groundwater study objectives were met during Phase 2 - they are listed below along with the primary deliverables:

Groundwater Study Objectives	Main Deliverable(s) and Authors
1. To develop a comprehensive State-of-the-Basin report to synthesize the current state of knowledge of groundwater in the Okanagan Basin and document sources of information on groundwater.	*Groundwater and Hydrogeological Conditions in the Okanagan Basin of British Columbia – a State-of-the-Basin report*. **Appendix D**
2. To develop as thorough a series of conceptual models of the groundwater systems throughout the Okanagan Basin as is possible with existing information.	*Groundwater Study Objectives 2 and 3: Phase 2 Okanagan Water Supply and Demand Project – Final Report* **Appendix E**
3. To represent Okanagan groundwater systems in the format required by a water balance model of the basin.	Completed 1996-2006 monthly water balances for 79 unconsolidated aquifers. **Appendix K**

This summary focusses on the conceptual groundwater flow model developed in Appendix E. That model was based primarily on the information identified in Appendix D.

The methodology developed for the water balance modelling used a spreadsheet tool custom-designed for this Project (Groundwater Balance Analysis Tool - GWBAT). The water balance (GWBAT) model is based on upland areas recharging valley-bottom aquifers. The concept underlying the model is that a significant portion of the recharge in the upland areas of the Basin reports to a shallow bedrock flow system and that this flow, along with infiltration of some streamflow along the edges of the Okanagan Valley is conveyed to the Valley bottom unconsolidated aquifers.

Two upland groundwater flow systems exist within the conceptual model: i) a shallow upland flow system consisting of relatively thin and localized surface deposits overlying weathered upper bedrock formations; and ii) flow through deeper-seated bedrock fractures. The model assumes that upland recharge mainly supplies the shallow upland aquifer zone, not the deeper zone. Groundwater within this system stays within the boundaries of the overlying surface catchment area, and is recharged, stored and discharged to lower-lying unconsolidated aquifers and streams on a timeframe of years to decades. The model assumes that groundwater flow patterns are determined by local surface topography.

Upland recharge to fracture-flow systems in deep-seated bedrock is thought to be small as a percentage of total groundwater recharge, but occurs across a broad area and over a very long timeframe (hundreds to thousands of years). The deep-seated system may hold large amounts of water in storage, but due to the physical constraints of deep-seated fracture flow much of this water remains in storage and moves through the system on a timeframe that far exceeds the weekly/monthly time steps of the water balance analysis. It is possible that higher-permeability geological structures such as faults and fracture zones may exist in the deep-seated bedrock flow system, but the basin-wide scale of this study does not provide sufficient resolution to identify and quantify such features.

Recharge from bedrock to the lower-lying unconsolidated aquifers is assumed to be constant, whereas recharge from stream losses to unconsolidated aquifers is seasonally variable and proportional to surface water runoff, with the majority occurring immediately following snowmelt-generated peak streamflows in spring. In general, annual water level fluctuations in representative observation wells in valley-bottom unconsolidated aquifers are relatively small, ranging from less than 1 m to about 2 m. Larger water level fluctuations may be observed near pumping wells and in upland areas.

A total of 79 distinct unconsolidated aquifers were identified (Attachment 2), located primarily in the valley bottom. Characteristics of these aquifers are described in Section 5.0 and Appendix III of the main groundwater report (Appendix E).

Three areas of the Basin contain connected aquifer systems of regional importance (Section 7.3 of Appendix E):

- North Okanagan: Coldstream-Vernon and Spallumcheen unconsolidated aquifers;
- Central Okanagan: Greater Kelowna aquifers; and
- South Okanagan: Vaseux Lake to Osoyoos Lake aquifers.

Detailed analysis was applied to each aquifer, and the resulting models are applicable to a Basin-scale estimation of groundwater balance. Different results can be expected from other studies conducted at the local, sub-basin or catchment scale. The information from the Phase 2 work provides a useful starting point for gathering the quantitative groundwater and hydrologic/hydrogeologic information that would be needed for a local-scale study.

Monthly water balances were computed for the 79 unconsolidated aquifers delineated in this study. The spreadsheet-based water balance tool (GWBAT) allows for the determination of water balances for individual aquifers based on an approximate analytical solution, rather than a complex numerical solution. The tool used data from several sources that form part of the Phase 2 work, including gridded climate data, regional surface water runoff data, calculated bedrock recharge values, predicted groundwater use, and predicted irrigation return flow. In addition, the groundwater study team developed estimates of stream loss, recharge, physical aquifer properties, and water table evaporation for selected aquifers.

The estimated mean annual flow (total discharge to the valley-bottom rivers/lakes) in all 79 unconsolidated aquifers for the 11-year period 1996-2006 is 943,000 ML/yr. The year 2003 had the lowest annual flow (928,000 ML), while the highest annual flow was 956,000 ML in 1997 and 2000. The difference between the largest and smallest estimated annual flow is only 28,000 ML.

The mean annual groundwater discharge into Okanagan Lake is estimated to be 296,000 ML (40 percent of mean annual (total) inflow to the Lake, as reported in the Surface Water Hydrology report (Appendix G)), with Aquifer 234 (Summerland) contributing approximately 25 percent of this amount. Based on the water balance results, it can be inferred that 92 percent of the mean annual groundwater flow to the Lake occurs through the unconsolidated systems (many of which receive recharge from the shallow bedrock flow system), with many of these systems surrounded by large catchments. By comparison, the 11-year mean annual groundwater discharge to Okanagan Lake, calculated in Appendix G is only 41,300 ML. This is only 5.7 percent of the mean annual lake inflow (compared with 40% as calculated in the groundwater study). That these two independent methods give such different results is a reflection of the quantity and quality of the available groundwater data; and different approaches to accounting for groundwater-surface water interaction (e.g. aquifers can contribute baseflow to streams and streams can act as sources of recharge to groundwater – different accounting methods will account for these source/sink terms differently and could result in some of the groundwater being accounted for as surface water and vice versa). The actual volume of groundwater discharge reporting to Okanagan Lake, on a long-term annual basis likely lies between the two estimates and should be refined on a smaller scale (i.e. within specific sub-basins) once better groundwater data, streamflow data and baseflow separation analysis are available to support more detailed groundwater-surface water accounting.

Figure 7.1 provides a summary assessment of groundwater aquifer recharge in the Okanagan Basin. It should be emphasized that the red areas (areas of minimal recharge) may contain significant volumes of groundwater stored in bedrock aquifers. However, natural recharge to such aquifers appears to be very low, and more detailed study is warranted in these areas before significant groundwater development occurs. Most of the bedrock aquifers surrounding the mainstem lakes are denoted red on Figure 7.1 and are recharge-limited. Further development of groundwater resources in these recharge limited areas may not prove sustainable.

Recommended investigations to improve understanding of groundwater resources (Section 9, Appendix E) include:

- Surface water-groundwater interaction assessments - collecting and mapping streamflow data in creeks crossing alluvial fans and monitoring water levels in aquifers near the creeks to identify and quantify areas where streams may be losing or gaining with respect to groundwater;
- Adding more provincial groundwater observation wells in aquifers currently not monitored;
- Conducting studies to confirm the conceptual model of groundwater flow in bedrock areas; and
- Refining evapotranspiration values as this affects upland aquifer recharge, which has a large influence on Valley-bottom groundwater balances.

Ultimately, (as more data become available) it may be possible to use more sophisticated modelling approaches than those used in this basin-scale analysis to develop or refine aquifer water balance estimates.

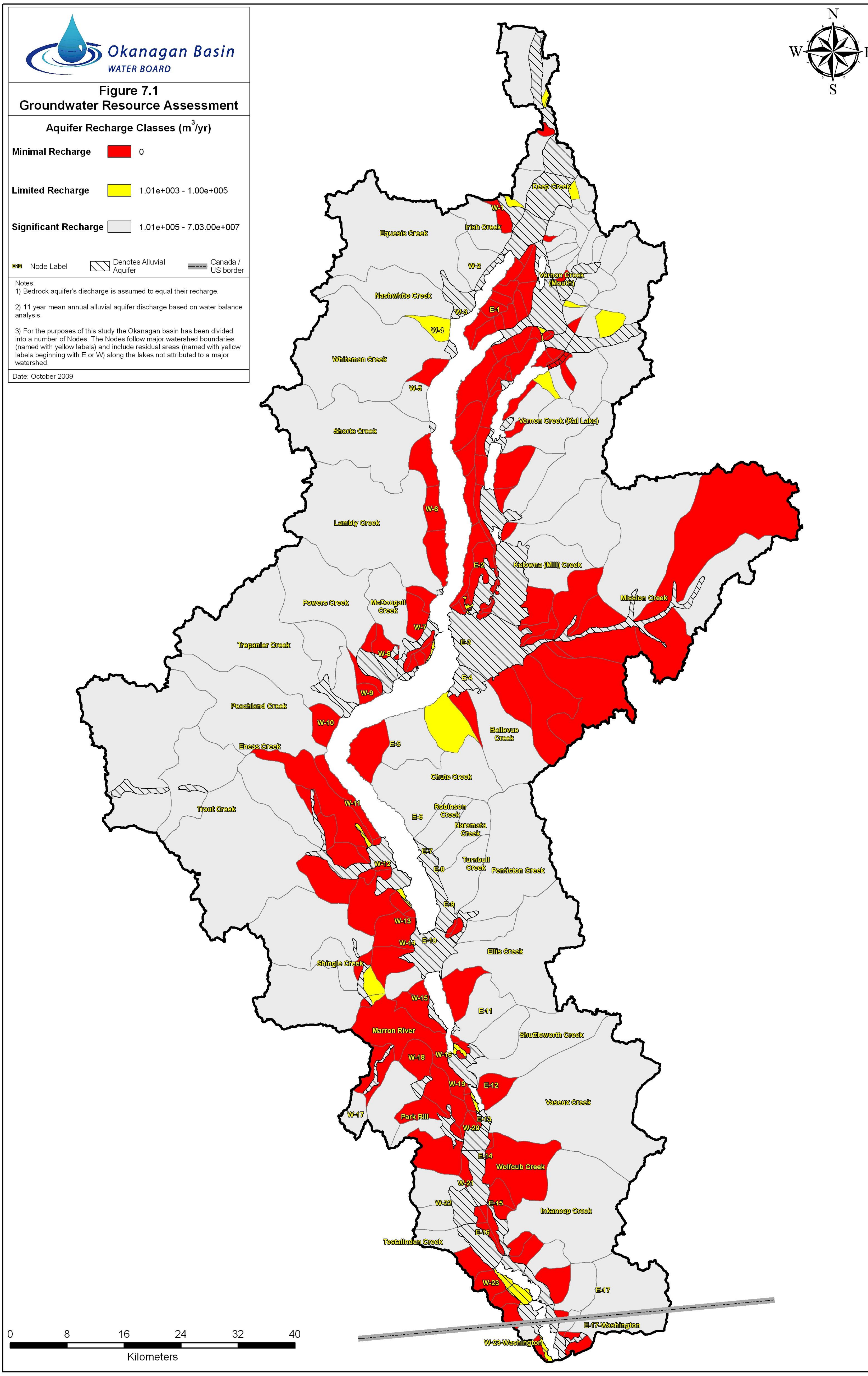

Figure 7.1 Groundwater resource assessment.

8.0 LAKE EVAPORATION

Little previous research has been done to quantify the amount of water lost to evaporation from the main valley lakes in the Okanagan. Accordingly, as part of this Project, Environment Canada undertook a study of lake evaporation, with the goal of identifying a model (or suite of models) most suitable for estimating lake evaporation in the Okanagan. Environment Canada also recommended a method for estimating evaporation from the upland lakes and reservoirs in the Basin. A summary of the Environment Canada report is presented in Appendix F1 of this Summary Report, and the full report is presented as Appendix F2.

Environment Canada evaluated 19 potentially relevant models for estimating lake evaporation in the Okanagan. According to these 19 models, estimates of average annual evaporation from Okanagan Lake range from 271 mm/year to 1,227 mm/year. Environment Canada stated a preference for the Trivett (1984) method, because the data used to make the evaporation estimates was considered slightly more reliable than the data underlying the other models. The Working Group chose the Penman-Monteith method for the purposes of Phase 2, because the advantage of slightly stronger data for the Trivett method was outweighed by problems integrating these results with other models used in Phase 2. The Penman-Monteith model is the same model used for estimating evapotranspiration in the Okanagan Water Demand Model. Lake evaporation estimates derived using the Penman-Monteith method are discussed in Appendix J, and summarized in Table 8.1. Average annual evaporation from the five mainstem lakes is 972 mm. For Kalamalka and Okanagan Lakes, the volume lost to evaporation is approximately 90% and 50%, respectively, of the net inflow to these lakes.

Table 8.1 Evaporation from the five Okanagan mainstem lakes.

Lake	Area (km^2)	Average annual evaporation (mm)	Average annual volume lost to evaporation (1996-2006) (ML)	Average annual net inflow (1996-2006) (ML)
Kalamalka	35.6	905	32,200	34,900
Okanagan	348	918	320,000	609,000
Skaha	20.1	963	19,400	651,000
Vaseaux	2.75	1008	2,800	660,000
Osoyoos	15	1068	16,000	696,000

Note: Evaporation values are estimated using the Penman-Monteith model. Average annual net inflow is taken from Appendix G.

Environment Canada also proposed a method for computing lake evaporation for upland reservoirs based on air temperature. The method was illustrated with evaporation data calculated using the Trivett method. One of the key advantages of this method is that daily air temperature data are available throughout the Basin from the 500 m by 500 m climate grid (Section 5.0). In future updates of the Phase 2 work, it is recommended that a simple air temperature-based method such as this be adopted for the purpose of estimating lake evaporation from upland reservoirs.

Further meteorological and limnological data collection and studies should be undertaken to determine the magnitude and timing of evaporation from Okanagan Lake and other mainstem lakes, and the upland Basin lakes. This would allow more detailed lake evaporation modelling and indicate the optimal model(s) for these lakes. With improved knowledge of evaporation volumes and timing, the accuracy of the water budget for the lakes and for the Basin as a whole would be improved.

9.0 SURFACE WATER RESOURCES

Introduction

The Surface Water Hydrology and Hydrologic Modelling Study consisted of three main parts. The overall objectives of Part One were to summarize existing information on surface water flows and develop a solid understanding of the natural surface water supply in the Okanagan Basin. The baseline data developed in Part One were used in Part Two (Appendix J) to calibrate and check the performance of the Okanagan Basin Hydrologic Model (OBHM) (Section 15.0). Once calibrated, the OBHM was used to run future water supply scenarios in Part Three in order to support the Okanagan Basin Water Accounting Model (Section 16.0).

This section summarizes the results of Part One – the "State of the Basin", which refers to the state of the current understanding of surface flows, climate and other biophysical factors that influence surface water flow, and the development of estimates of natural flow (i.e. streamflow in the absence of storage and diversions). Data were compiled and summarized for 81 points-of-interest or "nodes" in the Basin (Attachment 1) and naturalized flows were developed for 73 nodes for an 11-year period (1996-2006) that was adopted for modelling. This period is referred to as the "standard period" or the "calibration period" in this report. Flows were not naturalized for the mainstem lakes and the nodes on the Okanagan River because flows through the lakes and river have been regulated by dams and other control structures for many decades.

Methodology

Most Okanagan streams and lakes have been developed for surface water storage and withdrawals, thus the majority of streamflow records are considered *regulated* (i.e. affected by the storage and diversion of water). Determining natural streamflows using data from regulated watercourses is accomplished by a process of *streamflow naturalization* which removes the effects of human management from the data. Streamflow naturalization therefore requires information on water use and management, which was provided to the study team through the water management and use investigations (Section 6.0 and Appendix C). Streamflow estimates derived in this way are referred to as naturalized streamflows.

Although a reasonable number of streamflow measurement stations have existed or currently exist in the Basin, several streams have never had direct measurements of flow. For these locations, several estimation approaches for naturalized streamflow were used, depending on the available data.

Natural Streamflow Results and Patterns

The pattern of natural runoff in the Basin varies not only by elevation but also geographically in response to precipitation type and amount, evapotranspiration, and other factors such as soil type, vegetation, and the distribution of wetlands and ponds in catchment areas. For the 1996-2006 standard period, total natural streamflow from all tributaries and residual areas in the Okanagan Basin averaged 884,000 ML per year. If spread evenly over the entire Basin, this volume would cover the landscape to a depth of 117 mm. Approximately 83% of this total flowed into Okanagan Lake, while 17% of the total flowed into Okanagan River and the mainstem lakes downstream of Okanagan Lake. Upstream of Penticton, the runoff averages 130 mm, while downstream of Penticton, it averages 78 mm. Furthermore, runoff on the east side of the Basin tends to be higher than on the west side. This is because the prevailing winds are generally from the west – these winds are forced to ascend the east side of the valley, causing more precipitation on that side due to orographic effects. Total annual flow from the west side of the Okanagan Valley averaged approximately 371,000 ML over the 1996-2006 period (equivalent to 99 mm of runoff), while flow from the east side averaged 513,000 ML (or 134 mm of runoff).

