Canadian Water Resources Association
British Columbia Branch

Okanagan Basin Water Board

One Watershed – One Water

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Full conference proceedings on CD
See inside back cover

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Welcome from Conference Chairs

On behalf of the Okanagan Basin Water Board (OBWB) and the B.C. Branch of the Canadian Water Resources Association (CWRA), we welcome you to the One Watershed – One Water conference.

Both hosting organizations have a keen interest in sustainable water management in the Okanagan Basin in British Columbia. The OBWB is focused on sustainable water management throughout the Okanagan Basin. The CWRA is a national organization dedicated to wise water management in every region of the country, and has representation on the Okanagan Water Stewardship Council of the OBWB.

The highly successful CWRA conference in February 2005 in Kelowna made several action-oriented recommendations for improving water management in the Okanagan Basin. Since then, considerable local, provincial, and national attention has been focused on the Basin. A few recent successes are highlighted here:

- Creation of the Okanagan Water Stewardship Council – providing scientific and policy advice to the OBWB. A long-term vision and plan for sustainable water management in the Basin has been developed by the OWSC, which will be presented at the conference;
- Completion of an Irrigation Demand Model covering all irrigated lands in the Basin. The model will allow prediction of the effects of future changes in climate on irrigation water use;
- Strong leadership on critical local water issues, such as groundwater management and source water protection, has been provided by the OBWB; and,
- The Province and the OBWB, along with many partners, have initiated Phase 2 of a comprehensive Okanagan Basin water supply and demand project (several papers on this work will be presented at the conference).

The 2008 One Watershed – One Water conference will showcase local water-related initiatives and relevant experiences in similar settings, explore current knowledge and models, focus on emerging science, and consider future management and governance challenges and solutions. We hope that it will help to strengthen our individual and collective commitment to achieving the vision of a sustainable Okanagan region.

Brian Guy
Canadian Water Resources Association

Nelson Jatel
Okanagan Basin Water Board

October 2008

Welcome from President of Canadian Water Resources Association – B.C. Branch and Chair of Okanagan Basin Water Board

On behalf of the Okanagan Basin Water Board and Canadian Water Resources Association – B.C. Branch, we would like to welcome presenters and delegates to the 2008 One Watershed – One Water conference. This conference marks an historic partnership between our organizations and an historic turning point in the management of water resources – in the Okanagan and beyond.

The last CWRA-BC conference in Kelowna, “Water – Our Limiting Resource – Towards Sustainable Water Management in the Okanagan” (2005) concluded with a call to action – to the community and to the Premier – for changing the course of water management in the Okanagan Basin. Presenters and delegates highlighted the need to prepare for global climate change and population growth, the need to undertake science-based assessments of water supplies, and the need to reinstate a system of monitoring networks for stream flow, water quality, and weather stations. Since that time an impressive amount of research and planning designed to answer these needs has been initiated.

The One Watershed – One Water conference reports back on the successes of the past three years and highlights next steps and a new call to action for water in the Okanagan.

Welcome to the Okanagan watershed.

John Slater
Chair, Okanagan Basin Water Board

Peter Morgan,
President, B.C. Branch of the
Canadian Water Resources Association

About the Canadian Water Resources Association

The Canadian Water Resources Association (CWRA) is a national organization of individuals and organizations from the public, private and academic sectors that are committed to raising awareness of the value of water and to promoting responsible and effective water resource management in Canada. CWRA membership consists of water users and water resource professionals including managers, administrators, scientists, academics, students and young professionals.

CWRA has branch organizations in most provinces and members throughout Canada and beyond. CWRA activities include hosting conferences, symposiums and workshops dealing with a wide range of water issues, quarterly publication of the Canadian Water Resources Journal and the newsletter, Water News, as well as publishing papers and reports.

For more information about CWRA membership, please contact:

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Additional information about CWRA is available at: http://cwra.org/default.aspx.

About the Okanagan Basin Water Board

The purpose of the Okanagan Basin Water Board (OBWB), established in 1969, is to provide leadership to protect and enhance quality of life in the Okanagan Basin through sustainable water resource management. The OBWB delivers a variety of services including the Eurasian watermilfoil control program, the wastewater treatment grant program, and a water management function that includes water research project management and a water conservation and quality improvement grant program. The OBWB provides the following essential functions:

- **Implementing basin-wide programs** for watermilfoil control, wastewater infrastructure funding, water research and management – benefiting all Basin residents
- **Advocating and representing** local needs to senior government planners and policy makers – protecting Okanagan interests
- **Providing science-based information** on Okanagan water to local government decision makers and water managers – for sustainable long-term planning
- **Communicating and coordinating** between government, non-government, universities and businesses – increasing the effectiveness of water projects and research
- **Building funding opportunities** by providing leverage grants, securing external dollars and identifying cost-sharing partners – expanding local capacity

Additional information about the OBWB is available at: http://www.obwb.ca.

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Modelling Evaporation from Lake Okanagan, Mainstem Lakes, Upland Lakes and Reservoirs Based on Existing Databases

William M. Schertzer and Bill Taylor

Abstract

A model capable of using a limited existing database is required for quantification of evaporation from Okanagan Lake, mainstem lakes, and for small upland lakes and reservoirs. Nineteen models, grouped according to input data requirements, (e.g. energy budget, combination, mass transfer, solar radiation-temperature, temperature or daylength methods), were assessed for computation of daily lake evaporation from six of the largest Okanagan Basin lakes (1996-2006). The models were forced with "existing" land-based meteorology, modeled water surface temperature, and limited heat content values. Results were compared to the mass transfer technique derived from eddy correlation (ETR: Trivett, 1984) and also used here as the reference evaporation. Cumulative daily evaporation ranged from ~ 350 mm/yr to 1000+ mm/yr depending on model used. Mass transfer formulations ETR (Trivett, 1984) and EQN (Quinn, 1981) produced annual evaporation in the range (350 – 450 mm/yr). Significantly higher evaporation derived from the other methods was attributed to database limitations and assumptions. Considering the limitations of the "existing" database, the ETR model is recommended for the six largest Okanagan lakes. Using ETR, the 11-year average water loss from Okanagan Lake is 169.8 $x10^6$ m^3 yr^{-1}. Kalamalka, Skaha, and Osoyoos Lakes have water losses in the order 6.78 $x10^6$, 8.82 $x10^6$ and 5.53 $x10^6$ m^3 yr^{-1} respectively. The smaller lakes, Wood and Vaseux, have average evaporative losses of 2.63 $x10^6$ and 1.01 x 10^6 m^3 yr^{-1}, respectively.

Computation of evaporation for upland lakes and reservoirs is hampered because of a paucity of meteorological and lake data. Since air temperature has been extrapolated over the Okanagan Basin (500m x 500m) grid for climate scenario computations, a generalized 2nd order polynomial relationship between 11-year lake evaporation (ETR) vs. air temperature is derived (correlations: r = 0.79 – 0.95). A grouped "small" lake formulation is recommended for application over the small upland lakes and reservoirs.

Intensive multi-year in-lake investigations are required on all six Okanagan lakes to provide quality data for rigorous model testing and to derive lake to land transformations, which can enable more efficient use of the land-based meteorology for computation of lake evaporation.

Keywords: lake evaporation, evaporation models, surface temperature, heat content, radiative fluxes, Okanagan lakes, upland lakes

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Introduction

Water quantity and quality resource issues are of increasing concern as a consequence of increased water demands from socio-economic activities and climatic stresses (Schertzer *et al*., 2004). The Okanagan valley lies in a dry region of British Columbia in which there are gradual changes in climate between the south and north of Okanagan Lake. The replenishment of water to the Okanagan lakes is irregular due to large inter-annual variations in basin runoff. Quantification of the basin hydrological budget is required since the economy of the basin is heavily dependent on agriculture, which uses 70% of available water as well as water based tourism and recreational activities.

A comprehensive research investigation was initiated on the six main Okanagan lakes during 1971 (April – October) as part of the British Columbia Okanagan Agreement (1974) to provide a knowledge base for determining probable future states of the water resources in the Okanagan valley. A summary of investigation was prepared by Pinsent and Stockner (1974), which included knowledge gained on geological, physical, chemical and biological characteristics of the lakes. During the 1974 Okanagan Study, estimates were made of monthly evaporation but no actual measurements were made nor was any check possible. A better knowledge of lake evaporation was required for water management.

In 1980-81, the Implementation Board approved a study to provide a suitably precise yet practical method of estimating evaporation from Okanagan Lake. A mass transfer method was calibrated based on eddy correlation observations located at Penticton Marina (Trivett, 1984). The investigation concluded that Okanagan Lake evaporation was significantly over-estimated using methods such as pan, temperature index and Morton approach (Morton *et al*., 1980). In the intervening years since the 1984 results, the lake evaporation issue has not been resolved.

In 2004, the Province of British Columbia (BC) initiated a study to determine the current supply and demand for water in the Okanagan Basin. Phase I of the study identified and catalogued relevant data sources, identified gaps, and developed a strategy for future studies. Through partnership between the Okanagan Basin Water Board (OBWB), Environment Canada, Agriculture Canada and the First Nations, a Phase II study was initiated with three broad goals: (a) to determine the current supply of and demand for water throughout the Okanagan Basin; (b) to develop or select a model that routes water from tributaries into main valley lakes and downstream into Lake Osoyoos that can be used to examine water management alternatives; and (c) to identify future changes in both supply and demand and to run the model for several realistic future scenarios. A Work Scope was developed to investigate lake evaporation as one of the critical hydrological components in this assessment.

This study is focussed on assessing the capability to compute lake evaporation in the Okanagan Basin. The primary objective is to assess a range of lake evaporation methods to compute daily evaporation for Okanagan Lake, five other mainstem lakes (Kalamalka, Wood, Skaha, Vaseux and Osoyoos) and for upland lakes and reservoirs using existing meteorological, radiation, and limnological data over the period 1996-2006. Evaporation from the recommended models are to be uploaded to the ESSA database for assessment of hydrologic budget and climatic impacts for water management.

Lakes and Database Characteristics

The Okanagan Basin is a long north-south trench in the interior plateau of British Columbia (Zaremba *et al.*, 2005). Lake Okanagan lies within the Okanagan Valley (Fig. 1). It is a long and narrow lake approximately 120 km in length and ranges from 1.5 to 5 km in width. The lake has a complex bathymetry which divides it into three main basins. The Okanagan Basin also includes five other mainstem lakes (Kalamalka, Wood, Skaha, Vaseux and Osoyoos Lakes). The main physiographic characteristics of the six lakes are given in Fig. 1.

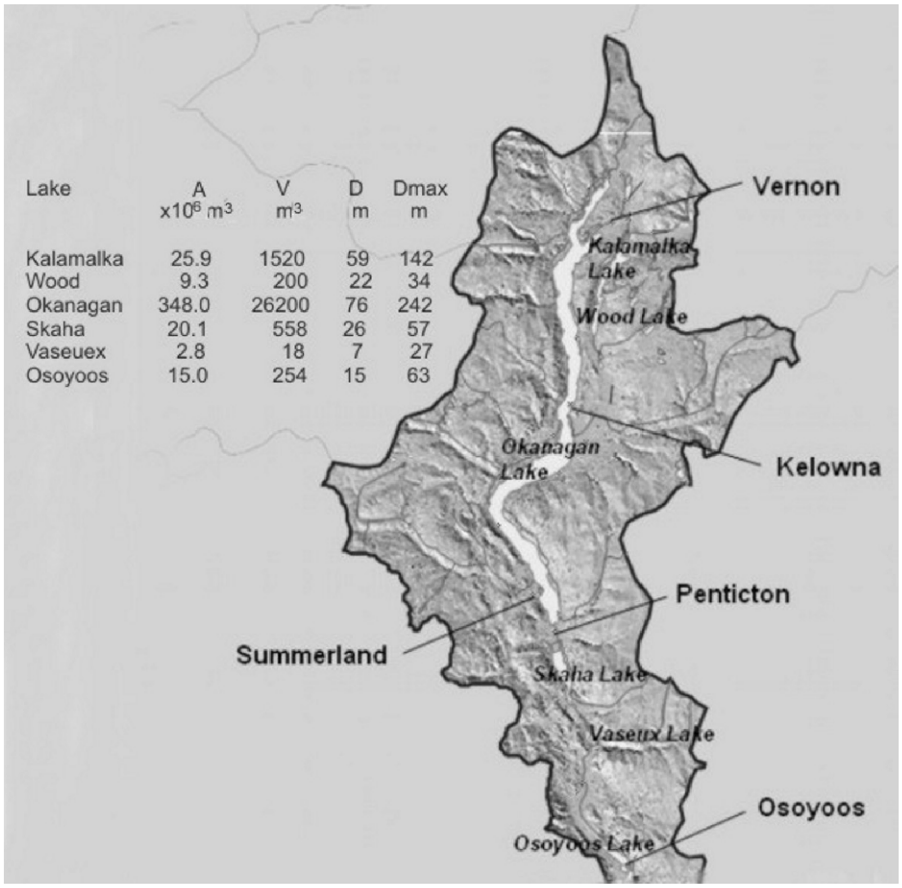


Figure 1: Okanagan Basin and location of the six main Okanagan Lakes, meteorological stations and bathymetric characteristics.

Data requirements for computing lake evaporation vary depending on the methodology chosen. Typical inputs may include basic meteorology, radiative fluxes, water surface temperature and heat content. This study is charged with using existing databases over the 1996-2006 period. No over-lake time-series data are available, therefore necessitating use of shore-based and computed values.

Daily-averaged meteorological variables were formed from hourly observations at five land-based sites (Penticton Airport, Kelowna Airport, Summerland CS, Osoyoos CS, and Vernon CS (Schertzer & Taylor, 2008). All stations include observations of air temperature, dewpoint temperature, wind speed and relative humidity with completeness ranging from 85 -100% of the record. Penticton Airport and Kelowna Airport include observations of cloudiness (~ 100% complete) and sunshine ranging 32-75% complete. Figure 2a shows an example of the long-term mean distribution of daily air temperature for Penticton A. Superimposed on the distribution is an 11-year long-term mean curve. Long-term mean curves have been derived for all of the required meteorological variables and used to substitute for missing data.

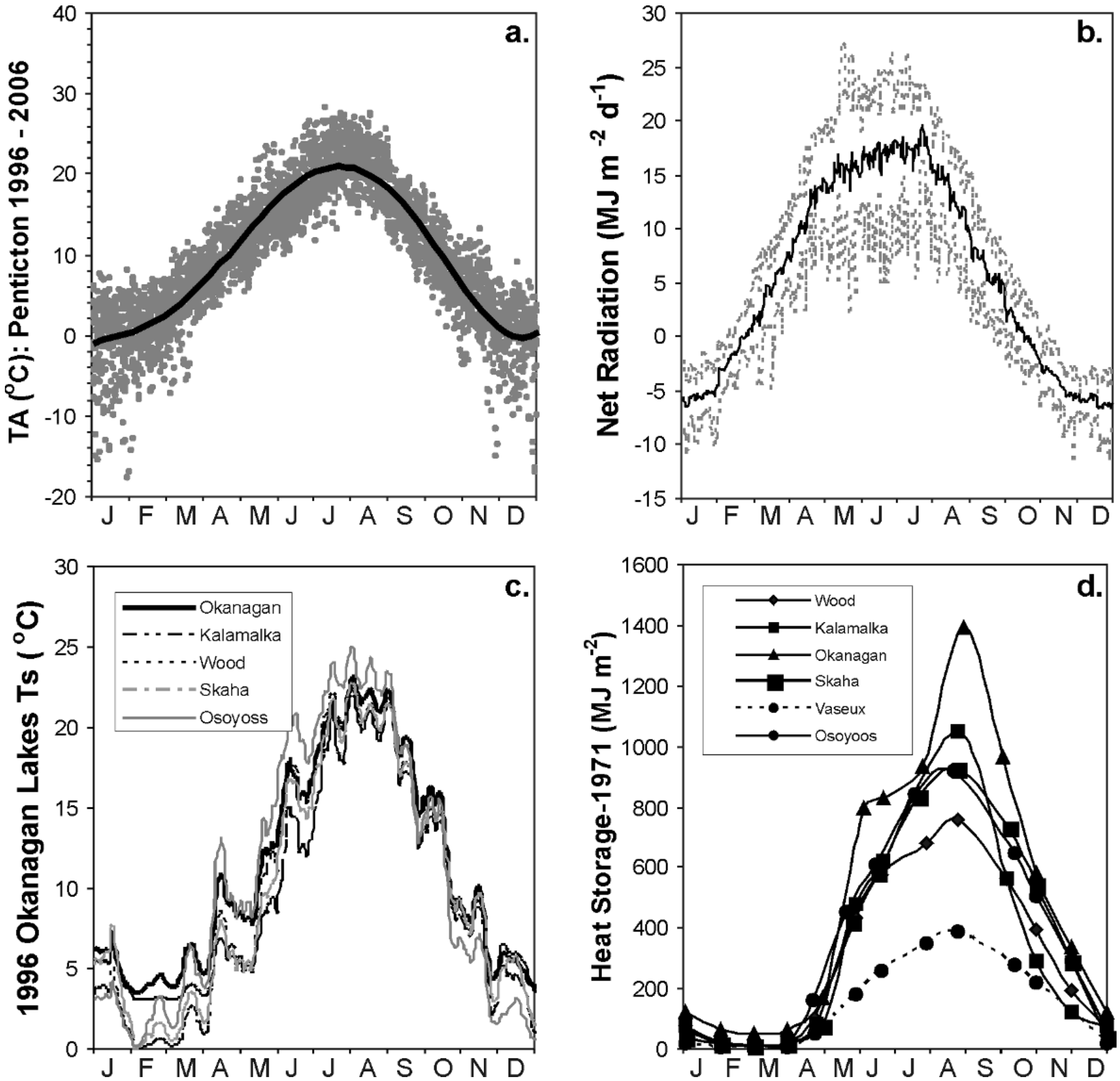


Figure 2: Example of the variation of (a) Penticton air temperature (1996-2006), (b) Okanagan Lake net radiation (1996-2006), (c) surface water temperature for Okanagan Lakes, (d) heat content of Okanagan Lakes (1971). For plotting, incoming fluxes are positive and vice versa.

For evaporation methods requiring net radiation, components of the net radiative balance were computed using existing meteorological data (Schertzer & Taylor, 2008), and summed algebraically to derive the net radiation (Q^*) in Fig. 2b (1996-2006). Solar radiation input is minimal during the late fall and winter months and heat gained from the summer is partially lost to the atmosphere through emitted longwave radiation resulting in low to negative net radiative fluxes. Net radiation is maximal in the summer months when solar radiation inputs are instrumental in lake heating.

Surface water temperature is an important variable for lake evaporation computation, however, it is not routinely measured for the Okanagan lakes. Consequently, daily surface temperature is computed for each lake for the entire period 1996-2006. The surface water temperature is based on a hysteresis function between 10-day mean air temperature and water surface temperatures (Hyatt *et al*., 2008). The relationship is $T_s = \mu_h + (\alpha_h - \mu_h)/1 + e^{\gamma_h(\beta_h - T_a)}$, where, T_s is estimated water surface temperature (^oC), T_a is measured air temperature (^oC), α_h is estimated maximum water temperature (^oC), μ_h is minimum water surface temperature (^oC), β_h is air temperature at inflection of S-shaped function, and γ_h is maximum slope of the function. Figure 2c shows an example of the computed water surface temperature for the six Okanagan lakes for 1996 using the Hyatt Logistical Model Approach (Hyatt *et al*., 2005). Minimum surface water temperatures that are equal to, or approach 0^oC are computed for Lakes Wood, Skaha and Osoyoos. In the absence of ice information, we have assumed ice cover if the computed surface temperature is 0^oC, however, based on Fig. 2c for 1996, there are few occasions at which the surface temperature is at 0^oC. During the heating phase, there are larger differences between lake temperatures than in the cooling phase. During the warming to the peak temperature in July-August, some of the highest temperatures are computed for Osoyoos Lake and the lowest for Kalamalka Lake. Peak temperatures in 1996 are computed in the range 22 – 25 ^oC depending on lake. In the cooling phase, from August – December the lakes have a nearly 3-month period in which surface temperatures are very similar. Oscillations in the surface water temperature may be related to weather; however, we note that the model uses 10-day mean air temperature as the predicted value, which is applied to dampen the larger daily air temperature changes compared to the water surface. Future research is required to refine the method.

Lake heat storage change *(Qx)* is a requirement in several complex evaporation models. A time-series of spatially representative vertical temperature profiles combined with the lake volume can be used to derive lake heat content from which the daily heat storage change can be computed. Unfortunately, such observations are not available for the Okanagan lakes except for 1971 based on a limited number of lake surveys (Blanton & Ng, 1971; 1972). An approximation of the heat storage *(H)* for each lake from May to November is derived by cubic spline interpolation through heat contents computed from limited summertime lake surveys and subjective interpolation over the remaining months ensuring closure of the heat content curves. Figure 2d shows the relationship between heat contents of the six lakes. Vaseux Lake has the lowest total heat content (~ 400 MJ m^{-2}) compared to Okanagan Lake (~ 1,400 MJ m^{-2}). In general, the slopes of the lake heat content curves during the heating cycle are less steep than in the cooling phase (after maximum heat content). Based on the limited data from 1971, Kalamalka Lake has a net heat loss at a similar rate as Okanagan Lake while lakes Skaha, Osoyoos, and Wood have similar rates of heat gains and loss although they have different magnitudes of maximum heat content. In the absence of spatially representative lake temperature profile observations for the Okanagan lakes during 1996-2006, the heat content curves generated from 1971 observations (Blanton & Ng, 1972), are assumed to apply for all years 1996-2006. This is a broad assumption since weather conditions vary from year to year and consequently the magnitude and timing of lake heat gains and losses can be affected. Daily heat storage change was approximated as

$Qx = dH / dt$, where t is one day. Heat storage change is small during the winter period January – March compared to other times of the year for all lakes.

Evaporation Models

This investigation follows the general design of several previous studies that evaluated multiple evaporation methods. In particular, this study includes many of the methods tested by Rosenberry *et al*. (2007) with the addition of several other techniques, which are either used in the Okanagan Basin or which may be applicable in other parts of the basin that have a paucity of observations.

Table 1 provides a listing of the 19 evaporation models categorized into 6 groups in terms of similarity and common data requirements as the Energy Budget Group, Combination Model, Solar Radiation-Temperature, Temperature, Daylength Method, and Mass Transfer Group. Trivett (1984) derived a mass transfer formula for Okanagan Lake based on eddy correlation observations. Details of the models listed in Table 2 can be found in the primary literature from the following: EEB (Harbeck, 1962; Bowen, 1926), EPT (Stewart & Rouse, 1976), EBR (deBruin & Keijman, 1979), EPM (Allan *et al*., 1998), EPN (Brutsaert, 1982), EPK (Maidment, 1992), EBS, Brutsaert & Stricker, 1979), EDB (deBruin, 1978), EJH (McGuinness & Bordne, 1972), EMK (Makkik, 1957), ESS (McGuinness & Bordne, 1972), ETU (Turc, 1961), EHM (Hamon, 1981), EBC (McGuinness & Bordne, 1972), EPA (McGuinness & Bordne, 1972), EHS (Hargreaves & Samani, 1985), ERH (Rassmussen *et al*, 1995), ETR (Trivett, 1984), EQN (Quinn, 1978). Since the 1980-81 evaporation study was the only one with verified evaporation measurements conducted on this lake and since the derived mass transfer coefficients are similar to those in other lakes, the mass transfer method of Trivett (1984) is also used as a reference evaporation value.