Average annual discharge and runoff were calculated for the 1996-2006 standard period at each node, with averages presented in Table 5.3 and Figure 5.4 of Appendix G. Mission Creek is the largest tributary, delivering 28% of the total flow in the Basin. Trout and Vernon Creeks are the second and third largest contributors, each delivering about 7% of the total. Although the residual areas[6] cover 17% of the Basin, they contribute only about 5% of the annual flow because of high actual evapotranspiration rates at lower elevations.

Over the period 1996-2006, total flow varied considerably from a peak in 1997 to a low in 2001. In seven of the 11 years, runoff was above normal, while in four of the 11 years it was below normal. Because it captures extremes, and includes a mix of “wet” and “dry” years, the 11-year standard period is appropriate for calibrating the Okanagan Basin Hydrology Model (OBHM).

On an annual basis, streamflow during the low flow months of August to February accounts for only 14% of the Basin total, while flows in March to July account for 86%. The August to February total streamflow averages about 18,200 ML per month, which is being contributed by groundwater as there is virtually no surface runoff during this period. This volume is a small fraction of the 334,147 ML in the peak month of May.

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[6] Residual areas are land areas in the watershed that do not have a major stream network.

Accuracy of Natural Flow Data

The natural and naturalized flow data was given a rating to indicate the estimated error and quality of the data (Table 6.5, Appendix G). Of the 73 nodes addressed in this study (including node “00” - inflows to Kalamalka Lake), 12 have uncertainty ratings of “2” (indicating uncertainties between 10% and 25%). A total of 18 nodes have uncertainty ratings of “3” (uncertainty between 25% and 50%) and the remaining 43 nodes have uncertainty ratings of “4” (uncertainty between 50% and 100%). However, 40 of the 43 nodes with ratings of “4” are residual areas, which have no major streams, and in total produce only about 5% of the runoff in the Basin. Therefore, high uncertainty in these minor flows has very little impact on the overall strong confidence in the results outlined in the study.

Recommendations:

The following recommendations are made for future studies to refine the estimates of natural flows in the Basin:

- Obtain improved water use and management information from the Basin water suppliers to improve naturalized flow estimates. The priority sub-basins are Kelowna (Mill) Creek, Powers Creek, Penticton Creek, Ellis Creek, Shuttleworth Creek, and Inkaneep Creek.
- Implement the recommendations of Dobson and Letvak (2008) to improve the existing Okanagan Basin hydrometric network and obtain better flow records for important streams.
- A key information gap identified in this study is data on streamflow-groundwater interactions where streams flow across alluvial fans and other unconsolidated deposits. Although there are ongoing modelling studies on this process, a field-based investigation should be undertaken that targets a select number of locations on critical streams.
- To provide further insight to streamflow–groundwater interactions, the groundwater regime should be assessed in areas of interest by establishing test wells and obtaining field measurements of groundwater levels. This program will increase our understanding of the spatial and temporal variability of streamflow gains and losses across alluvial fans in the Basin, which will further improve the Okanagan Basin Hydrology Model.
- Further investigation and monitoring is recommended to improve the flow estimates of small streams during low flow (or no flow) periods (late summer through winter). This would include obtaining flow information from local residents, conducting field surveys and discharge measurements, and incorporating this data into the surface water – groundwater interaction investigations.
- Consider the potential impacts of land use changes on runoff and infiltration over time.

10.0 INSTREAM FLOW NEEDS FOR THE OKANAGAN

The Working Group completed a study to determine the most appropriate office-based method(s) to apply in the Okanagan to identify instream flow regimes needed to both minimally sustain, and optimize conditions for, aquatic biota and their ecosystems. That study is presented in Appendix H.

The study describes the distribution of six (6) species of salmonid fishes that utilize the lakes and tributaries in the Okanagan (Table 2.2 of Appendix H). Extensive datasets on salmonids were assembled from studies relevant to the Okanagan region, and ranges of <u>optimal</u> spawning and rearing flows for these fish species in each of 36 Okanagan tributaries were identified (Figures B.1 to B.36 of Appendix H). The authors found that naturalized flows (i.e. flows that would exist without human use or management) are sufficient in most years to achieve optimal spawning flows for spring-spawning salmonids (i.e. rainbow trout and steelhead); however, naturalized flows usually fail to provide recommended flows for fall-spawning species (i.e. kokanee and sockeye). Optimal rearing conditions are mostly rare in the late summer to mid-winter for resident salmonids (Section 3.2 of Appendix H). Thus, estimates of naturalized flows suggest that most Okanagan streams historically provided suboptimal habitat for salmonid fishes and associated biota in late summer through mid-winter.

The study team recommended use of the BC Instream Flow Methodology (BCIFN) to identify instream flow regimes that protect aquatic life and sustain aquatic populations in individual tributaries. The minimum flow regime identified using this method is "conservative", meaning that even when flows are lower than the BCIFN flows, there is a relatively low risk of acute damage or extirpation for salmonid populations. The authors also identified the lowest 25th percentile of flows as a low-flow reference level. Salmonid fishes are generally regarded as sensitive "sentinels" of aquatic ecosystem integrity, under the assumption that if they are adequately protected, then most other aquatic species and their habitats will be protected.

The final flow parameter considered in this study was a "watershed conservation flow" - a high flow which should occur in spring every few years to sustain physical and biological processes along streams and riparian zones. The results (from the minimum instream flow regime estimation methods and the watershed conservation flow) are illustrated for each of the 36 Okanagan tributaries on Figures B.1 to B.36 in Appendix H.

Eight additional sensitive species and ecological functions that could be affected by instream flows are briefly considered in Section 3.4 of Appendix H. These species include the chiselmouth chub (fish), Mexican mosquito fern, tiger salamander, Great Basin spadefoot toad, vivid dancer damselfly, western painted turtle and Rocky Mountain ridged mussel. It is not yet possible to model their habitat requirements directly in an instream flow analysis.

An analysis comparing regulated flows to naturalized flows found that at some locations the recommended BCIFN minimum risk flows were achieved more frequently in the late summer dry period with regulated flows than with naturalized flows. This is likely due to water storage in these watersheds during the spring freshet, with subsequent release of this stored water later in the summer. However, regulated flows generally met BCIFN minimum risk flow thresholds less often than naturalized flows during other critical time periods (e.g. mid-winter - Table 3.3). These findings indicate the importance of upland reservoirs as a potential source of instream flow in support of aquatic habitat.

The BCIFN guidelines provide standardized methods for setting operational ecosystem objectives, indicators and reference points to facilitate water management decisions that are responsive to the requirements of federal and provincial laws, regulations and policies to promote the maintenance of ecosystem integrity and healthy populations of specified aquatic biota. However, the current study has demonstrated some weaknesses for effective application of outputs from these guidelines. These include: (a) the observation that minimum flow recommendations in drought prone areas such as the Okanagan under BCIFN guidelines may be higher than estimates of historic, naturalized low flows for a given stream, (b) the omission of any consideration of maintenance of water quality characteristics such as suitable temperatures for aquatic biota that may be controlled by the influence of interactions among surface and groundwater flows on habitat or ecosystem integrity, and (c) the failure of BCIFN guidelines to explicitly consider that maintenance of healthy populations of aquatic biota and ecosystem integrity frequently depend on interdependent processes (e.g. mating, spawning, rearing, and overwintering), operating at spatial scales involving migration or dispersal of aquatic biota among multiple streams exhibiting a wider range of seasonal flow variations than recommended from application of BCIFN methods.

Recommendations:

The following recommendations are made for future studies to refine the approach to specifying instream flow needs to maintain aquatic biota and their ecosystems in the Basin:

- Conduct additional studies to assess the consequences of failure to meet particular low flow thresholds – e.g. increased risk of production losses or extirpation of specified aquatic biota (e.g. fish and SARA-listed species).
- Initiate tests of the key assumption that habitat requirements of a broad range of sensitive aquatic biota will be met if the requirements of sentinel species such as salmonid fishes are satisfied.

- Assess the importance of combinations of surface and groundwater flows and withdrawals in various streams of the Okanagan to the maintenance of suitable, seasonal, thermal conditions required to sustain healthy populations of salmonids and other sensitive species of aquatic biota.
- Initiate work to identify how to expand effective application of the BCIFN methodology to sets of streams by determining the consequences of annual to seasonal temperature and flow variations on migration, dispersal, recolonization and production of sentinel species of aquatic biota among streams that taken together comprise the ecosystem(s) of such species.

In the meantime, when an appropriate minimum instream flow regime must be identified on a particular stream, it is recommended that:

- Agreement on an acceptable minimum instream flow regime for a set of streams will likely require that the agencies with a responsibility for aquatic species agree in advance on an acceptable level of risk to these species.
- A preliminary evaluation of the instream flows required to sustain aquatic biota should be made using the BC Instream Flow Methodology, with consideration of the 25th flow percentile documented herein.
- These office-based studies should be supplemented by site-specific field evidence for the stream (or representative member of a characteristic set of streams).

11.0 OKANAGAN WATER DATABASE

Phase 2 of the Okanagan Water Supply and Demand Project involved many modelling and analysis exercises to produce time series datasets for various water balance variables. The purpose of the Okanagan Water Database (OkWater Database) is to standardize these datasets and provide a website for automating remote delivery into a central long-term storage system. The system uses a flexible design that allows for additions and potential modifications in the future.

The central database is web-enabled via a web browser that allows users to upload MS Access templates through a simple import interface. This interface also enforces an audit trail and requires standard metadata information so that the datasets can be appropriately referenced and combined to form complete water balance scenarios.

Supporting Documents

Two major documents support the OkWater Database:

- Okanagan Water Database System Documentation (v.1.0.000) (ESSA 2009; Appendix K); and
- OkWater Database Users Guide Version 2.0 (Abraham and Alexander 2009; Appendix K).

The System Documentation (ESSA 2009) provides a comprehensive description of the system, its design concepts, requirements, and installation steps along with a full listing of the tables in the database (Table 5.1 of Appendix K).

The OkWater Database Users Guide (Abraham and Alexander 2009 – Appendix K) focusses on how to work with the website, the data import template, and the upload manager software.

Database Design

The OkWater Database consists of four components:

- A centralized relational database (SQL Server 2005 format);
- A data import template (MS Access 2003);
- A web application for specifying metadata and uploading template files; and
- A data export tool.

The relational database houses all core water budget data, related metadata and database look-up tables, attributes and standards. This SQL Server 2005 database is maintained and administered on a web-accessible Windows server computer.

The data import template mirrors the structure of the master database allowing compatible, standardized datasets to be uploaded. The OkWater Database Users Guide provides step-by-step instructions on using the template.

The web application consists of four elements:

- An "Upload Manager" for reviewing existing uploads and launching a new upload;
- A tab "Upload Details" for entering and reviewing meta-data and attaching supporting documentation;
- A "Templates" tab to download a copy of the current MS Access data import template; and
- Links at the top right of the page for changing an account password, accessing the Users Guide, and signing off.

In version 1.0.000 of OkWater Database, a custom data export tool (the "MikeSHE Exporter") was created to format datasets required by the Okanagan Basin Water Accounting Model (OBWAM). This tool currently supports the time series data products required for calibration of the model to 1996-2006 conditions, as well as for examining 15 alternative scenarios defined as part of Phase 2. Details on configuration and operation of this tool are described in Section 4.3 of the System Documentation (Appendix K).

12.0 OKANAGAN WATER INFORMATION REFERENCE LIBRARY

Overview

A great deal of potentially relevant information on water supply and demand exists for the Okanagan Basin. Efforts to collect and review information in Phase 1 of the Project (Summit 2005) focussed on information relating to surface water supply, water use, and groundwater, as well as population, land use, recreation, and tourism. The Okanagan Water Information Reference Library is a web-accessible database designed to make this information readily available to researchers and the public. Each report in the database is accompanied by an expert review. Authors of technical reports in Phase 2 provided additional documents and reviews to the database. As of June 2010, there were over 300 records in the database, all accompanied by a link to the full document.

The database design is simple and includes a user-friendly interface with the ability to create customized summaries, including a data gap analysis. The information database is useful for summarizing the variety of data sources and identifying the most useful resources for a given topic or geographic area within the Basin. The database is reproduced in Appendix L of this Summary Report.

Database Design

The database consists of 3 main sections: Source, Content and Evaluation (Figure 12.1). The Source section contains the reference information, including the citation, the location and available format (hardcopy or digital) of the original document. Electronic versions of each of the documents in the database have been created, and a user can directly access the document through a link provided by the database.

The Content section includes information regarding:

- Information type (data, data interpretation, or other);
- Classification (surface water, groundwater, or other);
- Geographic scope (Basin-wide or specific area of the Basin);
- The name(s) of the Okanagan sub-basins for which the document is relevant; and

- Scientific focus of the document (e.g. hydrology, water quality, groundwater, instream flow).

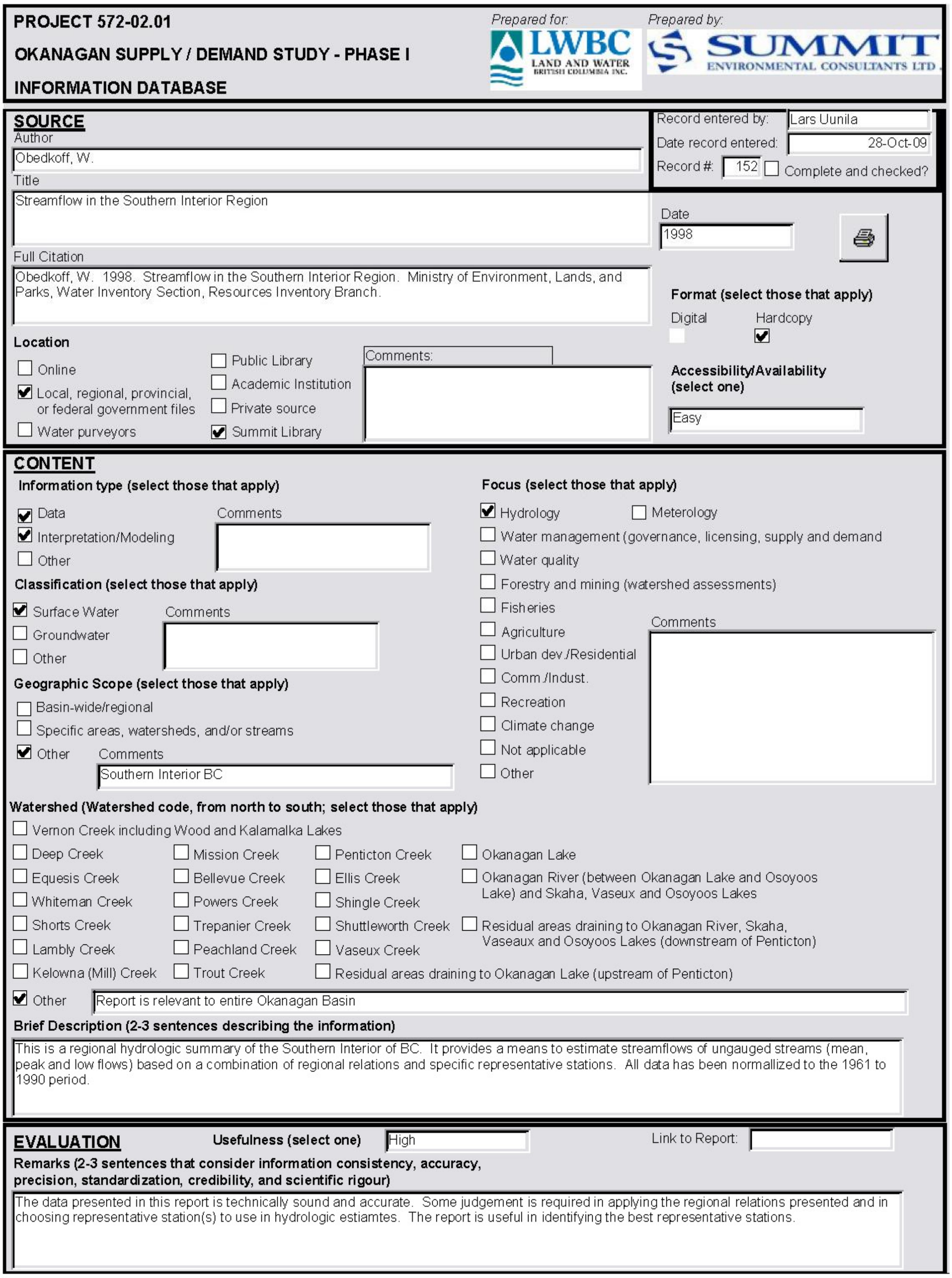
This section also includes a brief description of the information found in the source document.

The Evaluation section provides an evaluation of the document.

A database user can view, enter, search, filter or sort any of these fields through the interface.

Web Access

The interface of the database is available and searchable on the internet through the OBWB website: http://www.obwb.ca/obwrid/. This online tool also allows access to the digital documents.



PROJECT 572-02.01

OKANAGAN SUPPLY / DEMAND STUDY - PHASE I

INFORMATION DATABASE

Prepared for: LWBC LAND AND WATER BRITISH COLUMBIA INC.

Prepared by: SUMMIT ENVIRONMENTAL CONSULTANTS LTD.

SOURCE

Record entered by: Lars Uunila

Date record entered: 28-Oct-09

Record #: 152 ☐ Complete and checked?

Author: Obedkoff, W.

Title: Streamflow in the Southern Interior Region

Date: 1998

Full Citation: Obedkoff, W. 1998. Streamflow in the Southern Interior Region. Ministry of Environment, Lands, and Parks, Water Inventory Section, Resources Inventory Branch.