Table 1: Evaporation models used in this analysis. (see: Schertzer and Taylor, 2008)

Energy Budget Group

EEB : Energy Budget $$E = \frac{Qs - Qr + Qa - Qbs - Qx + Qv - Qb}{\rho(L(1+\beta) + cTo)}$$

Combination Group

EPT: Priestly-Taylor $$E = \alpha \cdot (\Delta / \Delta + \gamma) \cdot ((Q^* - Qx) / L\rho) \times 86.4$$

EBR: deBruin-Keijman $$E = \frac{\Delta}{0.85\Delta + 0.63\gamma} \frac{(Q^* - Qx)}{L\rho} \times 86.4$$

EPM: FAO Penman-Monteith $$E = \frac{0.408\Delta\left(Q^* - Qx\right) + \gamma \frac{900}{T + 273} U_2 vpd}{\Delta + \gamma\left(1 + 0.34U_2\right)}$$

EPN: Penman $$E = \frac{\Delta}{\Delta + \gamma} \frac{(Q^* - Qx)}{L\rho} \times 86.4 + \frac{\gamma}{\Delta + \gamma}(0.26 \cdot (0.5 + 0.54U_2)(es - ea))$$

EPK: Penman-Kimberly $$E = \frac{\Delta}{\Delta + \gamma}\left(Q^* - Qx\right) + \frac{\gamma}{\Delta + \gamma} \frac{6.43Wfvpd}{\lambda}$$

EBS: Brutsaert-Striker $$E = (2\alpha - 1)\left(\frac{\Delta}{\Delta + \gamma}\right)\left(\frac{Q^* - Qx)}{L\rho}\right) \times 86.4 - \frac{\gamma}{\Delta + \gamma} 0.26 \cdot (0.5 + 0.54U_2)(es - ea)$$

EDB: deBruin $$E = 1.192\left(\frac{\alpha}{\alpha - 1}\right)\left(\frac{\gamma}{\Delta + \gamma}\right)\frac{(2.9 + 2.1U_2)(es - ea)}{L\rho} \times 86.4$$

Solar Radiation – Temperature Group

EJH: Jensen-Haise $$E = (0.014Ta - 0.37)(Qs \times 3.523 \times 10^{-2})$$

EMK: Makkink $$E = \left(\left(52.6 \cdot (\Delta / \Delta + \gamma) \cdot (Q_S / L\rho)\right) - 0.12\right)$$

ESS: Stephens-Stewart $$E = (0.0082Ta - 0.19)(Qs \times 3.495 \times 10^{-2})$$

ETU: Turc

$RH < 50\%$: $$E = 0.013\left(Ta / (Ta + 15)\right)\left(Qs + 50\right)\left(1 + ((50 - RH)/70)\right) \cdot 86.4$$

$RH > 50\%$: $$E = 0.013\left(Ta / (Ta + 15)\right)\left(Qs + 50\right) \cdot 86.4$$

Temperature – Daylength Group

EHM: Hamon $$E = 0.55\left(D/12\right)^2 (SVD/100)(25.4)$$

EBC: Blaney-Criddle $$E = (0.0173Ta - 0.314) \times Ta \times (D / D_{TA}) \times 25.4$$

Temperature Group

EPA: Papadakis $$E = 0.5625(es\max - (es\min - 2))(10/d)$$

EHS: Hargreaves-Samani $$E = 0.0023\left(Ta\max - Ta\min\right)^{1/2}\left(Ta + 17.8\right) \cdot Ra$$

Mass Transfer Group

ERH: Ryan-Harleman $$E = \{[(2.7(\Delta\theta v)^{0.333} + 3.1U_2)(es - ea)] / L\rho\} \times 86.4$$

ETR: Trivett $$E = 0.024(es - ea)U_2$$

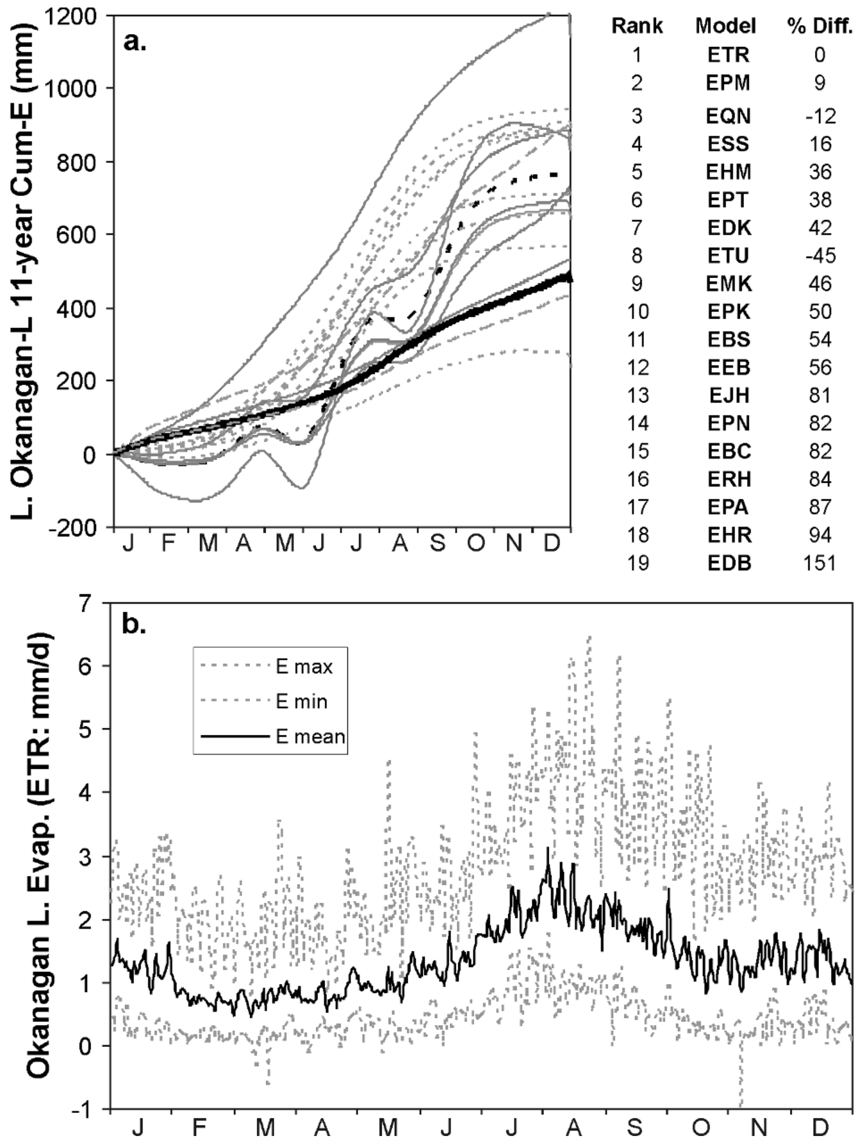
EQN: Quinn $$E = (0.052 + 0.0066U_3)(es - ea)U_3$$

Multipliers 10, 25.4 and 86.4 convert to daily values (Rosenberry *et al.*, 2007)

Results

Mainstem Lakes

Daily lake evaporation (mm/d) was computed based on 19 evaporation formulae representative of the six groups outline above. The daily evaporation estimates from each model for the period 1996-2006 were used to generate long-term mean cumulative evaporation curves for each model and lake.



Rank	Model	% Diff.
1	ETR	0
2	EPM	9
3	EQN	-12
4	ESS	16
5	EHM	36
6	EPT	38
7	EDK	42
8	ETU	-45
9	EMK	46
10	EPK	50
11	EBS	54
12	EEB	56
13	EJH	81
14	EPN	82
15	EBC	82
16	ERH	84
17	EPA	87
18	EHR	94
19	EDB	151

Figure 3: Example of the Okanagan Lake long-term averages (1996-2006) for, (a) distribution of cumulative daily evaporation – thick line is ETR, dotted line is EEB, grey line are combination models and dashed grey lines are all other models, and (b) the daily long-term mean and range of evaporation based on the mass transfer model ETR (Trivett, 1984).

Figure 3a shows an example of a comparison between long-term averaged (11-year mean) cumulative daily evaporation from each model for Okanagan Lake. A broad range of cumulative annual evaporation was computed between models for all six lakes. In general, evaporation from the Trivett (1984) mass transfer model is significantly lower than that derived from other methodologies. This was also observed for 1980-81 eddy correlation (mass transfer) results in comparison to pan, temperature index and Morton's method (Trivett, 1984). In Fig. 3a, oscillations in the energy budget and combination model outputs are related to the heat storage change. The annual total evaporation from each model was compared to the evaporation generated from the Trivett (1984) mass transfer formula through use of a simple rank order difference,

$$Rank = [(E_{(Model)} - E_{(ETR\ Model)}) / E_{(ETR\ Model)}] x100.$$

where, $Rank$ represents the percent difference compared to the reference evaporation (ETR model), $E_{(model)}$ represents evaporation from a model, and $E_{(ETR\ model)}$ is evaporation from the reference model (ETR: Trivett, 1984). The rank order is given alongside of Fig. 3a. For some lakes and models, the differences between computed evaporation and the reference evaporation (ETR) exceeded 100%. For Okanagan Lake, models with results within $\pm 20\%$ of the reference evaporation value (ETR: mass transfer) were models EPM, EQN, and ESS.

Figure 3b shows an example of the long-term (11-year) daily mean and the range of evaporation computed for Okanagan Lake based on the ETR mass transfer approach (Trivett, 1984). The seasonal cycle of the evaporation from Okanagan Lake differs from the Laurentian Great Lakes (e.g. Schertzer, 1997), which have low summertime evaporation followed by higher evaporative losses in the fall as large heat gains are lost through radiative and turbulent heat transfers. Fig. 3b indicates that evaporation for Okanagan Lake and (other mainstem lakes) is maximal in the summer - early fall period as a result of higher vapour pressure differences compared to the rest of the year. In general, mean evaporation is lowest for the more northerly lakes compared to Okanagan Lake and the lakes situated towards the south (Schertzer & Taylor, 2008).

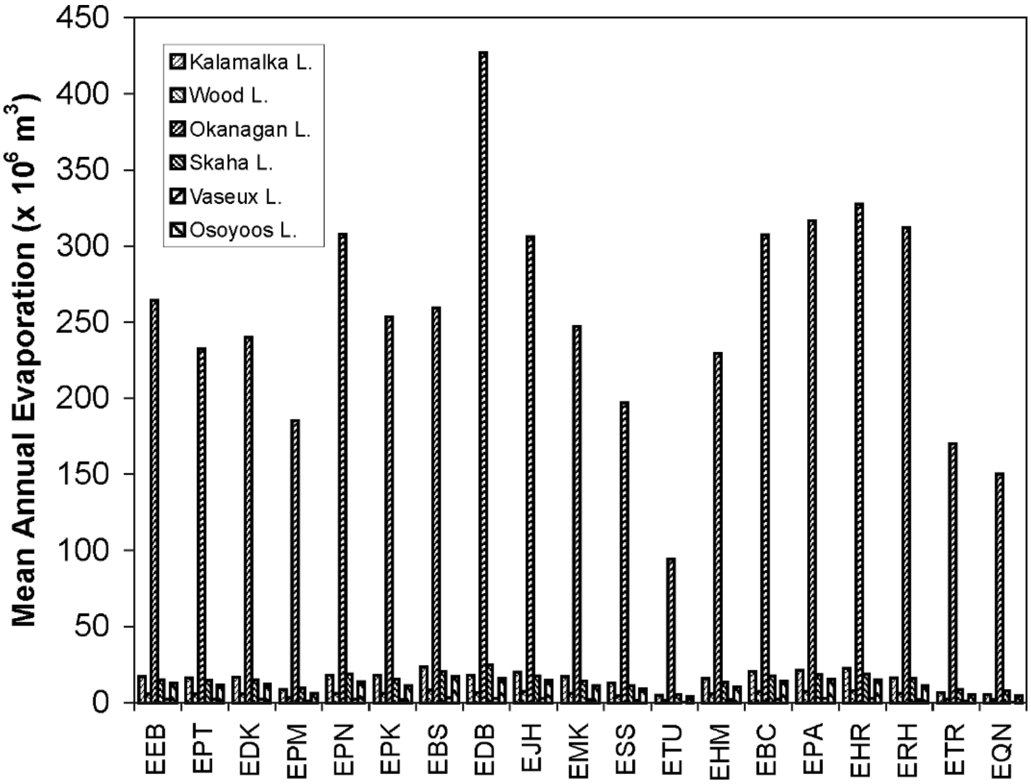


Figure 4: Comparison between 11-year mean annual volume of water evaporated based on 19 evaporation models from Kalamalka, Wood, Okanagan, Skaha, Vaseux and Osoyoos Lakes.

Each of the Okanagan lakes have different physical dimensions such as surface area, depth and volume (Fig. 1). The differing morphometric conditions affect such factors as the lake heat storage and the effective surface area available for the surface evaporation process. Graphical representation of the 11-year annual-averaged evaporation from Lake Okanagan based on 19 evaporation models is shown in Fig. 4 for Okanagan Lake and the other five mainstem lakes. Using ETR, the 11-year average water loss from Okanagan Lake is 169.8 x10^6 m^3 yr^{-1}. Kalamalka, Skaha, and Osoyoos Lakes have water losses in the order 6.78 x10^6, 8.82 x10^6 and 5.53 x10^6 m^3 yr^{-1} respectively. The smaller lakes, Wood and Vaseux had average evaporative losses of 2.63 x10^6 and 1.01 x10^6 m^3 yr^{-1} respectively.

Upland Lakes and Reservoirs

Database limitations are much greater for calculation of evaporation from upland lakes and reservoirs, which precludes application of such techniques as the energy budget or combination models. The analysis for the main lakes suggests that many of the empirical relationships that have less input data demands may also require further research to verify that the coefficients are applicable to the Okanagan Basin. The mass transfer approach also requires data that is not available in the area of the upland lakes and reservoirs. Since daily precipitation and temperature data have been interpolated to a 500 m x 500 m grid over the Okanagan Basin, an alternative approach is adopted that uses air temperature as a predict and for approximating lake evaporation (e.g. Rosenberry *et al*., 2007).

Figure 5 shows example scattergrams between longterm (11-year) mean lake evaporation versus air temperature with 2nd order polynomial curves superimposed for the smaller lakes Osoyoos-Vaseux and Kalamalka Lakes. For Okanagan Lake, the correlation coefficient is $r = 0.73$; Kalamalka Lake $r = 0.80$; Wood Lake $r = 0.90$; Skaha Lake $r = 0.74$; and Osoyoos/Vaseux Lakes $r = 0.95$. In general, the shape of polynomial curves generated for all lakes showing lowest evaporation occurring when air temperature ranges 0 to 10°C and increasing in conditions of higher air temperatures.

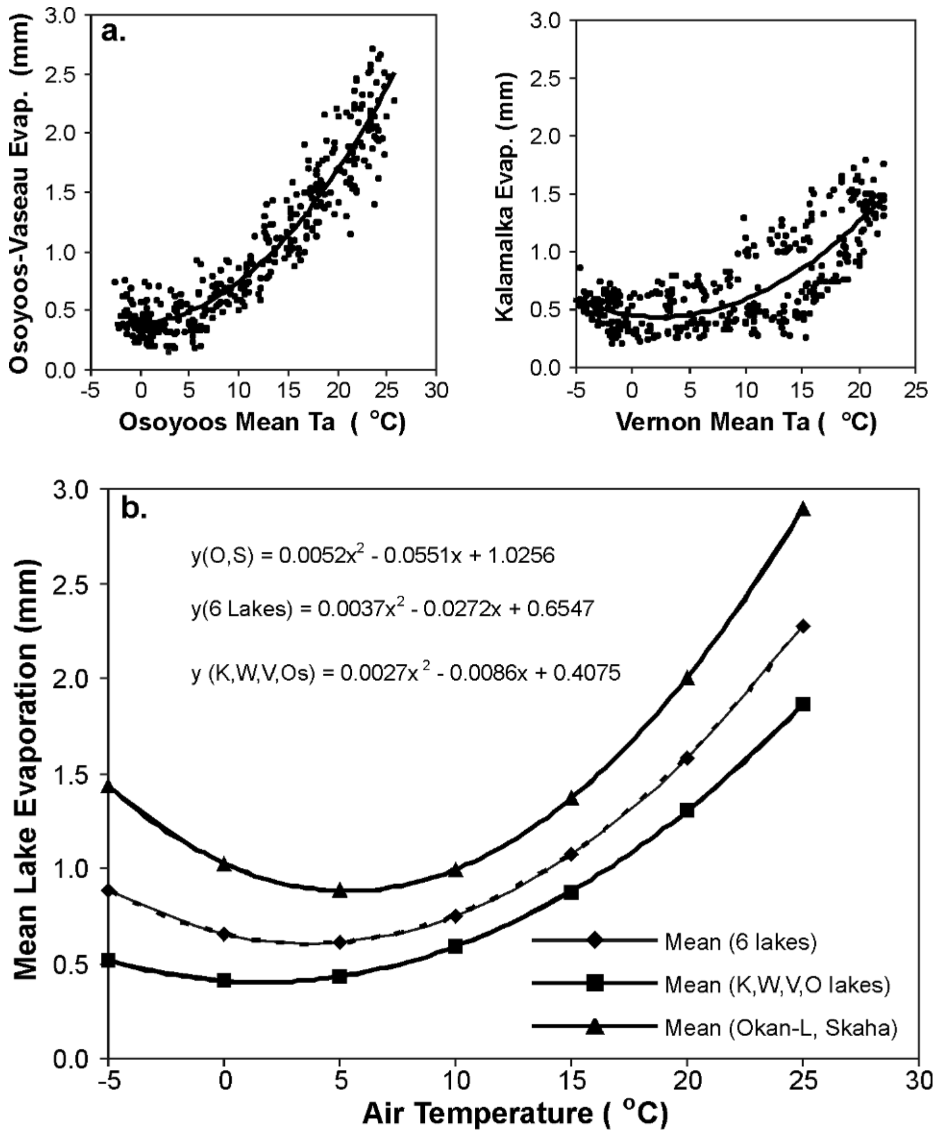


Figure 5: An example of (a) scattergrams of 11-year mean of evaporation (ETR: Trivett 1984) and air temperature for Osoyoos-Vaseux and Kalamalka Lakes with 2nd order polynomial curves, and (b) generalized regression curves between computed long-term mean lake evaporation (ETR model) and station air temperature for 3 lake combinations.

In low air temperature ranges of -5 to 0 °C, the 2nd order polynomials suggest either low or decreasing evaporation, however, the shape of the curves in this range of air temperature may be an artifact of the regression analysis. Okanagan Lake generally does not have a significant ice cover and evaporation may still be expected at a low rate during the winter conditions. Skaha Lake is downstream of Okanagan Lake and it may respond similarly to Okanagan Lake. Other lakes in the system experience ice cover during winter. The effect of ice is to decouple the lake surface from the atmosphere and consequently in the presence of a complete ice cover, evaporation from the lake does not occur. As such, application of the polynomial relations for approximation of lake evaporation should be constrained at times when air temperature is < 0^oC in the presence of ice. In the case of Okanagan Lake and Skaha Lake with no ice cover, evaporation should be arbitrarily set at a low value such as indicated at 0^oC. In the case of lakes with ice cover at temperatures < 0 ^oC, the evaporation rate should be arbitrarily set to zero. Future research is required on these lakes to verify these assumptions.

Essentially this procedure yields a family of curves ranging from large lakes (Okanagan Lake) to the smaller lake sizes. Lakes located in the basin are predominantly “smaller” size lakes (e.g. see Fig. 1). It is assumed here that the lake evaporation response for the Okanagan Basin smaller size lakes could be represented by an ensemble averaged curve representing lakes such as Kalamalka, Wood, Vaseux and Osoyoos (Fig. 5b: e.g. curve designated by squares).

Since the Basin lakes are likely to be “small” lakes, it is reasonable to assume that the regression curve built on the longterm ETR results for a range of lakes (e.g. Kalamalka + Wood + Vaseux + Osoyoos) would be applicable for computing a “first approximation” of the lake evaporation over the basin lakes ($E_{(BL)}$) as a function of air temperature (T_a), equation:

$$E_{(BL)} = 0.0027(T_a^2) - 0.0086(T_a) + 0.4075$$

There are a number of important advantages in applying the evaporation regression results to the Okanagan Basin lakes based on its existing database. The regression equation is not a data intensive procedure and can easily utilize the current air temperature data that has been developed over the 500 m x 500 m basin climate grid. The regression results indicate that for the small lakes, R^2 values range from 0.63 – 0.90 and the correlation coefficient ranges from r ~ 0.79 - 0.95 implying that there is an acceptable relationship between computed evaporation and associated air temperatures. The regression formulation can be applied over a given number of years from current climate (1996-2007), and since $E_{(BL)}$ is based on long-term evaporation results from the Trivett (1984) model (ETR), the computed basin evaporation will have correspondence to the evaporation computed for Okanagan Lake and the mainstem lakes.

Since the regression approach is not a physically-based procedure, it is subject to limitations that are common among empirical methods. For example, it is expected that there would be some limitations in applying the relationship outside the data ranges used to construct the relationship. This problem is reduced somewhat since it is based on long term (11-year) data.

Discussion and Conclusion

This investigation provides an assessment of the capability to compute evaporation from Okanagan Lake, five other mainstem lakes and upland lakes and reservoirs with the proviso of using the existing database of meteorological, radiation and limnological observations over the 1996-2006 period. The greatest challenge in this analysis was related to the limitations imposed by the existing database. Analyses conducted by Trivett (1984) identified that land-based meteorological observations at the primary meteorological stations were not representative of over-lake conditions. Recommendations for database improvements made in that study were largely not implemented. Consequently, nearly 25 years later, the current analysis required computation and numerous assumptions to provide required meteorological, radiation and limnological inputs from which to assess model performance.

A total of 19 lake evaporation models were selected representative of six Groups which ranged from more physically based and data intensive techniques to various levels of empirical formulations. The mass transfer formulation of Trivett (1984) was selected as a “Reference” evaporation in the absence of more direct methods such as from the eddy correlation approach. The Trivett (1984) mass transfer formulation was developed from eddy correlation observations conducted in 1980-1981. The performance of the selected evaporation models was compared to the selected “Reference” evaporation for all years and for all lakes.

Models of the Energy Budget and Combination Group were not recommended for application to Okanagan Lake and the other mainstem lakes because the existing database could not support determination of dominant components such as the heat storage change or the net radiative exchange. Empirical approaches were less demanding in terms of data requirements, however, correspondence with the “Reference” evaporation was generally poor and this was likely related to empirical coefficients not tuned to the Okanagan lakes. Several models compared reasonably well with the “Reference” evaporation (within +/- 20%) using the existing database (e.g. the Penman-Monteith Combination Model, the Stephens-Stewart Radiation-Temperature type model and the Quinn Mass Transfer approach with a variable transfer coefficient). The Penman-Monteith model is a data intensive approach and the Stephens-Stewart method only compared well with ETR for Okanagan Lake with the existing database. The Quinn mass transfer approach may be a viable alternative to the “Reference” evaporation (ETR model). Based on the assessments in comparison to the “Reference” evaporation, only the Trivett (1984) model could be recommended for application to Okanagan Lake and the five other mainstem lakes at the present time. A strong justification for recommending this model is provided considering that, (a) the derived mass transfer coefficient (M = 0.024) is very similar to that determined in other lakes of various sizes which implies that it is robust and not climate dependant and fully applicable to the Okanagan lakes, (b) it is the only method that is based on near-lake data from Okanagan Lake, and (c) it is derived from eddy covariance observations considered a direct evaporation method. The mass balance approach has appeal because of its simplicity and physical basis. Lake evaporation derived using the Trivett (1984) model is simply the product of wind speed and vapour pressure deficit scaled by an empirically derived mass transfer coefficient. The vapour pressure deficit is obtained from dewpoint and lake surface temperatures. Since the existing database does not have time-series of over-lake wind speed or water surface temperature, we note that there is uncertainty in the derived lake evaporation estimates. A sensitivity analysis on the mass transfer relationship on Okanagan Lake indicated that the computed lake evaporation is sensitive to the selection of meteorological station data. Future research with lake-representative data is required in order to fully test the suite of models to determine whether use of appropriate data will result in a convergence of evaporation estimates.

Determination of evaporation for the basin lakes was equally challenging since there was no meteorological, radiation or limnological database available for applying any of the selected 19 lake evaporation models. An existing 500 m x 500 m grid database constructed for the Okanagan basin contained only precipitation and air temperature. It was determined that there was a correspondence between long-term lake evaporation and air temperature. Consequently, a family of curves was derived to describe lake evaporation as a function of air temperature. A 2nd order polynomial formula based on “small” lakes was recommended as a possible method to approximate evaporation from the basin lakes using the minimal database.

Because of database limitations, the lake evaporation computations and recommendations for applicable lake evaporation formulae in the current analysis can only be considered preliminary. With respect to the requirement to provide a gross error estimate for the ESSA Database, we note that the lake evaporation was modeled with limited or questionable data (i.e. whether the land-based data are lake-representative). We suggest that the approximate range of the standard error of the lake evaporation estimates may be in the order > 25% - 50%.