Format (select those that apply)

Digital ☐ Hardcopy ☑

Location

☐ Online
☑ Local, regional, provincial, or federal government files
☐ Water purveyors
☐ Public Library
☐ Academic Institution
☐ Private source
☑ Summit Library

Comments:

Accessibility/Availability (select one): Easy

CONTENT

Information type (select those that apply)

☑ Data
☑ Interpretation/Modeling
☐ Other

Comments

Classification (select those that apply)

☑ Surface Water
☐ Groundwater
☐ Other

Comments

Geographic Scope (select those that apply)

☐ Basin-wide/regional
☐ Specific areas, watersheds, and/or streams
☑ Other

Comments: Southern Interior BC

Focus (select those that apply)

☑ Hydrology ☐ Meterology
☐ Water management (governance, licensing, supply and demand
☐ Water quality
☐ Forestry and mining (watershed assessments)
☐ Fisheries
☐ Agriculture
☐ Urban dev./Residential
☐ Comm./Indust.
☐ Recreation
☐ Climate change
☐ Not applicable
☐ Other

Comments

Watershed (Watershed code, from north to south; select those that apply)

☐ Vernon Creek including Wood and Kalamalka Lakes
☐ Deep Creek ☐ Mission Creek ☐ Penticton Creek ☐ Okanagan Lake
☐ Equesis Creek ☐ Bellevue Creek ☐ Ellis Creek ☐ Okanagan River (between Okanagan Lake and Osoyoos Lake) and Skaha, Vaseux and Osoyoos Lakes
☐ Whiteman Creek ☐ Powers Creek ☐ Shingle Creek
☐ Shorts Creek ☐ Trepanier Creek ☐ Shuttleworth Creek ☐ Residual areas draining to Okanagan River, Skaha, Vaseaux and Osoyoos Lakes (downstream of Penticton)
☐ Lambly Creek ☐ Peachland Creek ☐ Vaseux Creek
☐ Kelowna (Mill) Creek ☐ Trout Creek ☐ Residual areas draining to Okanagan Lake (upstream of Penticton)
☑ Other: Report is relevant to entire Okanagan Basin

Brief Description (2-3 sentences describing the information)

This is a regional hydrologic summary of the Southern Interior of BC. It provides a means to estimate streamflows of ungauged streams (mean, peak and low flows) based on a combination of regional relations and specific representative stations. All data has been normallized to the 1961 to 1990 period.

EVALUATION

Usefulness (select one): High

Link to Report:

Remarks (2-3 sentences that consider information consistency, accuracy, precision, standardization, credibility, and scientific rigour)

The data presented in this report is technically sound and accurate. Some judgement is required in applying the regional relations presented and in choosing representative station(s) to use in hydrologic estiamtes. The report is useful in identifying the best representative stations.

Figure 12.1 Example form in the Water Information Reference Library Database. (Note that the online version has a slightly different format.)

PART THREE – MODELS

Part Three of this Summary Report describes the three models that have been developed and used in Phase 2 of the Project: the Okanagan Water Demand Model, the Okanagan Basin Hydrology Model, and the Okanagan Basin Water Accounting Model. These models were developed and tested using the data and databases described in Part Two of this Summary Report. Together they simulate the natural and managed movement of water in the Okanagan Basin.

13.0 HOW OKANAGAN WATER CYCLES ARE SIMULATED

The natural water cycles and the effects of human use and management of surface and groundwater in the Okanagan are simulated using all three of these models. For a particular sequence of time (for example the 1996-2006 period, or for a future period, for example 2011 – 2040), the models are run in the following order:

1. the Okanagan Water Demand Model (OWDM); then
2. the Okanagan Basin Hydrology Model (OBHM); then
3. the Okanagan Basin Water Accounting Model (OBWAM).

Each model works on a daily (or even shorter) time-step, but the results are summed internally and output is generated for periods of one week. The climate dataset is the main driver of the OWDM, which computes the irrigation and non-irrigation water needed for each of thousands of discrete parcels of land, and integrates this up to 253 “water use areas”. The OWDM links the water used on each “water use area” to its water source, and calculates the weekly need for water from that source to satisfy the demand. The information [weekly water demand for each water use area (both total water use and water use subdivided into various categories) and weekly demand for water from each water source] is delivered to the OkWater database. It is exported from the OkWater database to the OBHM. The OBHM computes naturalized streamflows corresponding to the particular climate dataset. The OBWAM then combines the outputs of the OWDM and the OBHM to account for the effects of water extractions from groundwater and surface water sources, the effects of releases of water from upland reservoirs to meet those demands, and the effects of lake level management decisions to simulate tributary streamflows, Okanagan River flows, and lake levels on the main valley-bottom lakes.

14.0 OKANAGAN WATER DEMAND MODEL

The Okanagan Water Demand Model (OWDM) is used to estimate water demands for all indoor and outdoor purposes in the Okanagan Basin. Development of the OWDM was initiated by the Ministry of Agriculture and Lands (MAL) and Agriculture and Agri-Food Canada (AAFC) following completion of the Phase 1 work program in 2005. With assistance from Environment Canada (EC), MAL and AAFC first developed an agricultural irrigation model for the Okanagan Basin. Three refinements to the agricultural model were made in Phase 2:

1. The model was extended to incorporate other forms of outdoor irrigation, including:
   - Irrigation of domestic properties (e.g. lawns and gardens);
   - Irrigation of municipal land (e.g. parks, boulevards, and schoolyards); and
   - Irrigation of golf courses.

2. The model was expanded to calculate indoor water use (domestic, industrial, commercial, and institutional).

3. The model was modified so it could calculate the volumes of water extracted from surface and groundwater sources to meet the demands. This information was a key input parameter to the Okanagan Basin Water Accounting Model (Appendix J).

This section describes the Okanagan Water Demand Model. Appendix I1 provides a more complete summary of the model, and Appendices I2 and I3 provide additional supporting information.

Agricultural Water Use

The Agriculture (Irrigation) Water Demand Model (van der Gulik et al., 2010), which forms the core of the Okanagan Water Demand Model, is based on a Geographic Information System (GIS) database that contains cadastre information (showing the boundaries of land ownership), crop type, irrigation system type, soil texture and climatic data. This information was assembled from background information as well as high resolution orthophotos and GIS, and was ground-truthed during a comprehensive field program beginning in 2006. Since land uses (including crop type and method of irrigation) were identified and water demands were calculated at the scale of individual land parcels and finer (i.e. polygons, as outlined in blue on Figure 14.1), the model can provide estimates of water demand for individual crops on a parcel of land, or for entire sub-basins, local governments jurisdictions, or water purveyor areas by summing the demands within those areas. To incorporate the range in climates throughout the Basin, the gridded climate data sets described in Section 5.0 and Appendix N were used in the model. A detailed description of how the model calculates irrigation water demands is provided in Appendix I2. The model calculates optimal water demand. Calculated water use would equal actual use if all irrigators watered at optimal rates, and did not over-water or under-water their crops.

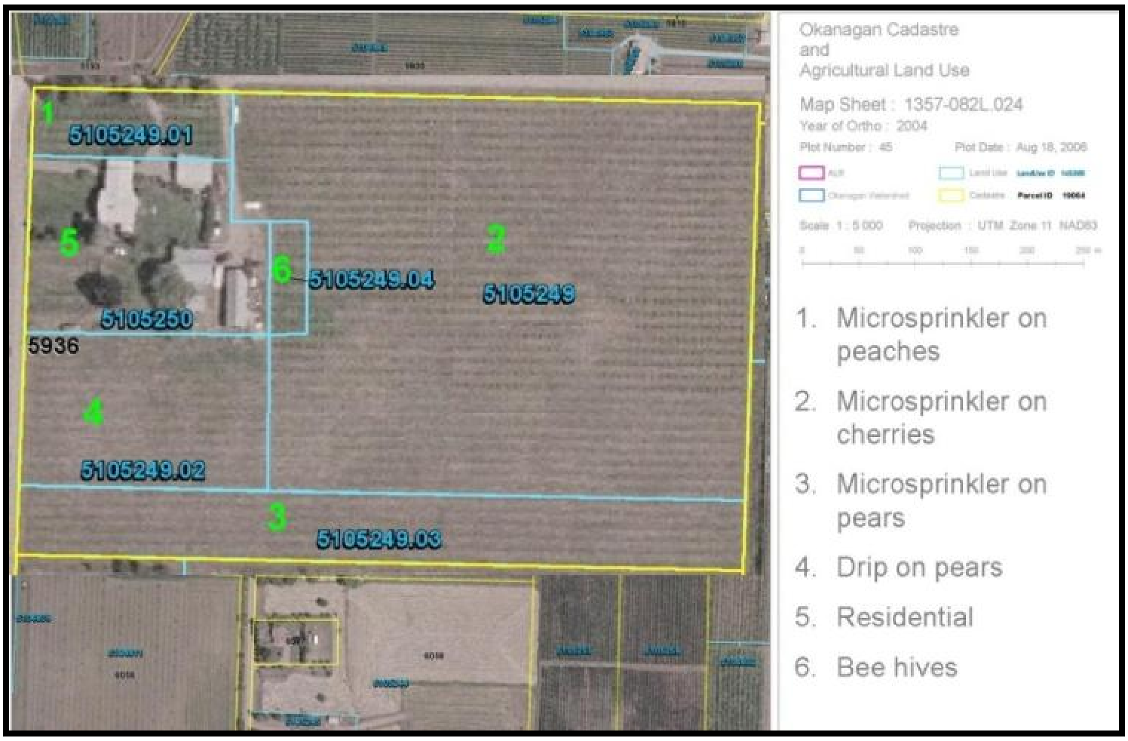


Figure 14.1 Example map sheet showing the resolution of the imagery used and the designated land use within a specific cadastre (i.e. property boundary).

Non-Agricultural Outdoor Water Use

The same methodology was used to estimate water demands on non-agricultural lands as was used for agricultural land. It was assumed that the "crop" on the non-agricultural irrigated areas was "turf grass".

A combination of image/aerial photo analysis, GIS techniques, and local government and BC Assessment data were used to identify the non-agricultural irrigated areas. These techniques were used to identify "green spaces" within residential, industrial, commercial, and institutional properties – i.e. areas likely under irrigation. These areas were then added to the database and used in the Okanagan Water Demand Model.

Indoor Water Use
Indoor water use by residential, industrial, commercial, and institutional users was incorporated into the Okanagan Water Demand Model by obtaining the BC Assessment Authority information on all land parcels in the Okanagan Basin, and assigning average daily water use values by land parcel based on an analysis of water meter records from key municipalities (Appendix I3). The average daily water use per water use category was entered into the database and used in the Okanagan Water Demand Model. Descriptions of the methods used to compute water use for each category are presented in Appendix I3.

Water Extractions from Streams, Lakes and Groundwater
To support the Okanagan Basin Water Accounting Model, it was necessary for the Okanagan Water Demand Model to link water demands on the land to extractions from water sources (e.g. streams, lakes and aquifers). Two steps were taken:

- A map of “water use areas” was developed that covers all areas in the Okanagan Basin where water is used (Attachment 3); and
- The source(s) of water supplying each of the delineated “water use areas” was identified.

The "water use area" map along with identified water sources was incorporated into the Okanagan Water Demand Model. Therefore, in addition to estimating water demands for each “water use area”, the model also estimates water extractions from each surface source or groundwater source needed to supply those demands[7].

Model Output
The results of the Okanagan Water Demand Model for the 1996-2006 period are provided in Appendix C and are summarized in Section 6.0 of this report. Future scenario results are summarized in Section 18.0. Recommendations for model improvements are made in Section 20.0.

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[7] For this work, surface sources were identified at the node level (i.e. sub-basin or residual area), and groundwater sources were identified at the aquifer level.

15.0 OKANAGAN BASIN HYDROLOGY MODEL

Overview

The Okanagan Basin Hydrology Model (OBHM) is a customized surface water and groundwater hydrology model covering the entire Okanagan Basin, based on the MIKE SHE/MIKE 11 integrated modelling system developed by DHI Water and Environment ULC (DHI). The MIKE SHE/MIKE 11 system simulates all of the land-based phases of the hydrologic cycle (Figure 15.1).

The OBHM was developed and calibrated against naturalized conditions for the period 1996 through 2006. The output (estimates of naturalized streamflows) is fed into the Okanagan Basin Water Accounting Model (OBWAM) (Section 16.0) that is used to assess water supply and demand in the Basin. This section highlights key attributes of the OBHM; Appendix J provides a complete technical description of the OBHM and the OBWAM. Further details on MIKE SHE are provided in DHI (2009).

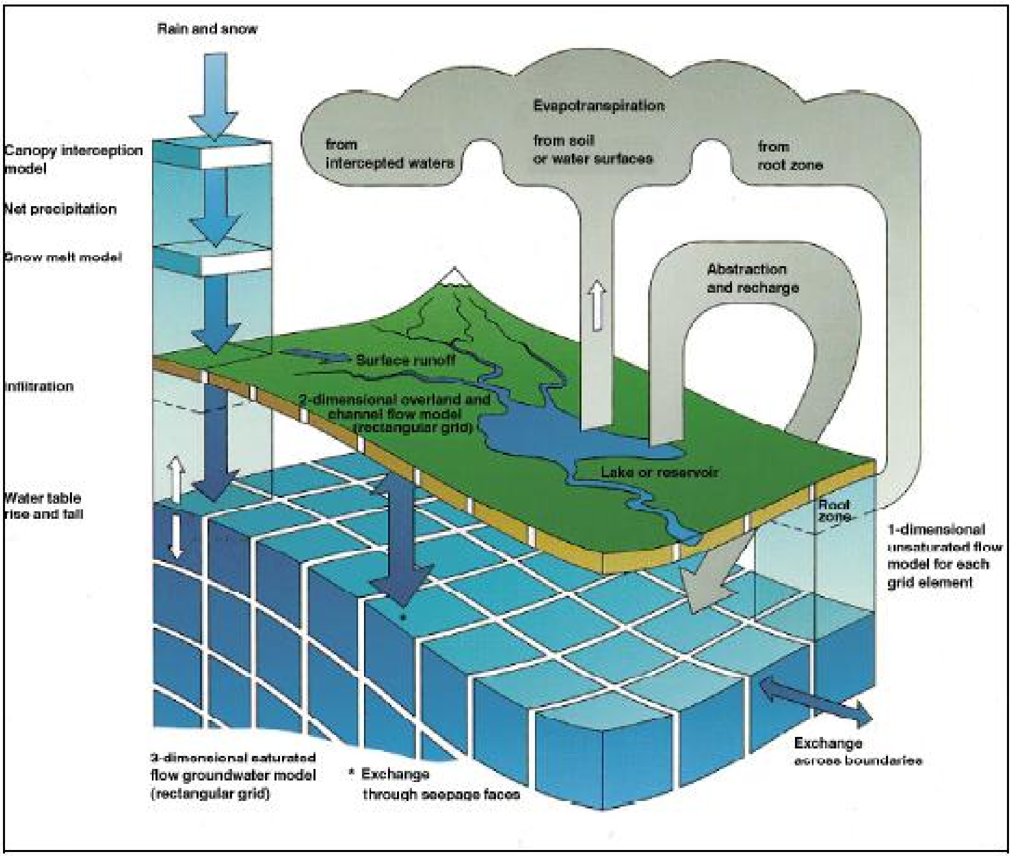

Figure 15.1 Simplified diagram of the hydrologic cycle identifying the processes incorporated in the Okanagan Basin Hydrology Model.

Development of the Okanagan Basin Hydrology Model

The OBHM utilizes the MIKE SHE and MIKE 11 modelling platforms developed by DHI. MIKE SHE is used to simulate the land-based processes of the hydrologic cycle, including snowmelt, evapotranspiration, overland flow, sub-surface flow within the unsaturated zone (i.e. above the groundwater table), and groundwater flow. MIKE 11 is used to simulate flows along the Okanagan River and through the main valley-bottom lakes, where flow regulation by dams and control structures exerts a major influence on river flows and lake levels. A summary of the specific methods used to simulate the hydrologic cycle is provided in Table 15.1. Additional features of the OBHM are as follows:

- In order to utilize the available climate datasets (Appendix N), a 500 m by 500 m grid resolution was adopted for the OBHM. As a result, the overland flow, unsaturated flow, and evapotranspiration calculations in the model are each computed for every 500 m square grid cell in the Basin.
- Groundwater calculations are based on the aquifers defined in the conceptual groundwater model (Appendix E), not at the 500 m by 500 m model grid resolution. The aquifers are simplified as linear reservoirs.
- Streamflow calculations occur at discrete node locations defined in the Hydrology State of the Basin Report (Appendix G).
- Model results were evaluated for the period from January 1, 1996 to December 31, 2006 (11 years), the period for which natural and naturalized flow estimates were developed in the Hydrology State of the Basin Report (Appendix G).
- The topography of the Basin was defined by a digital elevation model of the entire Basin, at an original resolution of 30 m; however, for the purposes of the model the resolution was resampled to 500 m.
- Detailed lake bathymetry was merged with the topography and incorporated into the model.
- Daily minimum and maximum temperature[8] and daily precipitation were extracted from the climate datasets (Appendix N). Additional calculations were performed to generate daily potential evapotranspiration (PET) using a modified Penman-Monteith method.