For investigation of lake processes such as evaporation, the existing database must be enhanced to include meteorology at lake-representative locations, solar (and longwave) observations at least at one site, and lake temperature either from a dedicated temperature mooring or through periodic lake sampling of temperature profiles. Determination of the magnitude and phase of evaporation from Okanagan Lake and the mainstem lakes can only be done with the implementation of an intensive field investigation. Such a study would allow development of land to lake transfer functions for critical meteorological variables, provide critical measurements relating to the energy terms in many approaches and provide accurate observations for determination of the lake heat storage. It would allow a detailed analysis of the performance of all of the selected lake evaporation models and recommendation of the optimum model(s) for these lakes.

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Mountain Pine Beetle and Watershed Hydrology: A Synthesis focused on the Okanagan Basin*

Todd Redding, Rita Winkler, David Spittlehouse, R.D. Moore, Adam Wei, and Pat Teti

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Abstract

As the mountain pine beetle (MPB) infestation expands into the southern interior, changes to British Columbia's lodgepole pine forests will affect stand water balances, hillslope hydrology and streamflow in many watersheds. The large spatial extent of this disturbance has prompted research from the stand- to watershed-scales to address uncertainty about the hydrologic effects of MPB, such as an increased potential for flooding, changes in water yield, peak flows, and low flows, slope and channel changes associated with increased runoff, as well as the effects of hydrologic change on aquatic habitat and drinking water. This paper will summarize the key hydrologic changes expected and will highlight the results of long-term research in the Okanagan, such as the Camp Creek and Upper Penticton Creek watershed experiments, as well as new research underway throughout the B.C. Interior and other regions to quantify changes in hydrologic processes and potential effects of MPB-related stand mortality and salvage logging.

Introduction

The forested uplands of the Okanagan Basin are a primary water source for valley bottom ecosystems and human populations. The current mountain pine beetle (MPB) infestation and associated salvage harvesting has the potential to affect the amount, timing and quality of water originating from the forest upland watersheds. The purpose of this paper is to review the research results regarding MPB and salvage harvesting impacts on the hydrology of forested watersheds, and how that may impact the valley bottom water users.

The hydrologic changes resulting from MPB mortality and harvesting are primarily related to the loss of canopy cover. When the forest canopy is reduced (e.g. MPB mortality) or removed (e.g. salvage harvesting) hydrological processes such as interception and transpiration are affected (Figure 1). The result is generally more water reaching the ground surface and potentially more water available for streamflow. Increased streamflows may have positive (e.g. more water

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available for human or ecological needs) or negative (e.g. increased flood potential, decreased water quality) effects, so understanding the magnitude and direction of changes is critical to account for hydrological risks in management and planning for both the upland watersheds and the valley-bottom infrastructure and water availability. It is also important to note that watershed specific impacts may be difficult to accurately predict due to the variable effects of basin geology, topography, soils and vegetation on hydrological response.

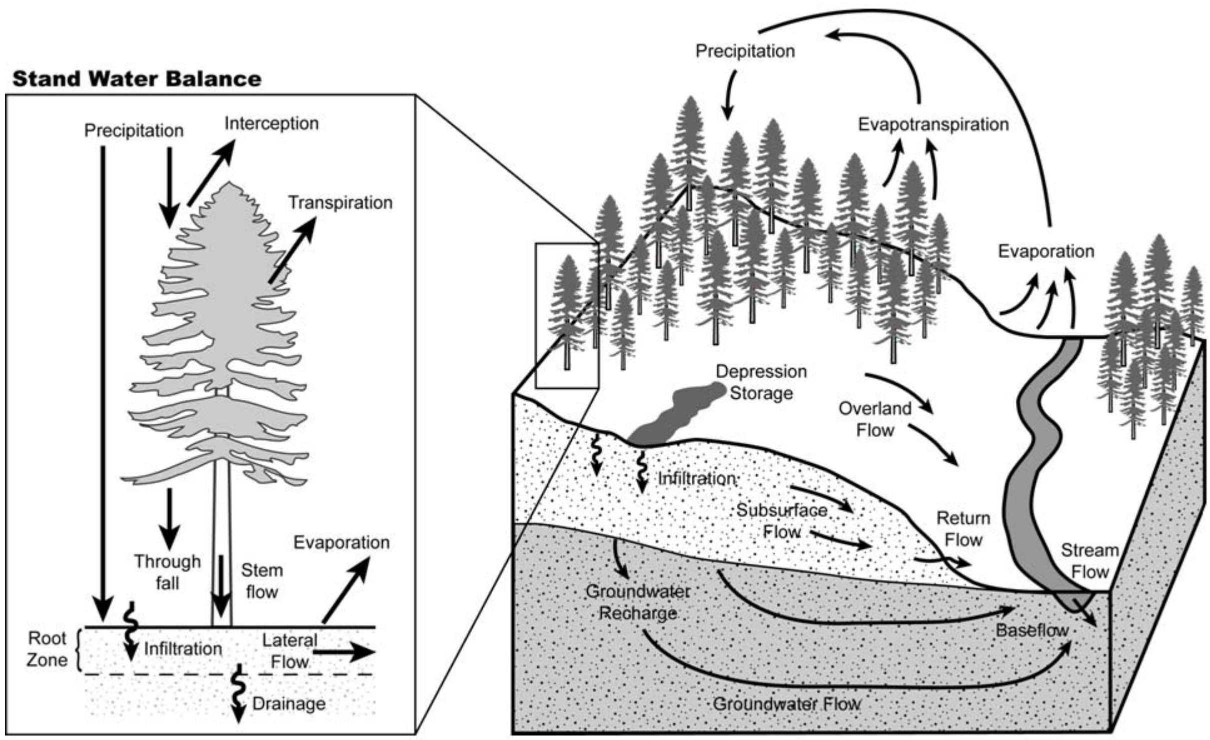

Figure 1: Hillslope hydrologic cycle and stand water balance. The loss of forest canopy influences the interception of precipitation and the subsequent loss through evaporation and transpiration. (adapted from Winkler et al. 2008a)

A generalized graphical illustration of the relative changes in hydrologic processes and watershed response to loss of canopy (e.g. through MPB, salvage harvesting, fire etc.) was developed by Redding et al. (2007) (Figure 2). This figure illustrates how hydrologic variables change along a gradient of canopy cover. While this is a useful tool for understanding the interaction of different processes, it is not meant to provide absolute magnitudes of response or address unique site conditions.

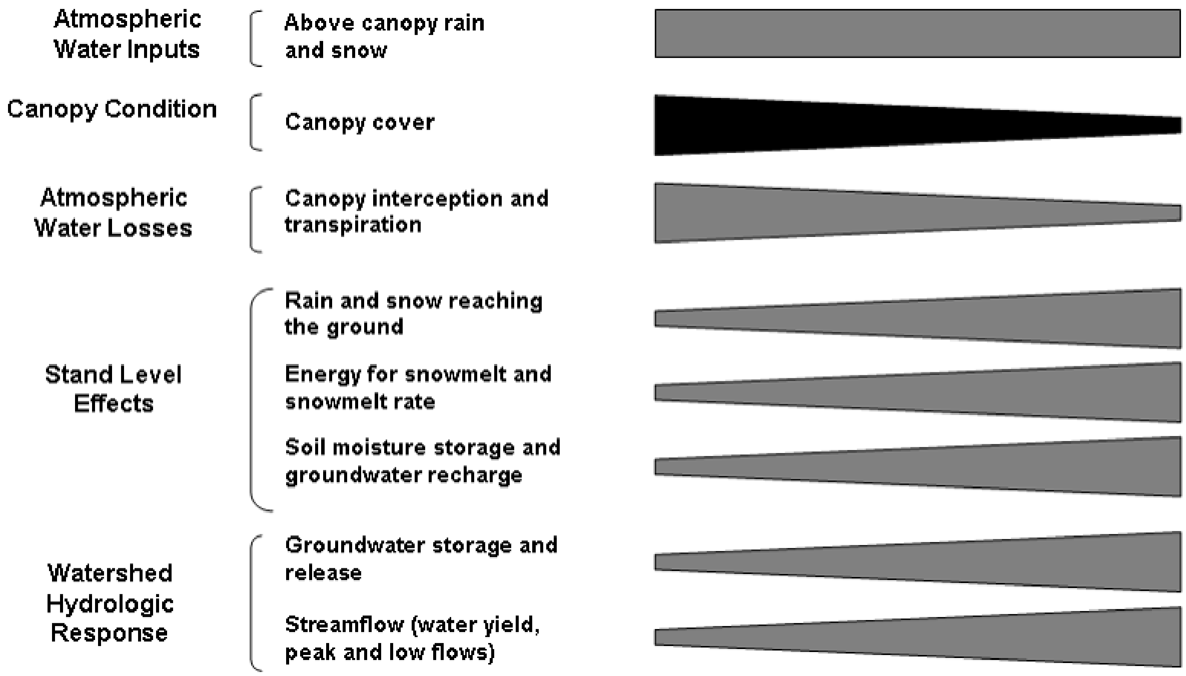

Figure 2: The influence of forest canopy alterations on water cycling. The thickness of a wedge represents the trend in a process or effect as the canopy cover (black wedge) is altered, and does not indicate the magnitude of the process or effect. Where the canopy cover is highest (wedge thickest) is representative of a well stocked healthy mature stand, and where it is lowest (wedge thinnest) is indicative of a recent clearcut. (adapted from Redding et al. 2007)

The purpose of this paper is to provide a brief summary of expected changes in water cycling as a result of MPB and salvage harvesting. For synthesis papers with greater emphasis on forest management issues, planning recommendations and available tools please see Winkler et al. (2008b) and Redding et al. (2008).

Mountain Pine Beetle in the Okanagan Valley

The upland tributary watersheds of the Okanagan basin contain significant areas of lodgepole pine. In 2006, as part of an inter-agency flood hazard mitigation initiative, the Provincial Emergency Program produced a series of overview maps for interior BC watersheds. The maps show all third-order and higher watershed boundaries, communities, public infrastructure, forests consisting of more than 40% lodgepole pine, and the area logged during the past 25 years over most of the Interior. Tables summarizing watershed area, the area of pine-dominated forest, and the area logged are also included. These maps and tables provide a useful indication of the extent of both lodgepole pine leading forest types, where significant stand mortality is expected, and past disturbance. The maps are available at: http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/. A summary of watershed data from a number of significant tributary basins is provided in Table 1. In the Okanagan River watershed, the overall proportion of pine leading (> 40%) stands is approximately 23% and the area of forest harvesting (< 25 yrs old) is 2% (Table 1).

Table 1: Area of pine leading stands and openings from forest harvesting in selected tributary watersheds to the Okanagan basin. Watersheds are listed in order of size. Pine area includes all forest cover polygons with greater than 40% lodgepole pine. Opening area includes all area logged between 1982 and 2007 (25 years). Overlap refers to the area with both greater than 40% lodgepole pine and forest havest between 1982-2007. Data from http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/hydrology/index.htm

Watershed Name	Watershed Area (km^2)	% Pine Area	% Opening Area	% Overlap
Okanagan River	1502	23	2	<1
Trout Creek	434	54	11	7
Vernon Creek	335	26	6	4
Mission Creek	285	23	12	7
Deep Creek	212	11	3	<1
Penticton Creek	184	54	11	3
Trepanier Creek	172	44	3	2
Coldstream Creek	162	22	12	6
Peachland Creek	142	47	6	5
BX Creek	131	10	3	<1

The latest forest health survey data indicates that the heaviest MPB attack in 2007 was on the west side of Okanagan Lake, with some movement south towards Peachland (Westfall and Ebata, 2007). At the northern end of the Okanagan Valley, where the infestation is most severe, the high elevation areas are dominated by mixed species stands (Englemann spruce and lodgepole pine) rather than pure pine which is more commonly found toward the southern end of valley. The impacts of infestation only in mixed-species stands likely will not have as great of hydrological consequences as pure stands (Huggard and Lewis, 2007). If mixed stands are salvaged using clearcut harvesting systems the potential impacts will increase.

Effects of MPB and salvage logging on hydrological processes and watershed response

The effects of forest disturbance (including MPB and salvage harvesting) are typically investigated at the stand and watershed scales. The stand scale effects investigated include snow accumulation and melt, rainfall interception, stand water balance, groundwater and stand-level hydrologic recovery. Watershed scale effects include impacts on streamflow, aquatic ecology and water quality.

Stand Scale Effects

Snow Accumulation and Melt

A significant portion of the total winter precipitation is intercepted by forest canopies and lost through sublimation. The forest canopy not only reduces snow accumulation relative to the open as well as influences how quickly snow disappears. Snow surveys throughout the BC Interior show large annual, geographic, and forest cover related variability in snow accumulation and ablation, even over distances of only a few kilometres (Winkler et al., 2004a; Winkler, 2007). Storm type also significantly influences canopy interception (Boon, 2007b).

Changes in snow accumulation due to changes in canopy cover have been studied at many sites in BC. At long-term research sites on the Thompson-Okanagan Plateau, the maximum snow water equivalent (SWE) in mature lodgepole pine stands averages 11% less than that in recent clearcuts while mixed species stands have up to 44% less SWE than clearcuts (Winkler, 2007). In the central interior, recently initiated studies in MPB-attacked stands have shown that at maximum accumulation, SWE in stands that have lost their needles (grey attack) and in a green stands were 25-50% and 50-70% 53% less, respectively, than that measured in adjacent clearcuts (Beaudry, 2007; Boon, 2007a). There was, however, little difference in snow accumulation between a green pine stand and a grey pine stand near Prince George during a year of low snowfall (Beaudry, 2007).

Snow ablation rates (the loss of snow through both melt and vaporization) are, on average, 15% lower, and snow persists for up to eight days longer in the forest than in the open (Winkler, 2007). Sixty percent slower ablation rates have been measured in the mixed-species stands relative to nearby clearcuts (Winkler, pers. comm. 2008). Snow ablation rates are reduced by forest canopies partly due to the reduction in solar radiation at the snow surface relative to that in the open (Spittlehouse and Winkler, 2004). Current research in British Columbia (P. Teti, pers. comm., 2008; D. Spittlehouse, pers. comm., 2008) has found that old pine stands that have not been defoliated, and mixed-species, pine-leading stands, transmit 15–30% of solar radiation in early spring depending on the canopy and stand density. This level increases as the stand deteriorates over many years. In a stand attacked in the 1980s, where the former canopy-forming trees had fallen down and natural regeneration was well established, transmittance to the snowpack was 57% (P. Teti, pers. comm., 2008). In contrast, salvage logging increased radiation transmittance to virtually 100%, for at least a decade (P. Teti, pers. comm., 2008). Transmission of radiation to the snowpack decreased rapidly after this time, dropping to approximately 20% within 35 years of logging.

Snow accumulation and ablation recovery (defined as the decrease towards that in the mature forest) were 43% and 29%, respectively, in the 20-year-old pine stands. Thinning to remove approximately one-half of the stems did not affect maximum snow accumulation but reduced snow ablation recovery to 13% (Winkler et al., 2005). On the Fraser Plateau, Teti (2007) found that for at least 12 years snow ablation rates in young stands were very similar to those in a clearcut. However, in 35-year-old forests, ablation rates were very similar to those in mature forest. Data from all snow surveys in the Thompson-Okanagan combined showed a 6% reduction in maximum SWE with every 10% increase in crown closure to a maximum of 55% reduction in SWE (Winkler and Roach, 2005).

In large openings at several steeper south-facing survey sites in the Okanagan, higher SWE is measured in the forest than in the open before the onset of melt, indicating that periodic snow disappearance occurs in the open before the main melt season (Winkler, pers. comm. 2008). These losses potentially mitigate the effects of increased SWE at other sites across the landscape, resulting in desynchronization of snowmelt and streamflow generation.

Rainfall Interception

There has been limited research on changes in rainfall interception resulting from canopy deterioration following MPB attack. In mature mixed pine, spruce, and subalpine fir forests, the canopy intercepts approximately 30% of growing season precipitation, which subsequently evaporates reducing the amount of moisture that reaches the ground (Spittlehouse, 2007). At Penticton Creek in the Okanagan Basin and Mayson Lake north of Kamloops, measurements of rainfall interception indicate 30- 40% of growing season rainfall is lost each growing season in a mature stand (Moore et al. 2008, Winkler et al., 2008a). In Colorado, a well developed understory below an old MPB killed stand intercepted as much rain as live trees (Schmid et al., 1991). Storage of rainfall in the litter and moss layers on the forest floor is 4-8 mm of water accounting for 20-30% of growing season precipitation in low rainfall regimes (Carlyle-Moses, 2007).

Stand Water Balance

Atmospheric water losses (interception, transpiration and soil evaporation) in mature pine stands at Penticton Creek typically account for 60-70% of annual precipitation inputs with 30-40% of precipitation draining below the rooting zone and available for groundwater recharge and to generate streamflow (Spittlehouse, 2007). Following MPB infestation and salvage harvesting, the proportions of the individual stand water balance components will change, resulting in an increase in drainage. Stand water balance modelling carried out for study stands at the Upper Penticton Creek Watershed Experiment indicates that after MPB attack and salvage harvesting there would be greater water available to recharge groundwater and generate streamflow (Figure 3) (Spittlehouse, 2007). When compared with mature lodgepole pine forest, red attack stands have similar amounts of interception loss, while the grey attack and clearcut stands have reduced interception. Evaporation (plant transpiration plus soil evaporation) are similar between the mature and clearcut stands, and reduced in the red and grey attack stands. The most water available for groundwater recharge and streamflow is in the clearcut and grey attack stands with the red attack intermediate and the mature stand lowest. The modelling indicated that a stand with less than 40% of the trees attacked had a similar hydrological balance to the attacked stand.

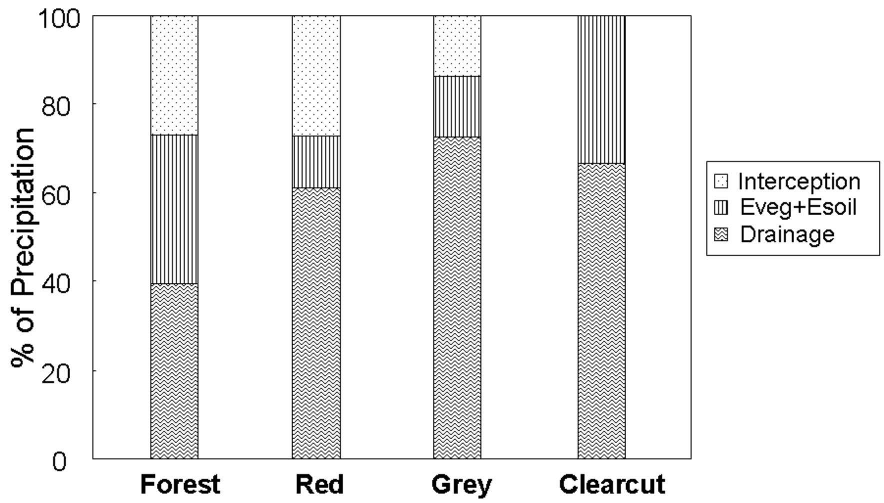

Figure 3: Modelled mean annual stand water balance for mature, red, grey and clearcut lodgepole pine stands at Upper Penticton Creek. Data are results of a process based stand water balance model run over the period of October 2002 through September 2006. Meteorological inputs (precipitation, temperature and radiation) and soil properties were held constant for all stands, and only canopy properties were varied. (adapted from Spittlehouse 2007)

Groundwater

With changes in the stand water balance resulting in greater drainage, and hence water available for groundwater recharge, it is not surprising that in some areas of heavy infestation and salvage harvesting there have been reports of rising water tables impacting trafficability and forest harvesting operations (Rex and Dube, 2006). In the Vanderhoof Forest Distict in central British Columbia, Rex and Dube (2006) have noted elevated water table levels in lowland areas (e.g., toe slopes, wetlands, or lowland landscapes) after harvesting. The risk of wet ground was found to increase with (1) decreasing drainage density, (2) decreasing understory vegetation, (3) increasing area of sensitive soils (poorly drained or fine texture), and (4) increased pine cover (Dube and Rex, 2008). Greater drainage below the rooting zone will also likely result in greater subsurface flow feeding stream channels and potentially affecting other values such as slope stability.

Hydrologic Recovery

For a given set of weather conditions, the magnitude and duration of stand-scale hydrologic change associated with MPB will depend on the percentage of overstorey that has been killed; the presence, age, and density of advance regeneration and understorey vegetation; and on the stand’s logging history. If MPB-attacked stands are left to deteriorate naturally, hydrologic change will be more gradual as trees turn from green to red, drop their needles, turn grey, lose fine branches, and eventually fall to the ground (Huggard and Lewis, 2007). At the same time, understorey vegetation may release due to increased light and reduced competition for nutrients and water. In contrast, clearcut salvage logging causes a large immediate change to the site water balance through removal of the overstorey. The hydrologic change associated with salvage logging will also vary with the amount of ground disturbance, intensity and type of site preparation, degree of drainage disruption, degree of understorey damage, and rate of forest regrowth.

To address uncertainties around MPB impacts on stand-level hydrological recovery, Huggard and Lewis (2007) used models of stand tree growth, field data on understory composition and measurements of hydrologic recovery as snow accumulation and melt to generate recovery curves for various forest management options in select IDF and MS subzones in the southern interior of BC. The results indicate that clearcut salvage harvesting and planting results in the greatest increase in equivalent clearcut area (ECA) and quickest recovery (see Figure 4 for hypothetical example). Full retention of the dead stand has the lowest maximum ECA but the longest recovery (Figure 4). In selecting a retention or salvage strategy it will be necessary to balance the risk of a more intensive disturbance with the benefit of a quicker recovery (Huggard and Lewis, 2007).

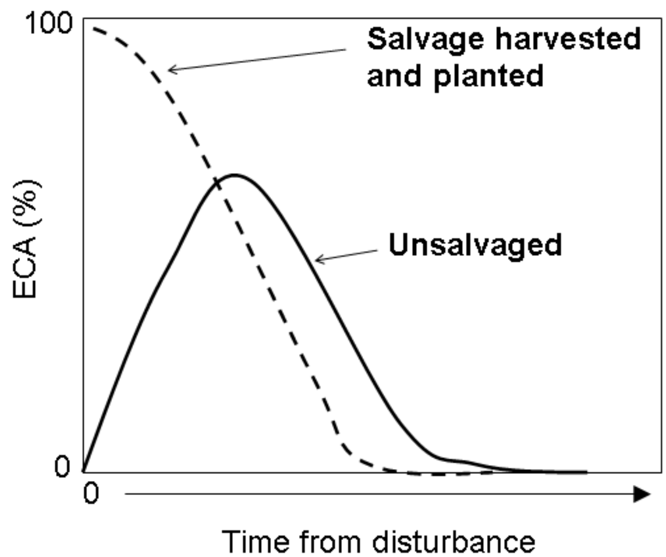

Figure 4: Hypothetical hydrological recovery trajectories for salvaged and planted and unsalvaged stands (complete retention). A lower value of ECA (equivalent clearcut area) indicates greater hydrological recovery. (adapted from Huggard and Lewis 2007)

Watershed Scale Effects

Watershed scale effects of forest disturbance can be difficult to quantify due to natural variability in climate, geology and other factors which control streamflow generation and timing. Two main approaches have been used to examine the effects of MPB and salvage harvesting effects on streamflow: retrospective streamflow analyses and numerical modelling.

Retrospective Streamflow Analyses

At Camp Creek in the Okanagan basin, 30% of the basin was salvage harvested in 1976-77 following MPB infestation (Cheng, 1989). Using a paired-watershed analysis it was found that annual water yields increased by 21%, peak flows increased by 21%, there was an advance in peak flow timing by 13 days, and April flows also increased (Cheng, 1989; Moore and Scott, 2005). The duration of peak flow increase lasted approximately 15 years, while elevated April flows have persisted for the length of data record. These values generally agree with stand-level measurements of hydrologic recovery of snow accumulation and melt processes (Moore and Scott, 2006). No changes in low flows were detected (Moore and Scott, 2005).

Extensive forest harvesting has taken place in both the Bowron River (related to a spruce beetle outbreak in the 1970's) and adjacent Willow River watersheds in central BC. There were no statistically significant effects of salvage harvesting on annual water yields, peak flows or low flows for the Bowron River watersheds (Wei and Lin, 2007). In the adjacent Willow River watershed, Lin and Wei (2008) found significant increases in spring and annual peak flows, and an increase in annual water yield that was attributable to harvesting. Neither watershed showed any significant changes in low flows. The reasons given for the differences in the effects of harvesting on these adjacent watersheds were differences in watershed characteristics, climate and the timing and location of harvesting (Wei and Lin, 2007).