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[8] An accurate representation of the spatial and temporal distribution of air temperature is arguably the most important factor influencing the OBHM's ability to properly simulate snow accumulation and melt processes in the Basin, and an accurate simulation of these processes is critical for accurately simulating the spring runoff timing and volume, which is the dominant runoff-generating process operating in the Basin.

Table 15.1 Summary of methods used by the OBHM to simulate the Okanagan hydrologic cycle.

Process	Method used in the Okanagan Basin Hydrology Model
Snowmelt	**Modified Degree-Day Method**, whereby the rate of melting increases as the air temperature increases. The main input parameters required are: 1) melting threshold temperature, 2) degree day coefficient, 3) minimum snow storage for full coverage, and 4) maximum wet snow fraction.
Overland flow	**Explicit Finite Difference Method**, whereby the model solves a two-dimensional diffusive wave approximation of the Saint Venant equations to calculate surface flow in the x- and y- directions and water depths for each grid cell of the model domain. The main input parameters are: 1) Manning's roughness coefficient, 2) detention storage, and 3) initial water depth. The overland flow algorithm interacts with the channel flow, the unsaturated zone, and the saturated zone components of the model.
Sub-surface flow within the unsaturated zone	**Two-Layer Water Balance Method** that functions in conjunction with the evapotranspiration component of the model. This method uses a simple mass-balance approach to represent the unsaturated zone, and accounts for interception storage changes, surface ponding, and water content in the root zone, infiltration, evapotranspiration, and groundwater recharge. The main input requirements are the following soil properties: 1) volumetric moisture content at saturation, 2) field capacity, 3) wilting point, and 4) saturated hydraulic conductivity. Values for all of these terms are required for each soil type included in the model. The first three terms are used to calculate the average moisture content in the soil, which is linearly dependent on the depth of the water table. The difference between the moisture contents at saturation and at field capacity provides an estimate of the storage capacity of the soil; while the difference between the moisture contents at field capacity and at the wilting point provides an estimate of the amount of water available for transpiration within the rooting zone. The saturated hydraulic conductivity is used to control the rate of infiltration of water through the unsaturated zone. This value is assumed to be uniform across the entire depth of the unsaturated zone, thus simulated infiltration is not dependent on the soil moisture content.
Evapotranspiration (ET) (Potential and Actual)	**Two-Layer Water Balance Method** is used for simulating ET which divides the unsaturated zone into an upper rooting zone, from which ET can occur, and a lower zone below the rooting zone, where ET does not occur. The simulated actual ET is based on the specification of potential ET (PET). For each ET time step, the model tries to meet the PET or determines to what degree the PET can be met from four different storages: the canopy, ponded water, the unsaturated zone, and the saturated zone, and is limited by the available water in each of these storages. The method also allows for upward movement of water from the saturated zone to the rooting zone to occur as a result of rooting zone ET demand. The primary input parameters include PET, Leaf Area Index, and Rooting Depth for the various vegetation types in the model. The Leaf Area Index (LAI) is defined as the (area of leaves)/ (area of the ground) and can vary between 0 and 7 (dimensionless ratio) depending on the vegetation type. LAI values were based on a combination of satellite imagery, land cover maps, and maps identifying forest disturbance by Mountain Pine Beetle, fire and forest harvesting. The Rooting Depth (RD) represents the maximum depth of active roots in the root zone. Values for rooting depths were obtained from the literature for similar vegetation, climate and soil conditions.
Groundwater flow	**Linear Reservoir Approach** is used to represent the groundwater system. This approach subdivides the watershed into a series of interdependent, shallow interflow reservoirs and deeper baseflow reservoirs that contribute to stream baseflow. If a stream is present in a given sub-basin, water will be routed through the linear reservoirs as interflow and baseflow and subsequently added as lateral flow to the MIKE 11 component of the model. Thus, the water that recharges from the unsaturated zone may either contribute to groundwater flow or move laterally as interflow towards the stream. Additionally, water held in the part of the baseflow reservoirs beneath the lowest interflow zone may be allowed to contribute to the rooting zone when the soil moisture is below field capacity.

Table 15.1 (continued)

<table>
<tr><th>Process</th><th>Method used in the Okanagan Basin Hydrology Model</th></tr>
<tr><td>Groundwater flow</td><td>Each interflow reservoir requires a value for:
Specific Yield: The volume of water released per unit surface area of aquifer per unit decline in total hydraulic head.
Initial depth: The initial depth of the water table in the reservoir, measured from the ground surface.
Bottom depth: The depth below the ground surface of the bottom of the reservoir - if the water level drops to the bottom of the reservoir, percolation stops
Interflow time constant: A calibration parameter that represents the time it takes for water to flow through the reservoir to the next reservoir
Percolation time constant: A calibration parameter that represents the time it takes for water to seep down into the baseflow reservoir
Interflow threshold depth: The depth of the interflow reservoir water table below the ground surface when interflow stops
For each baseflow reservoir pair, there are three items to define:
Fraction of percolation to reservoir 1: This is used to divide the percolation between each of the two parallel baseflow reservoirs
Fraction of pumping from reservoir 1: This is used to divide the pumping (if it exists) between each of the two parallel baseflow reservoirs
Use default river links: In most cases the simplified overland flow and the groundwater interflow are linked to all of the river links found in the lowest interflow reservoir in each subcatchment
The following parameters need to be defined for each of the parallel baseflow reservoirs:
Specific Yield: The volume of water released per unit surface area of aquifer per unit decline in head
Time constant for base flow: A calibration parameter that represents the time it takes for water to flow through the reservoir
Dead storage fraction: The fraction of the received percolation that is not added to the reservoir volume but is removed from the available storage in the reservoir
Unsaturated Zone feedback fraction: The fraction of base flow to the river that is available to replenish the water deficit in the unsaturated zone adjacent to the river (i.e. the lowest interflow reservoir in the subcatchment)
Initial depth: The initial depth to the water in the reservoir measured from the ground surface
Threshold depth for base flow: The depth below the ground surface when base flow stops
Threshold depth for pumping: The depth below the ground surface when pumping is shut off
Depth of the bottom of the reservoir: The depth below the ground surface of the bottom of the reservoir</td></tr>
<tr><td>Channel flow</td><td>MIKE 11 is a one-dimensional hydrodynamic modelling tool that is used to analyze water movement in a river network including flow through control structures and other hydraulic features. MIKE 11 has the capability of solving the fully dynamic, diffusive, or kinematic wave approximations of the Saint Venant equations for one-dimensional unsteady flows or the simple Muskingum equations. MIKE 11 was integrated with the MIKE SHE surface/groundwater model to simulate the routing of runoff conditions (or groundwater return flows) through a river network. MIKE SHE acts as a dynamic boundary condition that exchanges overland flows and groundwater baseflows with MIKE 11.

The majority of the surface water system in the OBHM was simulated using the kinematic wave approximation and a simplified routing approach with the exception of the five major lakes included in the model and the connecting rivers in between the lakes which were simulated using a fully-dynamic solution. The fully dynamic solution was used for these features in order to allow for representation of the series of outflow structures which regulate flow through the valley-bottom system.</td></tr>
</table>

Model Calibration

The OBHM was calibrated against data from eight natural streams, eight "high confidence" naturalized hydrographs developed in a parallel study (Appendix G), and snow water equivalent data at 21 locations throughout the Basin for the 1996-2006 period. Additionally, the model output was compared against other naturalized hydrographs (Appendix G), estimates of lake evaporation from a parallel lake evaporation study (Appendices F1 and F2), and previous estimates of various components of the overall water budget (Appendices C, D, and E).

In general, the pattern and timing of snow accumulation and melt in the model agrees well with the observed snow water equivalent data (Figure 15.2), but the model has a tendency to over-predict snow accumulation at low elevations and under-predict snow accumulation at high elevations.

The simulated total flow volume agrees well with the natural and high confidence level naturalized hydrographs (Figure 15.3) as does the flow volume simulated during the spring snowmelt period. The model over-predicts flow volumes during the low-flow period and the majority of this over-prediction can be attributed to runoff events simulated by the model during the autumn months that are larger than recorded values. The simulated winter baseflow however agrees well with the comparison data.

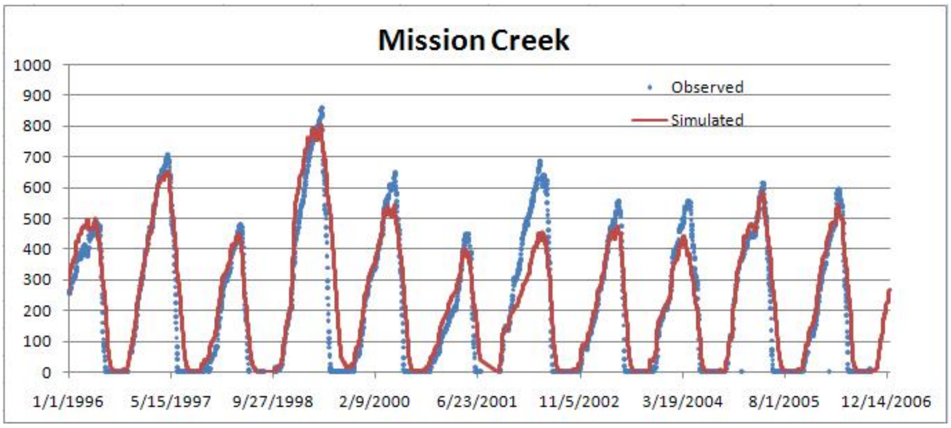

Figure 15.2 Comparison of simulated snow water equivalent (mm) with snow pillow data from the Mission Creek sub-basin.

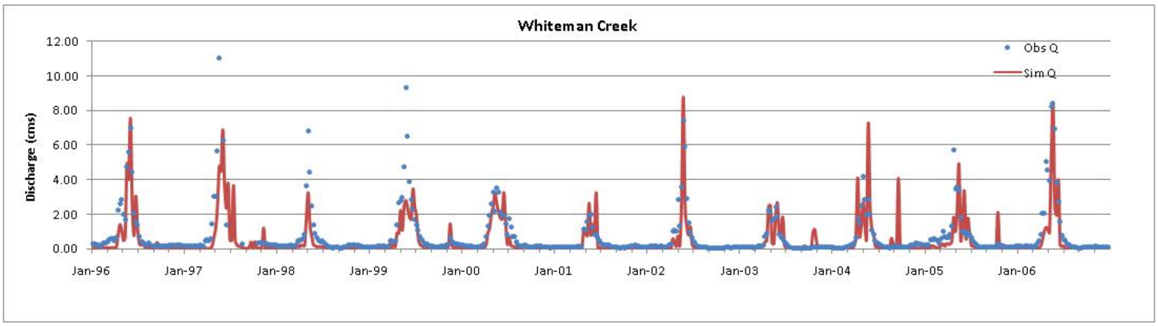

Figure 15.3 Comparison of simulated and observed discharge at Whiteman Creek.

Several methods are available for computing evaporation from the main valley lakes in the Okanagan (Appendices F1 and F2). For consistency with the Okanagan Water Demand Model, the Penman-Monteith equation was chosen.

While the model was calibrated and compared to a wide variety of data, the majority of this data consists of estimates from other studies, rather than measured data. This makes it difficult to know if differences between simulated and "observed" components of the hydrologic cycle are due to deficiencies in the model or deficiencies in the comparison data.

That the model appears capable of reproducing observed snow water equivalent and natural and naturalized hydrographs reasonably well largely reflects the high quality of the air temperature data in the climate datasets. However, these datasets are based on extrapolations of observed data and have limitations. It is likely that where the model does not represent streamflows well (such as occasionally occurs in late fall), the differences between simulated and observed conditions are likely largely due to the limitations of the climate datasets.

An overall water balance for the Basin, derived using the water management and use information presented in Section 6.0 and the information presented in other sections, including the present section, is presented in Figure 6.1. An average annual water balance for Okanagan Lake is presented in Figure 6.2. Inflow to the lake is small relative to the volume of the lake - only about 1/60 of the volume of the lake is refreshed each year.

Recommendations for improvement of the OBHM are made in Section 20.0.

16.0 OKANAGAN BASIN WATER ACCOUNTING MODEL

Overview

The Okanagan Basin Water Accounting Model (OBWAM) was developed to combine the results of the Okanagan Water Demand Model (OWDM) and the Okanagan Basin Hydrology Model (OBHM). The OBWAM is used to determine the influence of humans on water within the Basin.

Development of the OBWAM involved combining the calibrated OBHM (Section 15.0) with water management and demand information. The model was then verified against the available streamflow and lake level data. Through this process, improvements were made to the model to achieve a better calibration to the observed lake levels in the main valley lakes and Okanagan River flows.

Development of the Okanagan Basin Water Accounting Model

The human influences that are accounted for in the OBWAM are thoroughly described in Appendix B, and include:

- The operation of reservoirs in the upland portions of the Basin, which capture runoff in the spring and release water in the summer;
- Surface return flows, including municipal wastewater discharge to waterbodies, specifically Okanagan Lake and Okanagan River;
- Groundwater return flows, including septic system discharge and losses of surface water by percolation to groundwater as a result of over-irrigation;
- Water imports from sources outside the Basin;
- Water extractions from surface water (e.g., streams and lakes); and
- Water extractions from groundwater.

These human influences were quantified by parallel Phase 2 studies and models (Appendices C, D, E, and I) for the calibration period 1996-2006, and were used to develop weekly time series of the "net water use", which accounts for <u>all</u> the above-noted human influences at each point-of-interest in the Basin. Net water use was then subtracted within the OBWAM from the modelled natural streamflows to determine actual streamflows.

Calibration of the Okanagan Basin Water Accounting Model

The goal of calibrating the OBWAM was to verify the hydrology of the OBHM and to calibrate the operational strategies of the mainstem lakes to achieve a good fit between the simulated and observed mainstem lake levels and discharges along the Okanagan River.

Computer model calibration is necessary before considering use of the model for predictive or scenario modelling purposes.

Tributary Streamflows

Once the net water use data were accounted for in the OBWAM, modelled streamflows were verified against the measured streamflows in regulated tributaries. Figure 16.1 provides a plot comparing the simulated and observed flows in Mission Creek (a complete series of calibration plots and statistics is provided in Appendix J). Since Mission Creek is the most significant tributary in the Basin, it is a key indicator of how well the OBWAM is calibrated. As shown in Figure 16.1, the simulated flows are close to the actual flows, both during peak flows and during low flows, and in both wet years and dry years.

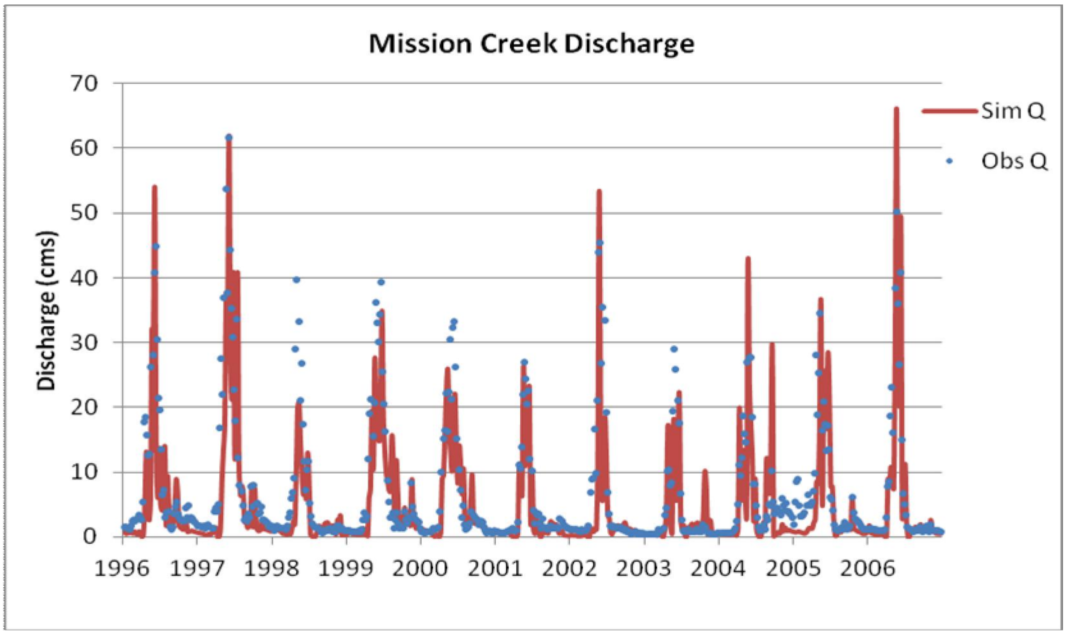

Figure 16.1 Simulated vs. observed streamflows in Mission Creek.

Lake Levels and Outflows

Calibration of the OBWAM to the mainstem lake levels and Okanagan River discharges was challenging. The data quality of the lake levels and river discharges is good, and the operational rules are well documented in dam operating plans, but implementation of the rules is at the discretion of the dam operator. As a result, there are some observed lake levels which could not be reproduced by the model because the observed levels contradict the written rules by which the lakes are supposed to be operated. Therefore, the calibration of the operational rules involved several iterations to find the right combination of rule priorities, frequency of gate adjustment, and gate level increment schemes.