Similar increases in peak flow and water yield have been found in Montana and Colorado. In Montana, Potts (1984) found in a watershed that was 35% defoliated that annual water yield increased by 15%. While there were no changes in peak flow magnitude, the annual peak occurred 14-21 days earlier and high flow conditions persisted longer with a greater spring monthly water yield. In addition, low flows increased by 10%. In two Colorado watersheds following defoliation of 30% of their area, Bethlahmy (1975) found increases in annual water yield of 16%. Peak flows occurred 2-11 days earlier and were 4-27% larger following defoliation and low flows also increased 10-31%.

The Fishtrap Creek watershed, near Kamloops BC, was severely impacted by wildfire during the summer of 2003. Post-fire there has been an increase in flows during the early stage of the freshet, and high flow periods are lasting longer than pre-fire. The earlier and longer period of high flows may be the result of changes in snowmelt dynamics in the basin resulting in a desynchronization of basin melt (Moore et al., 2008). The longer duration of high flows appears to be impacting channel processes and sediment movement through the burned floodplain of the watershed (Moore et al., 2008).

Modelling of MPB Infestation and Salvage Harvesting Scenarios

Two hydrologic models have been applied in the Okanagan basin to examine the impacts of MPB and salvage harvesting on streamflows. The HBV-EC model, which has relatively modest data requirements, was able to reproduce the statistical distributions of post-harvesting streamflow changes (Moore et al., 2007). Streamflows in any given year were not always accurately simulated, likely due to an overly simplistic model representation of canopy influences on snow accumulation processes (Moore et al. 2007). The UBC Watershed Model has been applied to simulate the effects of complete clearcut harvesting on peak flows and water yield for a number of Okanagan tributary watersheds (Alila and Luo, 2007). The results showed peak flow increases of 30-100% for 1 and 2 year return period events and freshet water yield increases of 40-75%.

To examine the potential effects of extensive MPB infestation and salvage harvesting on peak flows and water yield, the DHSVM hydrological model was applied to the 1570 km^2 Baker Creek Watershed near Quesnel (BC Forest Practices Board, 2007). For scenarios with extensive MPB killed stands (53% MPB, 34% harvested) and extensive salvage harvesting (80% harvested, 17% MPB), the model predicted 60% and 90% increases in peak flow and 15 and 16 day advances in peak flow respectively (BC Forest Practices Board, 2007). The results indicated the potential for a major shift in flood frequency in the watershed, with floods with a baseline return period of 20 years moving to a return period of three years with the extensive salvage harvesting scenario.

The WRENSS model was applied to four Alberta foothills watersheds between Grand Prairie and Grand Cache using a scenario of reducing pine cover by 75% within 20 years. Annual water yields were predicted to increase by 9-29%, while 2-year return period flows were increased by 7-53% and 100-year return period flows were predicted to increase by 1-20% (Rothwell and Swanson, 2007).

Impacts on Aquatic ecology

Changes in streamflow regimes following watershed disturbance have the potential to impact aquatic communities and processes (Johannes et al., 2007). Large woody debris in streams is critical for habitat formation, and harvesting in riparian zones has the potential to disrupt inputs. Source distancing studies completed in the Prince George Small Streams Study identified that the majority of active in-stream LWD originiated within 10 m of the streambank (Beaudry and Beaudry, In Preparation). In the Okanagan, Wei et al. (2007) found there were similar LWD input rates between MPB-attacked and non-attacked stands, however, the MPB attacked stands had greater LWD movement distances. In the Bowron River watershed, riparian harvesting in the 1970s is still affecting LWD recruitment and stream recovery (Nordin, 2008). Protecting riparian function and aquatic habitat will have major implications for fish populations, including salmon, throughout the interior of BC (Johannes et al., 2007).

Impacts on Water quality

Water quality impacts of the mountain pine beetle epidemic have not been well studied, however, based on knowledge from other forest disturbances, some generalizations are possible. Increased road building and stream crossings for salvage harvesting combined with potentially higher flows have the potential to increase sediment delivery to watercourses. At Fishtrap Creek in southern BC, mortality of the riparian canopy due to wildfire has resulted in a loss of bank strength causing significant channel change and associated transient increase in suspended sediment concentration (Moore et al., 2008). Chemical properties of surface waters may be impacted by MPB infestation and salvage harvesting due to changes in water fluxes and biogeochemical cycling. In Colorado, elevated stream water nitrate concentrations have been measured following MPB infestation of watersheds and have persisted for a number of years but remain below drinking water standards (Stednick, 2007). The loss of riparian cover due to canopy mortality or harvesting can lead to increases in stream temperature which may adversely affect aquatic processes and fish productivity (Moore et al., 2005). At Fishtrap Creek, the burned canopy reduced the net radiation reaching the stream surface by about 30% as compared to no standing dead vegetation and radiation under the standing dead trees was 50% greater than for pre-fire conditions (Moore et al., 2008).

Conclusions

The potential effects of the MPB infestation and associated salvage harvesting include changes in the magnitude and timing of streamflows and impacts on water quality and aquatic habitat. Changes in flow regimes will be greatest in the short term where extensive salvage harvesting is applied. In addition, the effects of increased road construction on water quantity and quality are unknown at this time. The changes in flows may have major implications for the design of infrastructure on the flood plain and draws attention to the need for planning the extent of clearcut salvage harvest in infested watersheds, designating reserve areas, and carefully designing stream crossings (B.C. Forest Practice Board, 2007). Further information on watershed planning recommendations, management tools and ongoing research are available from Winkler et al. (2008b) and Redding et al. (2008).

The unforeseen nature of the MPB infestation and the potential hydrological effects to humans and the environment highlights the importance of maintaining long-term research sites such as Upper Penticton Creek Watershed Experiment and monitoring sites such as Camp Creek. These sites have provided primary data in the early days of the infestation, and the research and monitoring results continue to inform forest management planning. Given that these upland watersheds are the primary source of water for valley bottom use in the Okanagan Valley, it is critical that we understand both the basic hydrology and the effects of both natural and human caused disturbance on these systems.

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Agricultural Water Management in the Okanagan Basin

Ted W. Van der Gulik and Denise Neilsen

Abstract

The Okanagan watershed, covering 8,000 km^2 in the south-central interior of British Columbia, is characterized by a north-south running main valley at an elevation of about 300 m, surrounded by a plateau at elevations between about 1,500 and 2,000 m to the east and west. It is a relatively small and arid watershed, with annual precipitation averaging only about 300 mm in the dry valley-bottom areas to over 700 mm in some high elevation plateau areas.

The CWRA conference in February 2005 "Water – Our Limiting Resource – Towards Sustainable Water Management in the Okanagan" identified a need to improve water management in the Okanagan and implement mechanisms that encourage more efficient use. Agriculture uses 70% of the water currently licenced in the basin. It is estimated that 90% of the water available in the basin has been allocated and spoken for. Urban growth in this region is one of the highest in Canada, expecting to triple to one million over the next thirty to forty years. Agricultural land locked in the Agriculture Land Reserve is of little value without water and climate change will require additional water to irrigate what is currently farmed. Additional agricultural lands could be irrigated. Competing demands between fish, agriculture, recreation and urban growth has led to a realization that a water-in, water-out balance should be done for the basin.

The authors have initiated a project to determine agricultural water requirements in the basin now and in the future. This paper will outline the process that has been developed to accurately determine agricultural water requirements and how improved water management will be accomplished.

Background

An Okanagan Basin Water Strategy was initiated by Land and Water British Columbia (LWBC) in 2004 in response to significant pressures being exerted on the water resources in the basin. Rapid population growth, drought conditions from climate change, and the overall increased demand for water are driving this trend (Cohen et al., 2006). Several recent studies have supported the scenario of a pending water crisis as Okanagan water resources are expected to be fully allocated in the next 15 – 20 years.

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Climate change scenarios developed by UBC and Environment Canada in Summerland predict that winter snow packs will decrease as the climate warms and the snow level moves higher up the mountains (Merrit et al., 2006). Opportunities for storage will be limited if moisture is changed from snow to rainfall and the timing of precipitation also changes. Further, agricultural water demands are expected to increase as climate change creates hotter summers and longer growing seasons (Neilsen et al., 2006).

The first phase of the LWBC project was to revisit a comprehensive Okanagan Basin study that was completed in 1974. Many of the action items identified in the 1974 study have not been implemented, which has been of concern to water managers in the Okanagan. LWBC's review included conducting an assessment of the supply and demand data available, identifying information gaps and facilitating a process that would establish clear expectations and outcomes for Phase 2. Phase 1 was completed in 2005.

Phase 2 of the project, now being led by the British Columbia Ministry of Environment, will be to initiate a water balance strategy that is aimed at providing a detailed assessment of water supply and demand in the entire Okanagan Basin. Currently, the agricultural water demand is estimated to be 70 -75% of the water use in the basin.

The irrigation water demand model determines estimated water demand for every property in the Okanagan Basin based on crop, soil, irrigation system and climate data. A unified cadastral fabric has been created that allows for the model to summarize the water use by water purveyor, local government, sub watersheds in the Okanagan basin and groundwater areas. The model will also calculate future agricultural water demand for each agricultural property in the basin using climate data generated by six different Global Climate Models.

Climate Data

The agricultural water demand is dependent on climate, crop, soil and irrigation system. The Okanagan region's climate is quite diverse. The climate generally gets cooler and wetter as you move from south to north and as the elevation increases. Climate data have been developed to calculate irrigation water demand on a daily basis. Using the climate data, the model calculates evapotranspiration on a daily basis so that various scenarios such as changes to the length of growing season can be used to calculate crop water demand.

The climate data set has been developed by using existing data from climate stations in and around the Okanagan Basin from 1961-2006. This climate data set was then extrapolated to provide a climate data layer for the entire Okanagan Basin on a 500 m x 500 m grid. Figure 1 shows a map of existing climate stations that were used to determine the climate coverage.

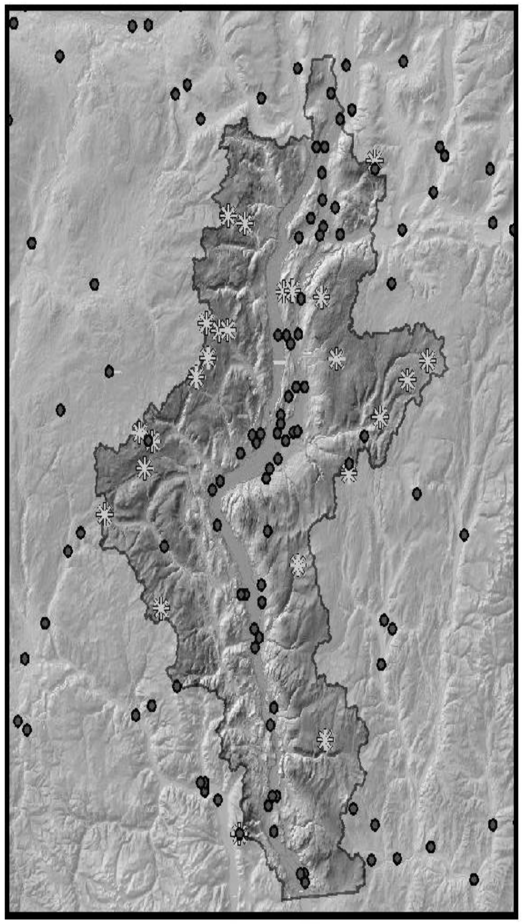

Figure 1: Okanagan climate stations.

Climate change scenarios have been developed until the year 2100 with precipitation, minimum and maximum temperature data stored for each grid cell and for each Julian day. The ClimateID is a Raster GIS-based dataset. The ClimateID grid cells cover the entire Okanagan Basin. The attributes that have been attached to each ClimateID include:

- Latitude
- Longitude
- Elevation
- Aspect
- Slope
- Precipitation, MaxT, and MinT

The indices that are selected, calculated and stored with the ClimateID are:

- Evapotranspiration – (ETo)
- Effective Precipitation (EP)
- Frost Free Days Growing Degree Days (base 5 and base 10) Corn Heat Units
- First Frost

There are a number of climatic indices that are crop based that must be calculated and stored with in the database as well. These are:

- Growing season length
- Beginning and end of the growing season

The model calculates the length of the growing season using the Climate ID and CropID. The CropID is an attribute of the PolygonID. The beginning and end of the growing season is also determined and recorded using Julian day. The calculated beginning and end of the growing season and growing season length are stored with the PolygonID. Potential evapo-transpiration (ETo) is determined using the FAO methodology of Allen et al. (1998) and modified to actual ET using crop coefficients.