In general, the results show a good fit between the simulated and observed lake levels, and a reasonable fit for the discharge from Okanagan Lake. The variability in the discharge is a reflection of the limitations of the way in which the operational strategies can be described in the model. As a result, in the model the rules are tested and the gates are adjusted more frequently than they are in reality, and this leads to frequent oscillations of the modelled discharge from the lakes.

Since the releases from Okanagan Lake are the main source of flows for the Okanagan River and downstream mainstem lakes, the majority of the lake operation calibration effort was spent on getting a good fit between the simulated and observed water levels on Okanagan Lake and discharge from the lake. Figure 16.2 shows a plot of the simulated vs. observed water levels at Okanagan Lake, and Figure 16.3 shows a plot of the simulated vs. observed discharges from Okanagan Lake at Penticton. Calibration plots and statistics for lake levels and discharge from the other mainstem lakes (Kalamalka, Skaha, Vaseux, and Osoyoos) are included in Appendix J.

For Okanagan Lake, the lake level shows a very good fit during normal and wet years, but the model tends to under-predict lake levels during dry years. Many attempts were made to correct this behaviour in the model and some success was achieved by adjusting the operational rules and settings, as well as incorporating inflow volume forecasting. However, a closer examination of the observed response vs. the documented operational rules indicated that, during dry years, the operation of the dam diverged from the operational rules. Since the logic used to operate the dams during these times was not specifically documented, it was not possible to incorporate it into the model.

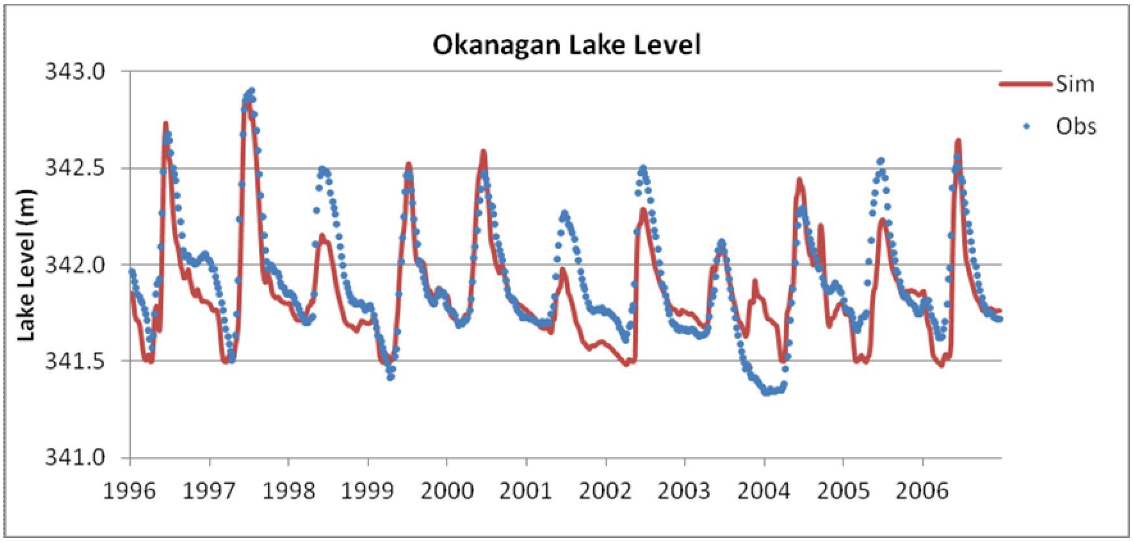

Figure 16.2 Simulated vs. observed Okanagan Lake levels.

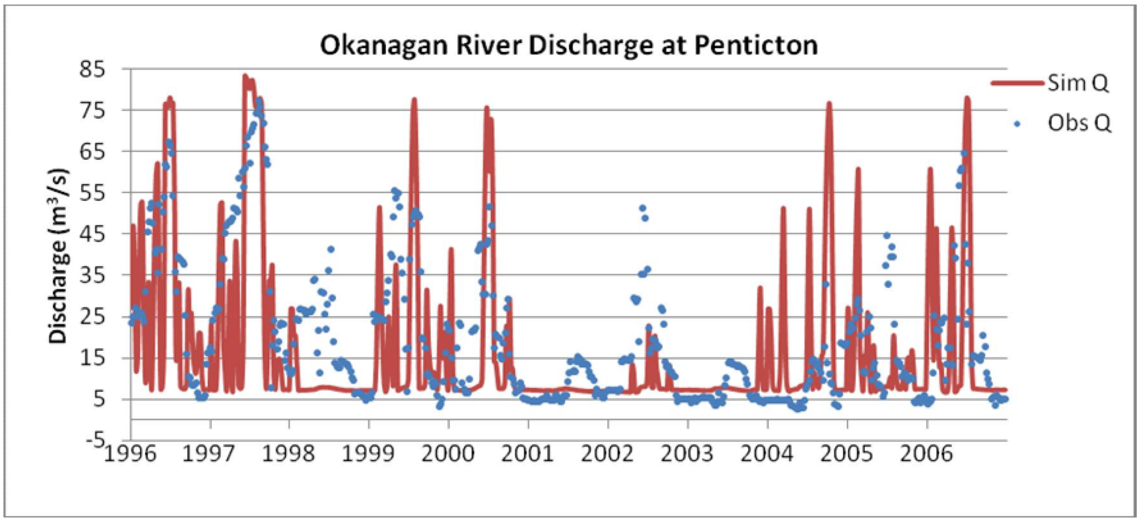

Figure 16.3 Simulated vs. observed discharge of Okanagan River at Penticton.

Although the simulated discharge from Okanagan Lake captures many of the major seasonal trends in the discharge, the high frequency of activity with the structures in the model causes short-term oscillations in discharge as the model tries to strictly meet the operational rules. This limitation could not be overcome during Phase 2, and should be investigated further in future phases of the Project.

In general, the calibration process was driven largely by the ability of the OBWAM to accurately represent the Basin hydrology (as measured by flows in the main tributaries) and the lake levels for Okanagan Lake. The OBWAM provides a very good representation of both the hydrology and the lake levels at Okanagan Lake, and a good fit for the lake levels for Kalamalka Lake, Skaha Lake, Vaseux Lake, and Osoyoos Lake. The discharge along the Okanagan River was reasonably well represented, but it was strongly influenced by frequent modelled gate adjustments as the model attempted to meet the operational rules.

Summary

The OBWAM developed during Phase 2 is a sophisticated, flexible and scalable model capable of incorporating physical data inputs that represent the spatially and temporally variable hydrologic characteristics of the Okanagan Basin, and the influences of human water storage and withdrawals. The model has been successfully calibrated to accurately reproduce a continuous hydrologic response over a wide range of climate conditions from 1996-2006. The OBWAM is also able to accurately represent and reproduce the real-time operational logic of the dams on each of the mainstem lakes in the Okanagan Basin. As a decision support tool, the model can help evaluate the impacts of potential climate change and water use considerations on the Basin-wide water supply. Recommendations for improving the model are provided in Section 20.0.

PART FOUR – SCENARIOS

Part Four summarizes the initial application of the Phase 2 models (OWDM, OBHM, and OBWAM) using 15 future scenarios. It summarizes the rationale for selection of these 15 scenarios, the work done to prepare the models for running scenarios, the scenario running process, the outputs of scenario runs, and the interpretation of scenario results.

17.0 SCENARIO SELECTION

One of the strengths of the Phase 2 models is that they can be used to examine alternative water scenarios. In Phase 2, only 15 of a very large number of possible future scenarios were examined. These particular scenarios were selected to demonstrate the power and utility of the models.

The 15 scenarios were selected to focus on the key factors that could affect water resources in the Okanagan in the future:

- Changes in climate;
- Changes in forest cover as a result of mountain pine beetle, wildfire, and forest harvesting;
- Changes in water use efficiency;
- Changes in the amount of agricultural land under irrigation; and
- Changes in population.

One of the most important drivers for the Okanagan Water Demand Model and the Okanagan Basin Hydrology Model is the climate dataset. As noted above, 12 different future climate datasets are available for the Okanagan. The Phase 2 Working Group selected one of these to run all 15 scenarios - the CGCM2 Model, using the A2 emission scenario. This is not necessarily the “best” climate dataset; rather it is one of several potentially realistic climate datasets.

Only one Mountain Pine Beetle scenario was evaluated: the expected progression of the pine beetle epidemic based on information and models obtained from the Province of B.C. Two possible rates of population growth were modelled: the expected rate and a high rate. The expected rate was based on provincial government estimates for the three Okanagan Regional Districts, and the actual growth rates from 2001 to 2006 in the major urban centres. The high growth rate was assumed to be 2.5% per year. Two possible future agricultural conditions were evaluated: the current amount of land under irrigation, and a larger area comprised of all reasonably irrigable land. Two possible trends in water use efficiency were studied: current trends[9], and a new trend represented by the Provincial Living Water Smart guideline of achieving 33% efficiency improvements by 2020.

Finally, recognizing the historic significance of the 1929-1931 drought sequence in the Okanagan, data were chosen from the future climate dataset (2010-2100 - Appendix N) to simulate a possible future three-year dry sequence. The three driest years (2076, 2033, and 2026) were selected and assumed to occur in succession.

A summary of the 15 scenarios is presented in Table 17.1. Scenarios 1-4 were run for the 2011-2040 period using the future climate data with the expected CO_2 emissions, the expected progression of the Mountain Pine Beetle infestation, and current trends of gradually reducing per capita water consumption. Using these conditions as a base, these scenarios examine the impacts of increased water usage due to increasing the population growth rate, and expanding the agricultural land base to all reasonably irrigable lands.

Scenarios 5-8 were run for the 2011-2040 period using the future climate data with the expected CO_2 emissions, expected progression of Mountain Pine Beetle infestation, and an accelerated implementation of water efficiency measures with 33% efficiency achieved by 2020. Using these conditions as a base, these scenarios examine the impacts of increased water usage due to increasing the population growth rate, and expanding the agricultural land base to all reasonably irrigable lands.

Scenarios 17-20 were run for the 3-year drought period using the future climate data with the expected CO_2 emissions, expected progression of Mountain Pine Beetle infestation, and current trends of gradually reducing per capita water consumption. Using these conditions as a base, these scenarios examine the impacts of increased water usage due to increasing the population growth rate, and expanding the agricultural land base to all reasonably irrigable lands.

Scenario 25 was run for the 2011-2040 period using the future climate data with the expected CO_2 emissions, expected progression of Mountain Pine Beetle infestation, present conditions of water consumption, present conditions of irrigation, and the present population. This scenario was used to isolate the impacts of climate change between the baseline condition and the 2011-2040 period.

[9] The assumed current trend is a 33% efficiency improvement between 2011 and 2040, or 1.1% per year over that period.

Scenario 26 is the same as scenario 25, except that the time period covers 2041-2070. This scenario was used to compare the impacts of climate change between the 2011-2040 period and the 2041-2070 period.

Scenario 27 was run for the 3-year drought period with expected CO_2 emissions, present levels of Mountain Pine Beetle infestation, present conditions of water consumption, present conditions of irrigation, and present population.

To evaluate the impacts of future climate change against historical conditions, it was necessary to run the OBWAM for the 1996-2006 period using climate data generated by the same model that was used to generate the future climate data. This provided a consistent baseline set of modelling results, which are referred to herein as the Baseline condition.

Several steps were necessary to facilitate the modelling of future scenarios in the three models (OWDM, OBHM, and OBWAM). Details on how drivers such as future population growth, water use efficiency, and agricultural land base expansion were addressed in the OWDM are provided in Appendix O. Details on how the OBHM and OBWAM were modified to account for future changes in climate, changes in land cover (e.g., disturbance by mountain pine beetle), and changes to water management are provided in Section 4.2 of Appendix J.

Table 17.1 Phase 2 scenario names and acronyms

Scenario number	Time Period	CO_2 Emission scenario	Mountain Pine Beetle	Efficiency	Agricultural Land Base	Population growth	Description	Acronym
1	2011-2040	Expected	Expected	Current use patterns and current trends	Present conditions	Expected rate	2011-2040 - current trends continued	T1C1M1E1A1P1
2	2011-2040	Expected	Expected	Current use patterns and current trends	Present conditions	High rate	2011-2040 - current trends, except rapid population growth	T1C1M1E1A1P2
3	2011-2040	Expected	Expected	Current use patterns and current trends	Irrigate all	Expected rate	2011-2040 - current trends except expanded agriculture	T1C1M1E1A2P1
4	2011-2040	Expected	Expected	Current use patterns and current trends	Irrigate all	High rate	2011-2040 - current trends except rapid population growth and expanded agriculture	T1C1M1E1A2P2
5	2011-2040	Expected	Expected	33% Efficiency	Present conditions	Expected rate	2011-2040 - efficient water use, otherwise current trends continued	T1C1M1E2A1P1
6	2011-2040	Expected	Expected	33% Efficiency	Present conditions	High rate	2011-2040 - efficient water use, rapid population growth, otherwise current trends	T1C1M1E2A1P2
7	2011-2040	Expected	Expected	33% Efficiency	Irrigate all	Expected rate	2011-2040 - efficient water use, expanded agriculture, otherwise current trends	T1C1M1E2A2P1
8	2011-2040	Expected	Expected	33% Efficiency	Irrigate all	High rate	2011-2040 - efficient water use, rapid population growth, expanded agriculture, expected climate and pattern of MPB	T1C1M1E2A2P2
17	3 driest years 2011-2100	Expected	Expected	Current use patterns and current trends	Present conditions	Expected rate	3 successive drought years - current trends continued	T2C1M1E1A1P1
18	3 driest years 2011-2100	Expected	Expected	Current use patterns and current trends	Present conditions	High rate	3 successive drought years - current trends, except rapid population growth	T2C1M1E1A1P2
19	3 driest years 2011-2100	Expected	Expected	Current use patterns and current trends	Irrigate all	Expected rate	3 successive drought years - current trends except expanded agriculture	T2C1M1E1A2P1
20	3 driest years 2011-2100	Expected	Expected	Current use patterns and current trends	Irrigate all	High rate	3 successive drought years - current trends except rapid population growth and expanded agriculture	T2C1M1E1A2P2
25	2011-2040	Expected	Expected	Present conditions	Present conditions	Present conditions	2011-2040 - effect of climate change alone	T1C1M1E3A3P3
26	2041-2070	Expected	Expected	Present conditions	Present conditions	Present conditions	2041-2070 - effect of climate change alone	T3C1M1E3A3P3
27	3 driest years 2011-2100	Expected	Present	Present conditions	Present conditions	Present conditions	3 successive drought years starting 2011	T2C1M2E3A3P3

Notes:

3 driest years 2010-2100 occur in 2076, 2033, 2026

CO_2 emissions:	1. Expected = CGCM2 A2
MPB:	1. Expected: Expected pattern of current MPB infestation and associated vegetation changes
	2. Present conditions (assume 2011, 2012, 2013)
Efficiency:	1. Current use patterns and current trends: Based on current use patterns and current trends in efficiencies (both irrigation and non-irrigation water uses); irrigation demand driven by climate
	2. 33% Efficiency improvement in all water use by 2020, no reductions past 2020 (per LWS plan); irrigation demand driven by climate
Ag Land Base	1. Present conditions: current crops and systems
	2. Irrigate all: Irrigation of all reasonable possible irrigable land
Population growth	1. Expected rate
	2. High rate
Assumptions:	For MPB, Efficiency and Population growth:
	3 driest years 2011-2100 (scenarios #17-20) - assume 2038-2040

18.0 SCENARIO RESULTS

Scenario results are presented in three parts: the first part illustrates the expected climate change impacts on Basin hydrology; the second part illustrates how water use is expected to change under the selected scenarios; and the third part identifies how changing water use can affect Basin hydrology. To simplify the evaluation of the consequences of the scenarios this Summary Report focusses on the identification and interpretation of long-term trends in the results rather than evaluating specific results at particular locations and times.

Climate Change Impacts on Basin Hydrology

Average precipitation and evapotranspiration in the Basin are not likely to change appreciably over the long term. However, maximum temperature, minimum temperature, and average temperature will likely increase over the long term. The maximum amount of water held in the upper elevation snowpack in winter will likely decline over time and the date that the snowpack reaches its maximum extent will likely become earlier (Figure 18.1). As a result, snowmelt runoff will likely peak earlier in spring, and the spring snowmelt process will likely provide a smaller amount of runoff.

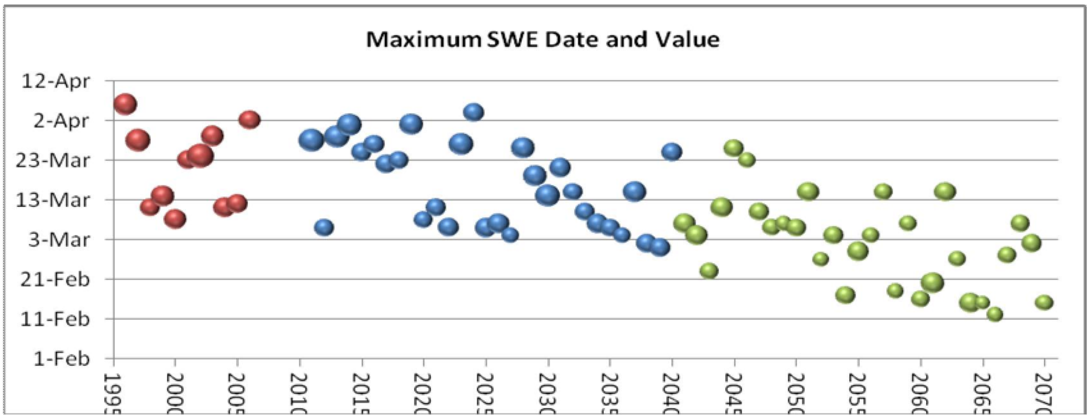

Figure 18.1 Maximum snow water equivalent (SWE) value and date of occurrence.

In Figure 18.1, the size of the bubbles indicates the relative value of the annual maximum snow water equivalent (SWE); the red bubbles represent the baseline condition (1996-2006), the blue bubbles represent the 2011-2040 scenario, and the green bubbles represent the 2041-2070 scenario.

Although there is likely to be little change in the annual total net inflow to Okanagan Lake, the scenario modelling suggests a clear shift in the timing and magnitude of the inflows to Okanagan Lake over time, as described below (Figure 18.2):

- Warmer winter temperatures will likely result in more winter precipitation in the form of rain, resulting in increased inflow during winter.
- In the spring, peak inflows will likely occur earlier and the magnitude of the peak inflow will be reduced, as a result of less snow accumulation during winter.
- The summer low flow period will likely increase in duration over the long-term.

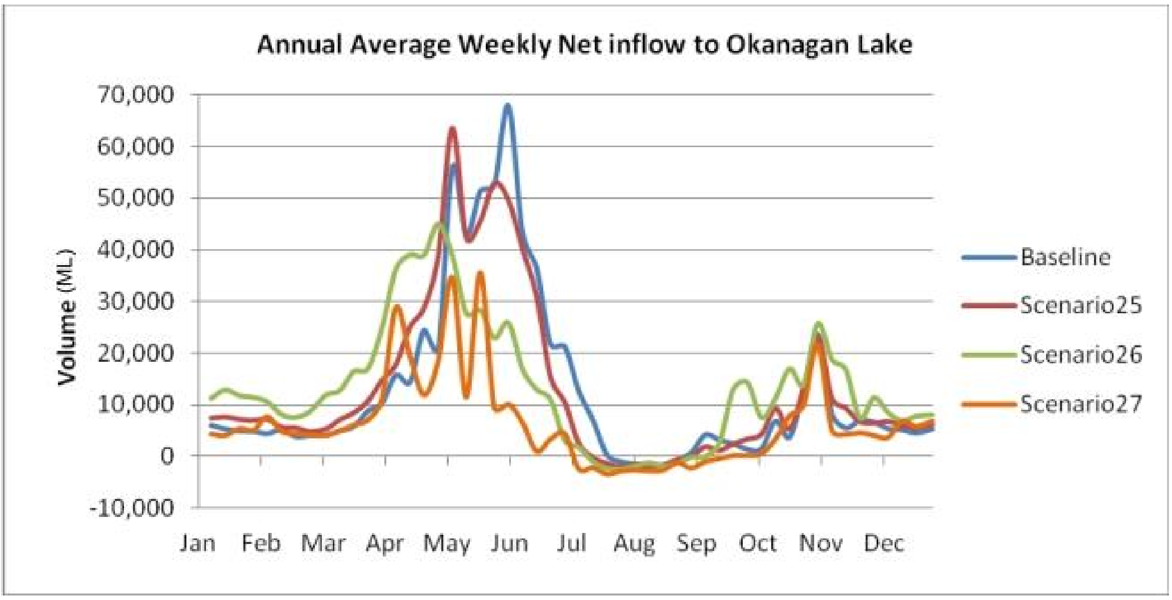

Figure 18.2 Average weekly net inflows to Okanagan Lake for the baseline condition (1996-2006) and the three scenarios that isolate the effect of climate change.

Over the long-term, Okanagan Lake will likely still operate within the 'normal' range of lake levels, but it will likely operate near or below the 'normal' range during conditions represented by the scenario 27 (Figure 18.3).

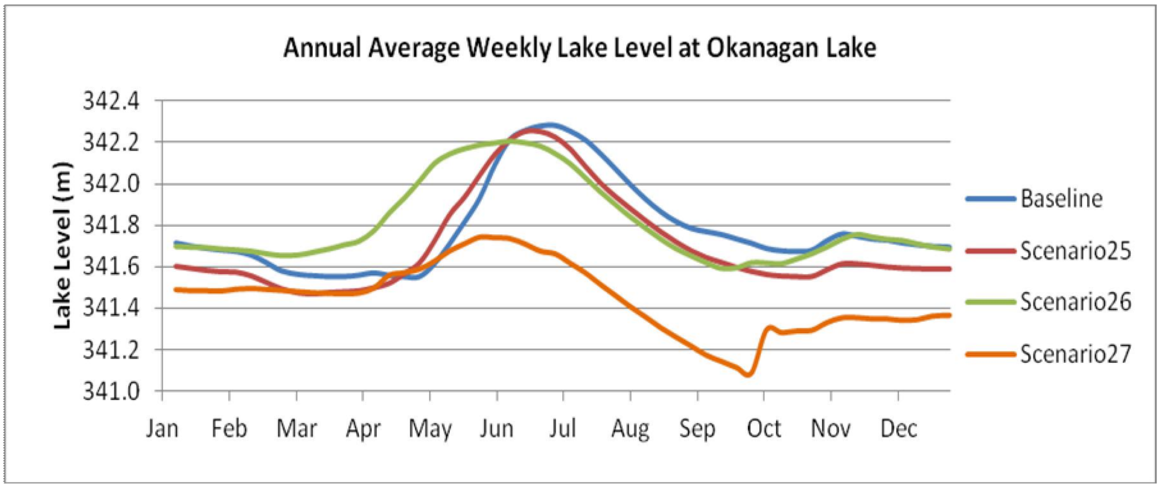

Figure 18.3 Average weekly Okanagan Lake levels for several scenarios.

In general, all of the tributaries examined in detail (e.g. Mission Creek, Figure 18.4) and the Okanagan River exhibit the same response to climate change as described above; i.e., higher flows throughout the winter months, due to warmer conditions resulting in rainfall-generated runoff; an earlier start to the spring snowmelt runoff, likely due to an earlier onset of warm spring temperatures; and a lower peak flow during the spring snowmelt runoff, likely due to less snow accumulation over winter.

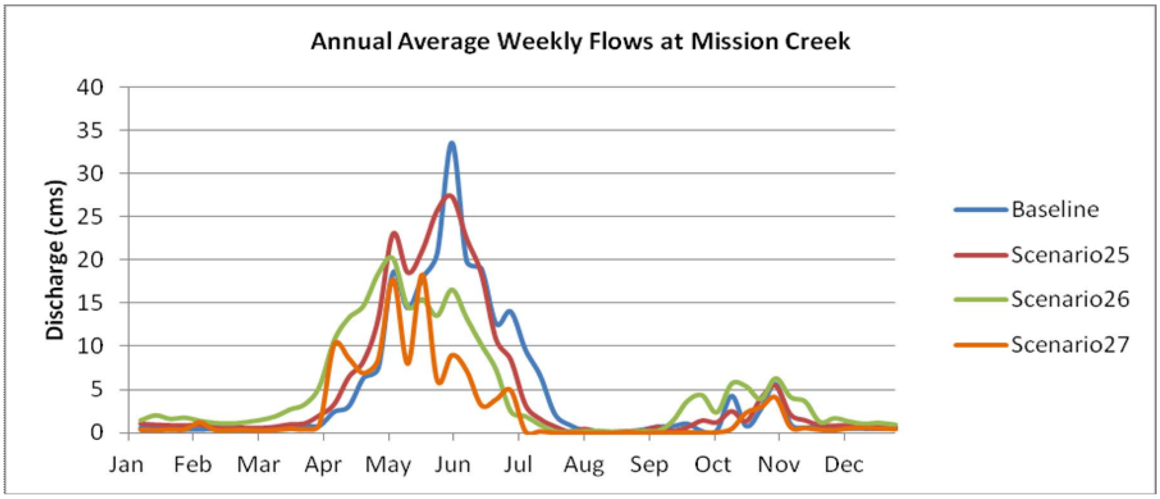

Figure 18.4 Average weekly Mission Creek flows for several scenarios.

Future trends in upland reservoir storage (Figure 18.5) show a similar response to climate change as those noted above:

- Earlier increases in water stored, likely due to an earlier onset of spring temperatures;
- Lower peak storage, likely due to lower snow accumulation;
- Earlier drawdown of storage, likely due to smaller spring snowmelt runoff volumes; and
- Significantly less stored water available in the late summer due to a longer summer season.

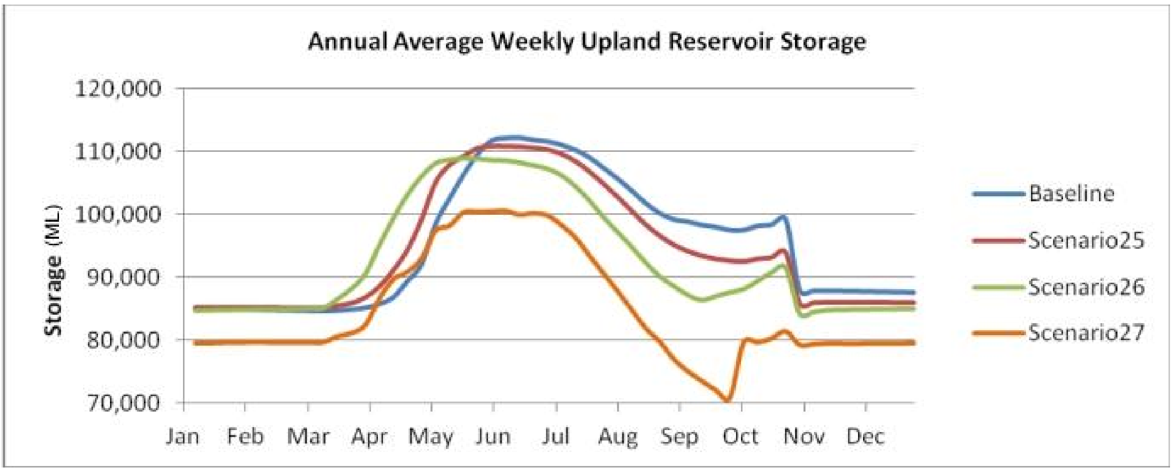

Figure 18.5 Average total weekly storage in upland reservoirs for several scenarios.

Future Water Use Changes

Future water use under each of the 15 scenarios, as estimated by the Okanagan Water Demand Model, is summarized in Figure 18.6. The key findings are as follows:

- If we assume that <u>only climate changes</u> and everything else (population, land use, amount and type of irrigated area, and water use efficiency) remains the same as it is currently, total water use is expected to increase by 10% for the 2011-2040 period and 17% for the 2041-2070 period relative to the present (i.e. scenarios 25 and 26 relative to the baseline condition (1996-2006).

- If we assume that the <u>population grows as expected</u>, and assume that water use efficiencies continue to improve at present rates, the average water use over the 2011 – 2040 period will be 4% less than it is today (i.e. scenario 1 relative to scenario 25). But if the <u>population grows faster than the estimated rate</u>, with present rates of improvements in water use efficiency, total water use will be roughly the same as it is currently (i.e. scenario 2 relative to scenario 25).

- If all reasonably possible agricultural land becomes irrigated, over the 2011-2041 period, annual water use will be 13% higher than it is currently (i.e. both scenario 3 relative to scenario 1 and scenario 4 relative to scenario 2).

- Assuming accelerated implementation of water efficiency measures with 33% efficiency achieved by 2020, water use is expected to decrease by 6-7% (i.e. scenario 5 relative to scenario 1; scenario 6 relative to scenario 2; scenario 7 relative to scenario 3, and scenario 8 relative to scenario 4).

- Under the modelled drought conditions, climate change alone is expected to increase water demands by 16% relative to the present (scenario 27 relative to the baseline condition). However, the effect of population growth alone during drought conditions will likely be outweighed by improved efficiencies (at the present rate of improvement) (scenario 17 relative to scenario 27 and scenario 18 relative to scenario 27). Expansion of the irrigated agricultural land base is however expected to result in a 25% increase in water use during drought conditions (i.e. scenario 19 relative to scenario 17 and scenario 20 relative to scenario 18).

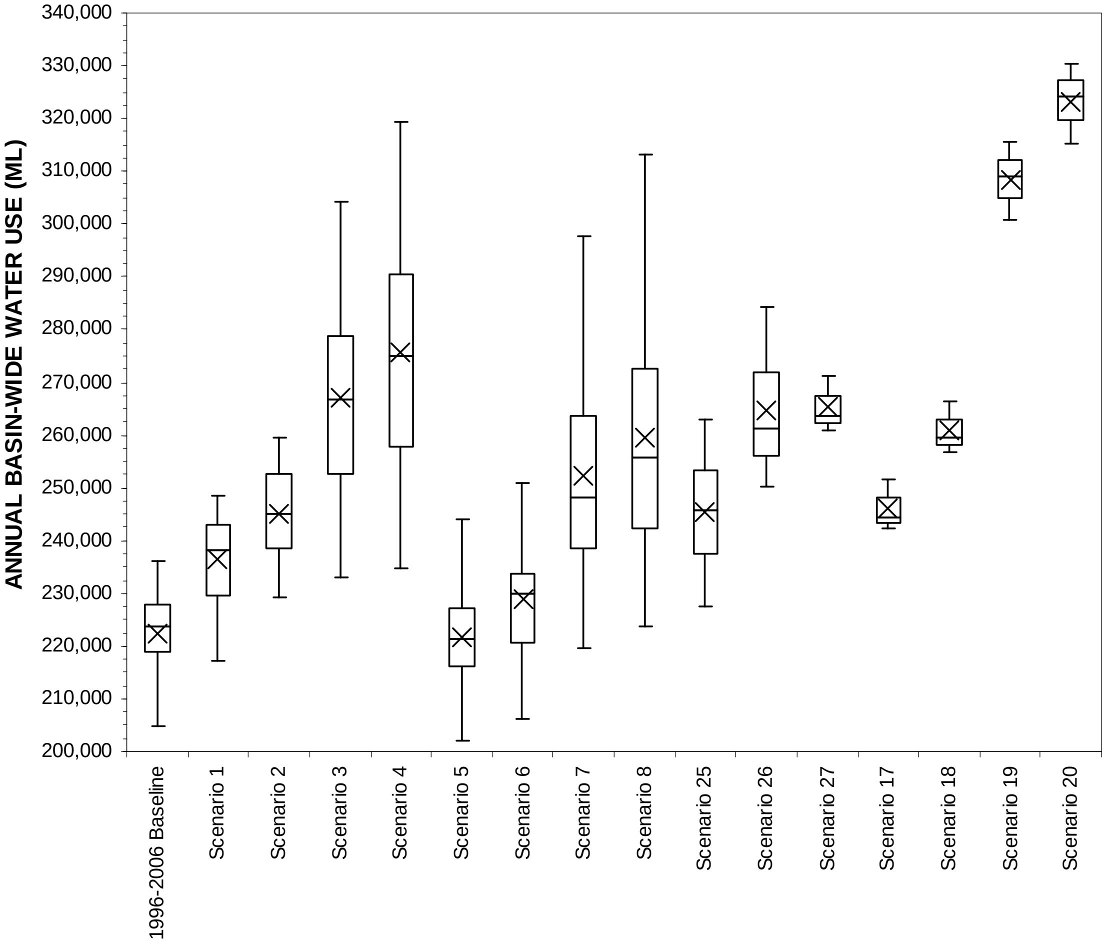

Figure 18.6 Box plot summarizing annual Basin-wide water use under the 15 scenarios.

The upper, middle and lower horizontal lines on each box on Figure 18.6 indicate the 75th percentile, the median, and the 25th percentile, respectively. The "X" indicates the average value over the simulation period, and the upper and lower "whiskers" indicate the maximum and minimum value under each scenario. Note that scenarios 27 and 17-20 are based on only three years.

Water Use Impacts on Basin Hydrology

The effects of the different combinations of future water use on Basin hydrology were examined by comparing the relative difference in model results between scenarios 1-8 relative to scenario 25. The key results are outlined here.

Water use efficiency measures will not have a significant impact on the annual net inflows to Okanagan Lake (Figure 18.7). There is sufficient water supply on an annual basis in the Basin to meet water demands now and well into the future. Although this seems like good news, it is not the whole story because the problems with water supply occur mostly during the summer when the supply is low and the demand is high. It is important to focus only on the trends in Figure 18.7, not on results for particular years, as the models cannot make predictions for specific years.

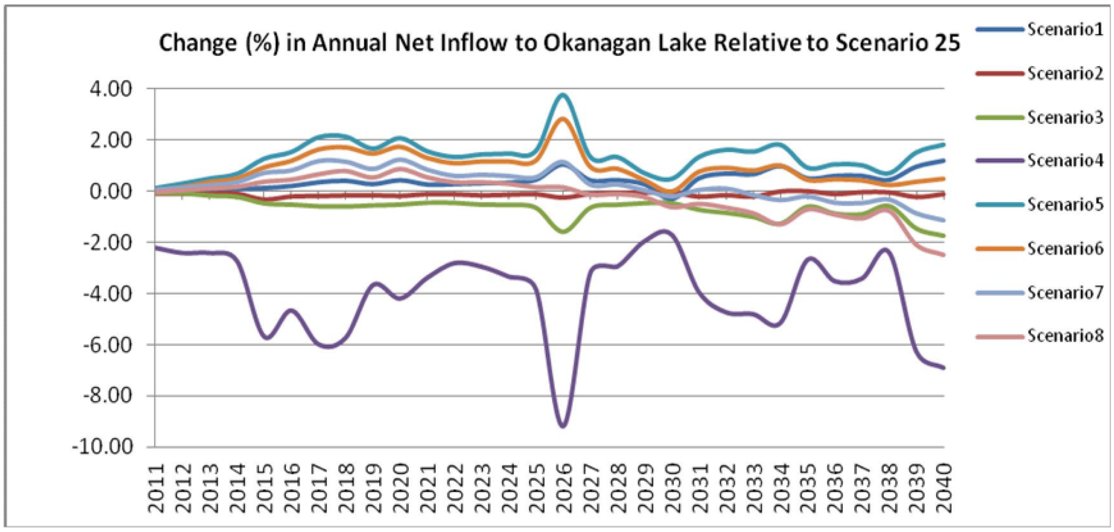

Figure 18.7 Change in annual net inflow to Okanagan Lake relative to scenario 25.

Water use has a much more significant impact on net inflows to Okanagan Lake during the summer months (i.e. June to September) when the natural runoff is usually low and demand is relatively high (Figure 18.8). For example, during the dry period from 2015-2018, the accelerated water use efficiency measures in scenario 8 will require 20% less of the available net inflow to Okanagan Lake than the worst case represented by scenario 4. As for Figure 18.7, Figure 18.8 cannot be used to infer that this specific four year period (2015-2018) will be dry - rather that there could be a similar four-year dry period sometime in the future.

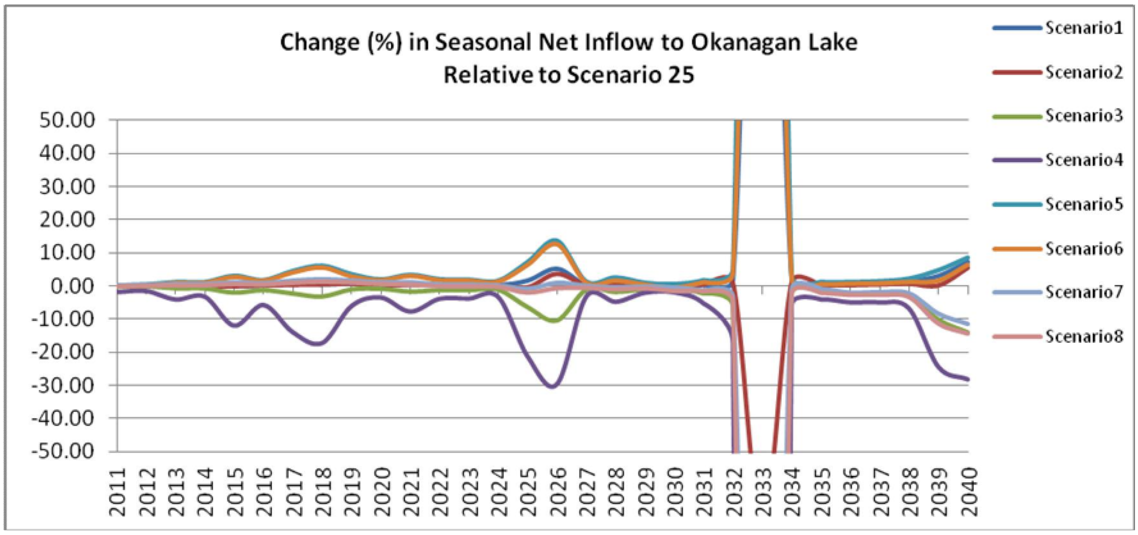

Figure 18.8 Change in seasonal (June – September) net inflow to Okanagan Lake relative to scenario 25.

As with inflows to Okanagan Lake, water use impacts on tributary streams are minimal on an annual basis, but can be significant on a seasonal basis and during periods of drought. For example, on Mission Creek (Figure 18.9) accelerated water use efficiency measures can have a positive impact (up to 25%) on summer flows.

As discussed previously, the flows in the tributaries will likely begin declining earlier in the year, and the withdrawals for human use will be significant relative to the available streamflow for longer periods of the summer. As such, even moderate reductions in water withdrawals will likely make a significant difference in either the available flows in the tributaries, or the amount of water required to be released from the upland reservoirs.

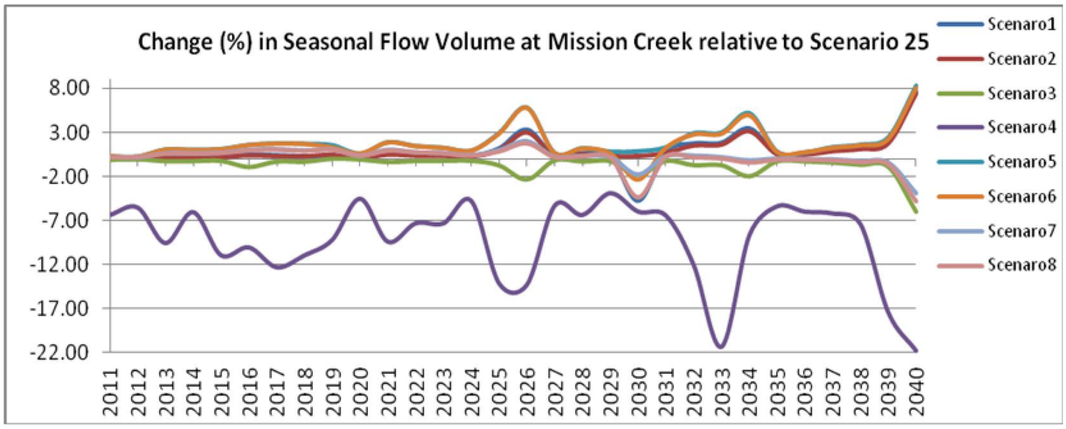

Figure 18.9 Change in average seasonal (June - September) flow in Mission Creek relative to scenario 25.

PART FIVE – KEY FINDINGS AND RECOMMENDATIONS

Part Five of this Summary Report summarizes the key findings and recommendations that were made during the Phase 2 studies.

19.0 KEY FINDINGS

Key findings of the technical studies, database development work, model development, and scenario modelling completed during Phase 2 are outlined here.

Water Management and Use

Annual Water Balances

The average annual water balances for the Okanagan Basin and for Okanagan Lake are shown in Figures 6.1 and 6.2, respectively.

Water Suppliers

- 101 known water suppliers in the Basin supply approximately 82% of the total water used in the Basin.

Water licences

- There are currently over 4,000 active water licences to store or use surface water in the Basin. In total, 443,000 megalitres (ML[10]) of surface water is allocated annually for offstream use and 350,642 ML is allocated for in-stream (conservation) use and other non-consumptive uses, for a total allocation of 793,642 ML. This compares with an estimated natural streamflow of 884,000 ML (1996-2006 average). Approximately 163,000 ML of licensed storage supports some of the water uses. About 95% of the total volume of water licensed for offstream use is held by 57 of the main water suppliers in the Basin. These same suppliers hold 88% of the licensed storage in the Basin.

Water Storage

- There are 36 large upland reservoirs in the Basin with a total developed storage capacity of 133,000 ML (82% of the total licensed storage).

[10] A megalitre (ML) is a million litres. A ML is the same as a cubic decameter (dam^3). An Olympic-sized swimming pool contains 2.5 ML.

Water Imports

- Eight (8) water suppliers import water from outside the Basin or divert water between sub-basins to supplement existing water supplies. The 1996-2006 average annual volume of water imported from outside the Okanagan Basin is 17,000 ML. This represents about 8% of the total water used in the Basin. Most of this water is routed directly to water supplier distribution systems or reservoirs.

Water Use

- The 1996-2006 average annual volume of water used in the Basin is 219,000 ML, of which 147,000 ML is taken from surface sources (this is about 33% of the licensed allocation from surface sources).

Sources of Water

- Water used in the Basin is derived from several sources, in the following proportions (Figure 6.4):
  - Surface water: 67%
  - Groundwater: 22%
  - Imported water: 8%
  - Recycled wastewater: 3%
- Amongst the surface water sources, the three most heavily utilized are:
  - Okanagan Lake
  - Mission Creek
  - Kalamalka–Wood Lake
- Groundwater is an increasingly utilized source of water. There are currently 23 main water suppliers and numerous private users that pump groundwater in the Basin.

End Uses of Water

- Of the total water used in the Basin, the proportions used by each end-use category are as follows (Figure 6.5):

  Outdoor: Agriculture: 55%
  Domestic outdoor: 24%
  Golf courses: 5%
  Parks and open spaces: 2%
  TOTAL: 86%

  Indoor: Domestic indoor: 7%
  Institutional: 1%
  Commercial: 4%
  Industrial: 2%
  TOTAL: 14%

- Outdoor irrigation areas and requirements (including losses to the subsurface) are as follows:
  - Agriculture: 18,300 ha require an average of 120,000 ML (660 mm),
  - Golf courses: 1,060 ha require an average of 10,000 ML (960 mm),
  - Parks and open spaces: 590 ha require an average of 5,000 ML (920 mm)
  - Domestic outdoor: 5,935 ha require an average of 53,000 ML (890 mm)
- Total annual irrigation requirements for 1996-2006 average 188,000 ML or 86% of the total water use in the Basin.
- Basin-wide total domestic water use averages 675 L/person/day year-round, of which 150 L/person/day is for indoor use and 525 L/person/day is for outdoor use. This means that during the landscaping irrigation season, actual outdoor use likely exceeds 1,000 L/person/day in the Basin.
- Between <u>all end-uses</u>, approximately 51,000 ML or 23% of all water extracted, imported or recycled in the Basin is lost or unaccounted for. The largest component of this [25,000 ML (11% of the total water use)] is associated with over-irrigation resulting in deep percolation of water below the root zone. An additional 10,000 ML may also be recharging aquifers through septic systems.

Groundwater Resources

- Because of minimal regulation of groundwater use, and the limited records of groundwater use, there is relatively little information on groundwater resources in the Okanagan Basin.
- A conceptual model was developed to describe the movement of groundwater beneath the land surface in the Okanagan from the uplands down to the valley bottom – a shallow flow system accounting for 85% of groundwater flow and a deep bedrock system accounting for 15% of groundwater flow.
- 79 distinct unconsolidated aquifers were identified – located primarily in the lower elevation valley bottom. Three areas of the Basin contain connected aquifer systems of regional importance: (1) North Okanagan – Coldstream/Vernon and Spallumcheen unconsolidated aquifers; (2) Central Okanagan - Greater Kelowna aquifers; and (3) South Okanagan - Vaseux Lake to Osoyoos Lake aquifers.
- Based on the assumptions and methods used in the groundwater study, the estimated mean annual groundwater discharge to the valley-bottom rivers/lakes in all 79 unconsolidated aquifers is 943,000 ML/yr. This value significantly exceeds the value estimated independently in the surface water study and by the OBHM – approximately 290,000 ML.
- The mean annual groundwater discharge into Okanagan Lake is estimated to range from 41,300 ML (surface water study) to 296,000 ML (groundwater study). The

large range in estimates is a reflection of two independent methods of analysis, and a reliance on estimated (vs. measured) groundwater properties.

Lake Evaporation

- There are at least 19 potentially-relevant methods for computing evaporation from the main valley-bottom lakes, all of which suffer from a lack of data for making the calculations.
- The Penman-Monteith method was chosen for computing lake evaporation because it is widely accepted globally due to its theoretical justification, and is the method used in both the Okanagan Water Demand Model and the Okanagan Basin Hydrology Model for computing evapotranspiration from the land surface.
- Evaporation from the main valley lakes averages 972 mm annually, based on the Penman-Monteith method.
- The evaporated volume is a significant component of the water balance of Kalamalka and Okanagan Lakes, accounting for 90% and 50%, respectively of the net inflow to these lakes.

Surface Water Hydrology

The surface water study that provided the data for calibrating the OBHM indicated the following:

- The pattern of natural runoff in the Basin varies considerably by elevation, and varies spatially in response to precipitation type and amount, evapotranspiration, and other factors. For the 1996-2006 period, total natural streamflow from all tributaries and residual areas in the Okanagan Basin averaged 884,000 ML per year. When converted to a depth, this volume would cover the watershed surface (excluding the main valley lakes) to a depth of 117 mm. Streamflow is comprised of direct surface runoff and baseflow contributed by groundwater. Approximately 83% of the annual total flows into Okanagan Lake, while 17% of the total flows into Okanagan River and the mainstem lakes downstream of Okanagan Lake.
- Upstream of Penticton, the runoff averages 130 mm, while downstream of Penticton, runoff averages only 78 mm. Furthermore, runoff on the east side of the Basin tends to be higher than on the west side. Annual flow from all tributaries and residual areas on the west side of the Okanagan Valley averaged approximately 99 mm over the 1996-2006 period, while those on the east side totalled approximately 134 mm.
- Mission Creek has the largest streamflow, delivering 28% of the total flow in the Basin. Trout and Vernon Creeks are the second and third largest contributors, each producing about 7% of the total.
- Streamflow during the 7 months of August to February accounts for only 14% of the annual total, while the 5-month period March to July accounts for 86%. The August

to February total streamflow averages about 18,200 ML per month, which is mostly contributed by groundwater (baseflow).

Instream Flow Assessment

- Prior to the beginnings of human management of water in the Okanagan, most Okanagan streams had insufficient flow during parts of the year for optimal fish production.
- Minimum instream flows for sustaining aquatic populations in 36 Okanagan tributaries were calculated using the B.C. instream flow needs (IFN) methodology, which is a desk-top analytical method. The outcomes provide a guide for selecting a minimum instream flow regime for Okanagan tributaries.
- A comparative analysis of regulated flows and naturalized flows showed that at some locations the BCIFN minimum risk flows were achieved more frequently in the late summer dry period with regulated flows than with naturalized flows. However, the opposite was true at other critical time periods (e.g. mid-winter). This indicates the importance of upland reservoirs as a potential source of instream flow in support of aquatic habitat.

OBHM and OBWAM Model Results

Based on the 11-year calibration period 1996-2006, the overall water balance for the Basin, as determined by the OBHM in conjunction with other Phase 2 studies, is shown in Figure 6.1. The values indicated on the figure are annual totals, but they are spatially and temporally averaged: i.e. they are averaged over the entire Basin surface, and they are averaged over the period 1996-2006. The figure does not indicate the variability which characterizes both water supply and demand. Decision-making must consider the seasonal variability in both supply and demand, the differences from place to place within the Basin, and the annual variability of both supply and demand.

Scenario Modelling Results

To demonstrate the power and utility of the three models developed during the study, 15 possible future scenarios were examined using the three study models. The outputs are not intended to provide the best estimate of the future. They provide one possible future outcome, based on a reasonable set of assumptions. Using the Canadian Global Circulation Model with the expected rate of global CO_2 production, the models suggest the following:

- Total annual precipitation and evapotranspiration do not exhibit any obvious trends in the future, but the average temperature is expected to increase and the number of days with temperatures below freezing is expected to decrease significantly.
- As a result of climate change, the maximum amount of water stored in the snowpack is likely to decline by almost 30% by the mid-point of this century, and the date that the peak snowpack occurs will likely become earlier by almost 3 weeks. As a result,

snowmelt runoff will likely peak 2-4 weeks earlier in the year, and spring snowmelt will provide a smaller amount of runoff.

- Although there is likely to be little change in the annual total tributary runoff, inflow to Okanagan Lake, and Okanagan River flows, the scenarios suggest a clear shift in the timing and magnitude of streamflow over time. Warmer winter temperatures will likely result in more winter precipitation in the form of rain, resulting in increased flows during winter. In the spring, peak flows will likely occur earlier and the magnitude of the peak flow will be reduced, as a result of less snow accumulation during winter. Furthermore, the summer low flow period will likely become extended over the long term.
- Over the long term, levels of Okanagan Lake are likely to remain within the "normal" range of lake levels during normal or wet years, but could be near or below the "normal" range during drought years.
- The effect of climate change on upland reservoirs will likely include earlier filling, as a result of an earlier onset of spring temperatures; lower peak volumes stored, in response to lower snow accumulation; earlier drawdown of storage, due to small spring snowmelt runoff volumes; and an average of 10% less stored water available in the late summer due to a longer summer season.
- If we assume that only climate changes and everything else (population, land use, amount and type of irrigated area, and water use efficiency) remains as it is currently, total annual water use is expected to increase by 10% for the 2011-2040 period, and 17% for the 2041-2070 period, relative to the present.
- If we assume that the population grows as expected, and assume that water use efficiencies continue to improve at present rates, the average annual water use over the 2011 – 2040 period will be 4% smaller than it is today. But if the population grows faster than the estimated rate, with present rates of improvements in water use efficiency, total water use will be roughly the same as it is currently.
- If all reasonably possible agricultural land becomes irrigated over the 2011-2041 period, annual water use will be 13% higher than it is currently.
- Assuming accelerated implementation of water efficiency measures with 33% efficiency achieved by 2020, water use is expected to decrease by 6-7%.
- In a future 3-year drought, climate change alone is expected to increase annual water demands by 16% relative to the present.
- If the irrigated agricultural land base expands to its potential size, annual water use during a 3-year drought is expected to be 25% greater than annual water use in an average year today.

20.0 RECOMMENDATIONS

The Phase 2 studies have outlined a number of recommendations for further work to improve our understanding of the water resources of the Okanagan Basin. These recommendations are summarized below.

Water Management and Surface Water

Because information on actual water use in the Basin is limited, this Project has had limited success in conclusively determining actual water use in the Okanagan Basin. The estimates of water use reported herein are based on estimates generated by the Okanagan Water Demand Model (OWDM), supported by limited data from water purveyors. Similarly, a thorough calibration of the OWDM against measured data has not been possible. It is recommended that:

- Water purveyors should measure their water withdrawals (from both surface and groundwater sources), and the amount of water they distribute to customers.
- Large water purveyors should report their water use to the Province on a regular basis. An appropriate definition of "large" could be derived from the studies reported herein. This information will improve our understanding of actual water use and will be useful in improving the natural streamflow estimates generated by the surface water hydrology study.
- Scenario results demonstrate that continuing to achieve greater efficiency in water use is very important to ensuring the long-term sustainability of the water supply. Because most of the water used is for irrigation, it is recommended that effort continue to be placed on achieving efficiencies in both agricultural and non-agricultural irrigation practices, using proven conservation measures.

Deficiencies in the hydrometric network make it difficult for water suppliers to manage their water supplies. These limitations affected the calibration of the OBHM. Recommendations include:

- Monitoring of the water supply should be improved through an extension of the hydrometric network. Monitoring stations should be placed downstream of the major storage reservoirs in the Basin. In particular, to improve the OBHM, additional monitoring should be focussed in the southeast portion of the Basin, where the network is particularly weak. Other recommendations of Dobson and Letvak (2008) should be considered.
- A field-based program to assess streamflow-groundwater interactions where streams flow across alluvial fans should be completed – this will lead to improvements in the OBHM.

- Streamflow estimates for small streams during summer low flow (or no flow) periods should be improved.
- Scenario results showed that in future, upland snowpacks will likely become smaller and melt earlier in the spring. In addition, the summer irrigation season may become longer. This will have implications for water suppliers reliant on storing spring runoff in upland reservoirs. It is recommended that water suppliers maintain their options for increasing storage in upland reservoirs in order to continue to provide reliable water supplies. Increased storage in these reservoirs could also be used to provide increased instream flows for aquatic species.

Implementing these recommendations will improve our understanding of water demand and supply in the Basin, our confidence in the OWDM and the OBHM, and our ability to make informed water management decisions. A continued focus on water use efficiency will mitigate the effects of changes in climate, population, and other drivers of water use.

Groundwater

Both groundwater resource availability and groundwater use are poorly understood in the Okanagan Basin. The following recommendations are made:

- Groundwater use should be regulated using the same system used to regulate surface water.
- Water use from groundwater should be reported to the Province.
- The network of Provincial groundwater observations wells should be extended to aquifers that are not currently monitored.
- Interactions between surface water and groundwater on the major alluvial fans in the Basin should be evaluated. This will improve the calibration of the OBHM during the low flow season from September through March, will improve our understanding of the role of groundwater, and will assist in identifying appropriate instream flow needs for key aquatic species.
- Studies to confirm the conceptual model of bedrock flow systems should be undertaken.
- Measurement and modelling of actual evapotranspiration should be conducted within the Basin – this will improve our understanding of recharge to groundwater aquifers in the Basin, and of the role of groundwater in the overall Basin water balance.

Lake Evaporation

Lake evaporation is a significant component of the water balance of some of the major valley-bottom lakes in the Okanagan Basin, yet our ability to determine reliable estimates of lake evaporation remains weak. Modelled results provide a range of estimates that result in large uncertainty. It is recommended that:

- Direct measurements of lake evaporation should be made in the main valley-bottom lakes in the Okanagan Basin. This will provide a better understanding of actual evaporation losses, and permit identification of a reliable method of estimating lake evaporation in the Basin.

Instream Flow Needs

Despite a comprehensive evaluation of relevant methods of estimating the instream flows required to sustain populations of aquatic biota and their ecosystems in the Okanagan, it is apparent that there are no desk-top methods available for reliably estimating the required instream flows. The following recommendations are made for future studies to refine the approach to specifying instream flow-needs to maintain aquatic biota and their ecosystems in the Basin:

- Conduct additional studies to assess the consequences of failure to meet particular low flow thresholds – e.g. production losses or extirpation of specified aquatic biota (fish and SARA-listed species).
- Initiate tests of the key assumption that habitat requirements of a broad range of sensitive aquatic biota will be met if the requirements of sentinel species such as salmonid fishes are satisfied.
- Assess the importance of combinations of surface and groundwater flows and withdrawals in various streams of the Okanagan to the maintenance of suitable, seasonal, thermal conditions required to sustain healthy populations of salmonids and other sensitive species of aquatic biota.
- Initiate work to identify how to expand effective application of the BCIFN methodology to sets of streams by determining the consequences of annual to seasonal temperature and flow variations on migration, dispersal, recolonization and production of sentinel species of aquatic biota among streams that taken together comprise the ecosystem(s) of such species.

In the meantime, when an appropriate minimum instream flow regime must be identified on a particular stream, it is recommended that:

- Agreement on an acceptable minimum instream flow regime for a set of streams will likely require that the agencies with a responsibility for aquatic species agree in advance on an acceptable level of risk to these species.
- A preliminary evaluation of the instream flows required to sustain aquatic biota should be made using the BC Instream Flow Methodology, with consideration of the 25^{th} flow percentile documented herein.

- These office-based studies should be supplemented by site-specific field evidence for the stream (or representative member of a characteristic set of streams).

Okanagan Water Demand Model, Okanagan Basin Hydrology Model and Okanagan Basin Water Accounting Model

Although these models make very good use of the available data and information, there are some areas where the models could be improved. The following recommendations are made:

- The techniques used to estimate outdoor water use in the OWDM should continue to be improved.
- The information used to estimate indoor water use in the OWDM has several limitations. This information should be improved as better information is made available in the future through improved reporting of water use.
- Site-specific research studies may be needed to better calibrate the computed water demand for all crops, including non-agricultural crops.
- Air temperature is a very important driver for several key hydrologic processes simulated by the OBHM. It is recommended to expand the network of stations measuring climate information in the Basin, particularly at middle and high elevations. This will make it possible for future improvements to be made in the downscaled gridded climate data used to drive the OBHM.
- The gridded temperature data should be re-examined to see if there is an apparent tendency to under-represent temperature gradients between high and low elevations, or over-predict temperatures at higher elevations, particularly during fall and winter when temperature inversions can occur.
- The manner in which the operational rules for the dams along the mainstem lakes are represented in the model should continue to be improved, to reduce the short term oscillations currently in the modelled outflow from the main lakes.
- The calibration period for the OBHM and the OBWAM could be extended to 2010, to evaluate and continue to improve the model.
- Groundwater will likely continue to be developed as a water supply source, with potential impacts to existing groundwater users and surface water bodies receiving groundwater discharge. Further hydrogeological characterization and quantification of groundwater flow and groundwater-surface water interactions are recommended. Numerical models could be used to evaluate the impacts of future groundwater development and changes to future hydrological inputs.
- Since the upland reservoirs play a key role in managing the supply of water to the downstream lakes and water licence holders, methods to improve the way the upland reservoirs operations are implemented in the model should be investigated.

- Scenario runs indicate that management of upland reservoirs will continue to be a very important aspect of future water supply for the Basin.
- In order to properly bracket the potential impacts of climate change, several additional climate models should be applied and evaluated before any final conclusions regarding climate change can be made.

Water Licences

- The OBWAM makes it possible to evaluate the impact of a water licence decision on other licensees. It is recommended that future licensing decisions consider the possible impacts of water withdrawals on other licensees within the Basin, both upstream and downstream of the proposed point of diversion.
- The OBWAM also makes it possible to evaluate the impact of a water licence decision on compliance with fisheries components of the Canada - B.C. Okanagan Basin Agreement (OBA). It is recommended that future licensing decisions consider the possible impacts of water withdrawals on compliance with the OBA.
- It is recommended that water licence decisions are made with an understanding of the wide year-to-year variability in climate that characterizes the Okanagan Basin.
- Scenario runs showed that it is possible that the irrigation season could begin earlier in spring, and extend later in the fall than at present. It is recommended that the Ministry of Environment consider extending the length of the irrigation season for these licences, subject to maintaining compliance with the Canada–B.C. Okanagan Basin Agreement.

Other recommendations

Other recommendations of Phase 2 include:

- A communication plan should be developed to communicate the results to stakeholders and the public. The web-based reporting tool currently under development should be a key part of this communication plan.
- The three Project models are capable of providing scientifically-based information to support water management decisions. The OBWB and other agencies should develop key questions that can be addressed by the models, and run these additional scenarios.
- The Project models make good use of available information. However, the models should all be improved following a period of additional data collection.

Phase 3 Work Program

The Working Group has developed a Phase 3 work plan that reflects these recommendations. The proposed Phase 3 work program can be subdivided into four components:

- Communication with stakeholders;

- Using and maintaining the databases and models;
- Turning results into policy; and
- Updating and improving the data and models;

Communication with Stakeholders

Development of the web-based reporting tool is continuing. The Project pages on the OBWB website will be enhanced for easier dissemination of Project reports. Videos on the three Project models are being developed – these videos will be available on the OBWB website. There are plans to develop visualization tools to help communicate Project results. Meetings to obtain input from stakeholders on key questions that could be addressed by the models are planned. Finally, a community consultation program is planned to communicate the Phase 2 results, and to identify ways to use the results in community planning.

Using and maintaining the databases and models

To make full use of the science developed in Phase 2 for policy development, the databases and models must be hosted and supported. This will permit and facilitate access to Project information from a broad audience – from academic personnel to the general public. It is anticipated that the OBWB will host the hardware and software for the data and models.

The OBWB plans to assist in the training of university researchers and local consultants to ensure a competent local knowledge base and to promote the use of the models. New scenarios will be examined to provide a better understanding of the possible range of water futures. Results of future scenario runs will be stored in the OkWater database so they can be viewed through the web-based reporting tool. The OkWater database will be expanded and made more accessible to the public and expert users. The OBWB will make sure that the reports used in the Project are available to the public through the OBWB website.

Turning Results into Policy

Phase 2 was primarily a technical study – it did not make policy recommendations. The work of extending the Phase 2 science and modelling to inform decision-making and policy will occur in Phase 3. In particular, three initiatives are planned:

- An analysis of the current water policies in the Okanagan, and how they are suited to respond to water shortages, with recommendations for changes as needed;
- The community consultation program identified above will inform a process to link water management and community planning; and
- Development of a strategy to facilitate equitable water distribution during shortages, such as a Basin-wide drought plan, water use plan, or water management plan.

Updating and Improving the Data and Models

Scientific work during Phase 2 was restricted to working with available data. In all cases, data gaps and data sparseness have constrained the results. This is particularly notable for the streamflow, water use, groundwater, lake evaporation, and climate data. Phase 3 will include improving the data inventories that provide the knowledge base for understanding natural processes and human management impacts in the Basin. In particular, a streamlined water use reporting tool will be developed for use by water purveyors to report their water use to the Province on a regular basis. A project to measure lake evaporation has been initiated. Funding and partnerships will be sought to improve the hydrometric network in the Basin, and the network of groundwater observation wells.

In addition, all three models developed during Phase 2 will be re-evaluated as the new data becomes available. New data will improve the performance of the models, and increase the level of confidence in their predictions. Improvements to the Okanagan Water Demand Model have already been initiated, driven by the needs of in-kind partners, including consideration of the effects of livestock water use, and refinements to the outdoor and indoor water use components of the model.

21.0 GLOSSARY

Alluvial fan	Fan shaped terrestrial deposit of alluvial sediment, which forms as sediment load is deposited because of a reduction in the stream gradient
Aquatic	With reference to water
Aquifer	An underground formation that stores groundwater
Basin	Land area from which water drains towards a common point
Bathymetry	The measurement of the depth of bodies of water
Bedrock	Rock at or near the Earth's surface that is solid and relatively unweathered
Cadastre	Property boundary
Calibrate	To check, adjust, or determine by comparison that a computer model will produce results that meet or exceed some defined criteria within a specified degree of confidence
Ecosystem	A system in which populations of species group together into communities and interact with each other and the abiotic environment
Evapotranspiration	The combined processes of evaporation and transpiration
Fracture-flow system	A bedrock aquifer in which the flow takes place primarily within fractures in bedrock
Groundwater	Water existing below the ground surface in aquifers
Hydraulics	Hydraulics deals with the mechanical properties of liquids. Free surface hydraulics and open channel flow are branches of hydraulics used to describe the properties of free surface flow, such as the flow in rivers.
Hydraulic conductivity	A measure of the ability of a soil or bedrock or unconsolidated aquifer to transmit a fluid such as water, that depends on properties of both the medium and the fluid
Hydrogeologic	Adjective of the noun hydrogeology
Hydrogeology	The geology of groundwater, with particular emphasis on the chemistry and movement of water
Hydrologic	Adjective of the noun hydrology
Hydrology	The science dealing with the properties, distribution, and circulation of water
Hydrometric network	A network of stations that measure water level and streamflow
Instream flow needs	The flow of water in a natural watercourse required to support and sustain fish and other aquatic dependent species
Limnological	Adjective of the noun limnology
Limnology	Scientific study of physical, chemical, and biological

	conditions in lakes, ponds, and streams
Metadata	A description of the data in a source, distinct from the actual data. An item of metadata may describe an individual datum, or content item, or a collection of data including multiple content
Naturalized flow	Flows that would have existed without human use or management
Nodes	Locations at which surface water properties are reported, such as the mouths of tributaries
Percolation	Vertical movement of water from the surface to the subsurface
Recharge	Refers to water entering a groundwater aquifer through percolation from the surface or through lateral movement from an adjacent upslope aquifer
Reservoir	An artificial lake used to store water
Salmonid	Of, belonging to, or characteristic of the family Salmonidae, which includes salmon, trout, and whitefish
Saturated hydraulic conductivity	The hydraulic conductivity that exists when the medium is saturated
Streamflow	The flow of water in a river or stream channel
Streamflow naturalization	The process of estimating the streamflow that would exist in the absence of human water management activities
Surface water	Water that flows in streams and rivers, and exists in natural lakes, wetlands, and in reservoirs
Transpiration	Loss of water vapour from plants
Topography	The relief exhibited by a surface
Unconsolidated aquifer	An aquifer that exists in an unconsolidated deposit
Unconsolidated deposit	Loosely arranged or unstratified sediment whose particles are not cemented together
Water demand	Water use determined using an estimation approach, such as a model
Water licence	A licence issued by the B.C. government to store water, or to withdraw water from a surface water source for a particular purpose
Water use	Volume or rate of water diverted or withdrawn from a water body (e.g. a stream, lake, or groundwater aquifer) for use by humans on the land surface. Actual water use is determined through direct measurement. Water demand is an estimate of actual water use.
Water use area	An area of the land surface which obtains water from a common location or locations
Watershed	See Basin

22.0 ACRONYMS

AAFC	Agriculture and Agri-Food Canada
AF	Acre-foot. One acre-foot is equal to 1.233 dam^3, i.e. 1.233 ML
BCIFN	BC Instream Flow Needs
cfs	Cubic feet per second. The Imperial unit of streamflow. One cfs = 0.0283 m^3/s (= 0.0283 cms)
CGCM2	Canadian General Circulation Model Version 2
CGCM2A2	Canadian General Circulation Model Version 2. A2 refers to a global CO_2 emissions scenario
cms	Cubic metres per second (an alternative form of m^3/s)
CO_2	Carbon dioxide
dam^3	Cubic decameter. One dam^3 is a volume of 10 m by 10 m by 10 m, i.e. 1,000 m^3 , i.e. 1,000,000 L, i.e. 1 ML.
EC	Environment Canada
ET	Evapotranspiration
GCM	General Circulation Model
GIS	Geographic Information System
GWBAT	Groundwater Balance Analysis Tool
ICI	Institutional, commercial, and industrial
IFN	Instream flow needs
L	Litre. There are 1,000 L in a cubic metre, and 1,000,000 L in a cubic decameter (dam^3). 1,000,000 L = 1 ML
LAI	Leaf area index
m^3/s	Cubic metres per second. The SI unit of streamflow. One m^3/s = 35.3 cfs
MAL	Ministry of Agriculture and Lands
ML	Megalitre. One ML = 1,000,000 litres, i.e. 1 dam^3
MPB	Mountain pine beetle
OBHM	Okanagan Basin Hydrology Model
OBWAM	Okanagan Basin Water Accounting Model
OBWB	Okanagan Basin Water Board
OkWater Database	Okanagan Water Database
OWDM	Okanagan Water Demand Model
PET	Potential evapotranspiration
RD	Rooting depth
UFW	Unaccounted for water
UNA	User needs assessment
WTP	Wastewater treatment plant

23.0 REFERENCES

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Appendices and Attachments

(on CD)

The Appendices and Attachments are provided on the attached Compact Disk titled:

Okanagan Basin Water Board – Okanagan Water Supply and Demand Project

Phase 2 Summary Report Text, Appendices, and Attachments

LIST OF APPENDICES

LIST OF ATTACHMENTS