Figure 2 graphically shows the variance in climate data for the Okanagan that can be expected for any day.

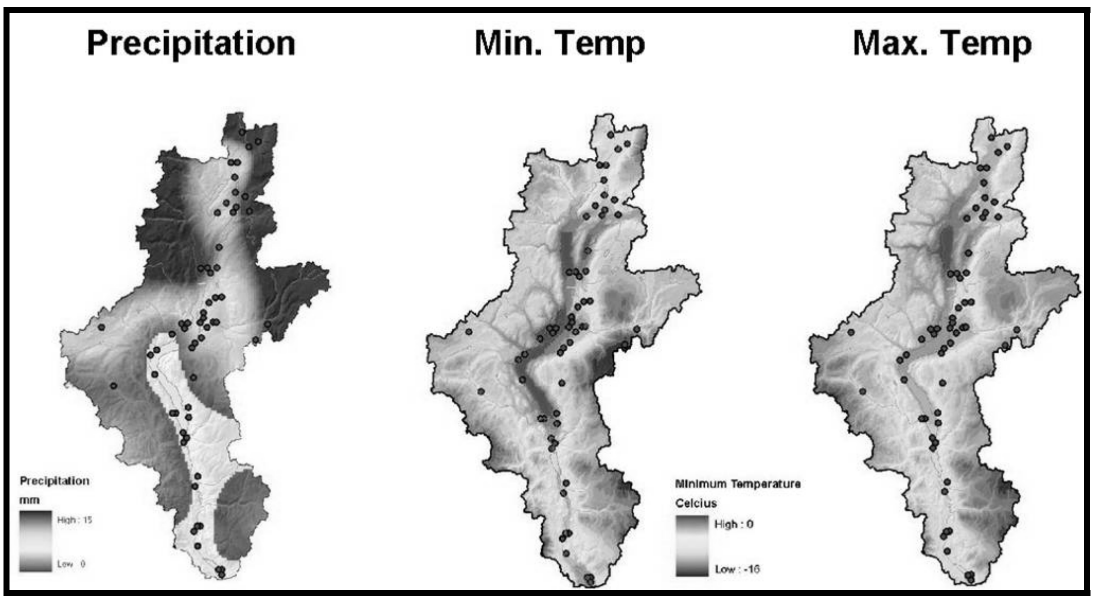

Figure 2: Climate data.

Cadastre

A unified cadastre has been developed for the Okanagan Basin using data provided by the Regional Districts and other local governments. A land use survey was completed on a parcel basis for all agricultural lands in the Okanagan Basin. The information collected included crop, irrigation system type and whether the property was irrigated or not.

Polygons

The smallest unit for which water use is calculated is the polygons within each CadastreID. A polygon is determined by a change in land use or irrigation system within a cadastre. The intersection of soil boundaries and the climate grid creates additional polygons within the cadastre. Figure 3 shows how polygons are generated based on land use in the Okanagan Basin.

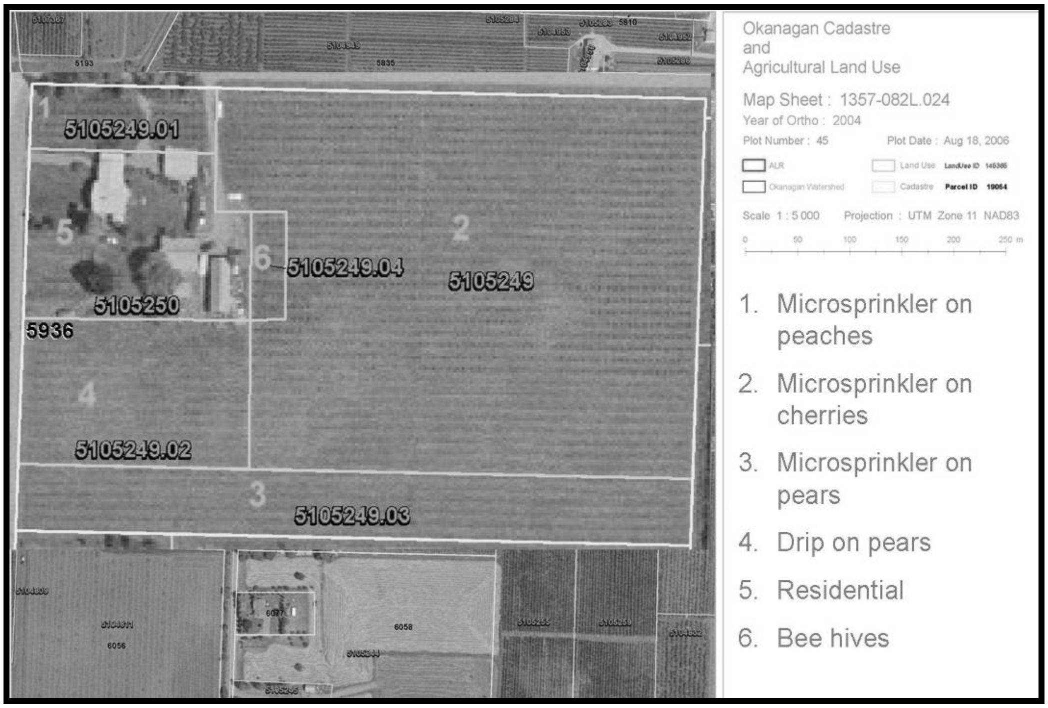

Figure 3: GIS land use.

Figure 4 shows how the land use information is divided into additional polygons using the soil and climate grid information. The climate grid, soil boundary, cadastre and land use information polygons are all used to calculate water use for each property. The water use for each separate polygon must be calculated and added together to determine the water requirement for each cadastral unit.

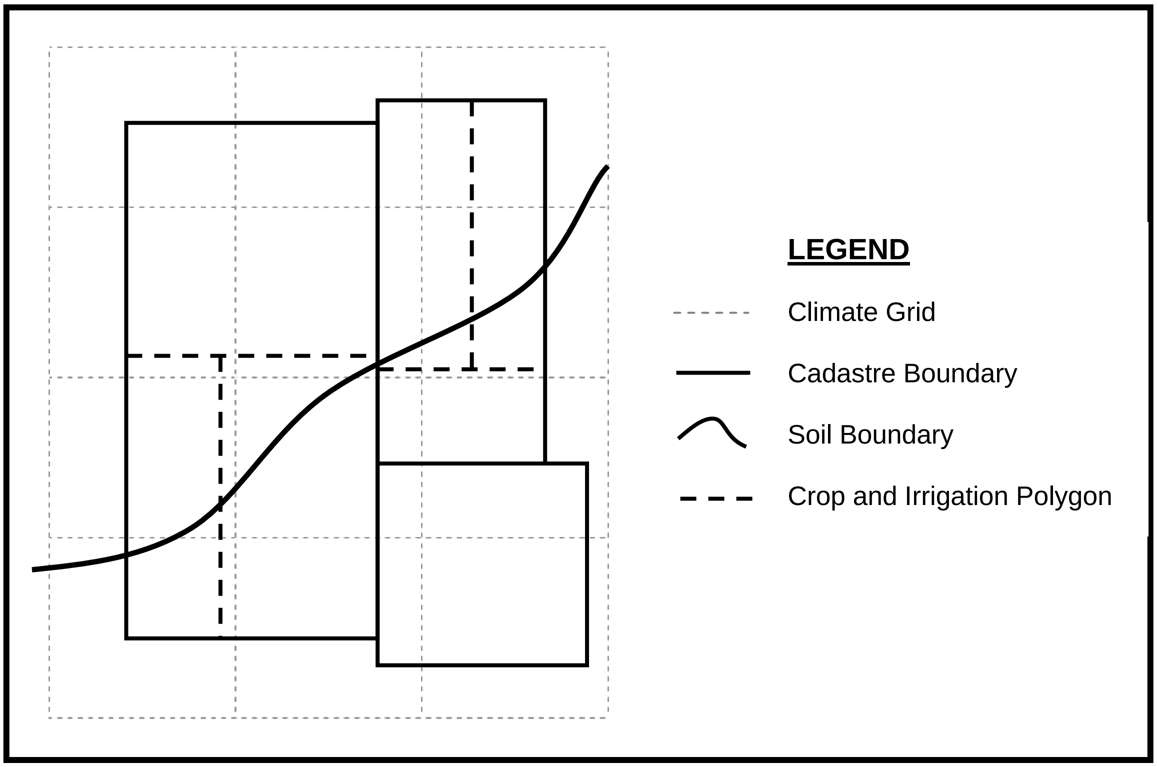

Figure 4: GIS model graphic

Crop

CropID is an attribute of the PolygonID. The crop information (observed during 2005 – 2007) has been collected and stored with PolygonID as part of the land use survey. CropID will provide cropping attributes to the model for calculating water use for each polygon. CropID is also used to calculate the growing season length and the beginning and end of the growing season.
The attributes for CropID include rooting depth, availability coefficient and a drip factor. The drip factor is used in the water use calculation for polygons where drip irrigation systems are used.

Irrigation

The IrrigID is an attribute of the PolygonID. The irrigation information has been collected and stored as observed during 2005 – 2007 with the land use data. The IrrigID has an irrigation efficiency listed as an attribute.

Soil

The soils layer provided is from CAPAMP data provided by the Ministry of Energy, Mines and Petroleum Resources. The attributes attached to the SoilID is the Available Water Storage Capacity (AWSC).

Irrigation Water Demand

The Irrigation Water Demand (IWD) is calculated for each polygon. The polygons are then summed to determine the IWD for each cadastre. The cadastre information is summed to determine the water demand by sub watersheds, groundwater areas, local purveyors or for the entire basin.

Water demand can also be calculated for various scenarios. For example the model can be asked to determine water use for areas that are currently not irrigated, or how a change of crop or irrigation system may affect water demand.

The model is currently operating and is undergoing a calibration and testing phase. It is expected that a report on water demand for the Okanagan Basin and various scenarios will be completed later in 2008 or early 2009.

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The Upper Penticton Creek Watershed Experiment: Integrated Water Resource Research on the Okanagan Plateau

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Abstract

Understanding the complex interactions between forests, forest land-use, natural disturbances, streamflow, and groundwater is essential to sustainable water resource management. Throughout the dry southern interior of British Columbia (BC), both the security of water supplies and the protection of aquatic habitat are issues of ongoing concern, particularly in areas where water is limited relative to demand. In response to these concerns, the Upper Penticton Creek (UPCr) Watershed Experiment was established in 1984. The goals of this experiment are to improve our understanding of hydrologic processes on the Okanagan Plateau and to develop effective forest practices guidelines that help to sustain both timber and water resource values. This paper provides an overview of the UPCr Watershed Experiment, results, relevance to water resource management in the Okanagan, and future directions.

Background

Studies worldwide have shown that removing forest cover in snow-dominated hydrologic regimes generally leads to larger spring peak flows and higher annual water yields. These changes occur as a result of increased snow accumulation and reduced total summer evaporation in the harvested areas (Bosch and Hewlett, 1982; Stednick, 1996; Moore and Wondzell, 2005). The magnitude of change is variable depending on watershed characteristics, the area harvested, and environmental conditions. Increased peak flows, prolonged periods of high flow, and increased soil moisture may result in slope failures, streambank erosion, accelerated channel migration, and increased sedimentation. These events may affect drinking water quality and aquatic habitat as well as put communities and infrastructure at risk (Hetherington, 1987; Gucinski, Furniss, Ziemer and Brookes, 2001). Removal of cover adjacent to small headwater

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streams may change detrital input and stream temperature, further affecting aquatic habitat (Webster et al., 1992). Late season low flows are also generally reported to increase or not change with forest cover removal and then decrease with forest regrowth as a result of changes in the interception of rainfall and transpiration (Austin, 1999; Pike and Scherer, 2003).

In BC, eight major water resource research projects have been established in snow-dominated inland watersheds. Of these, four involve intensive stand-scale studies in support of modelling (BC Forest Practices Board, 2007; Jost, Weiler and Gluns, 2007; Redding et al., 2008; Whitaker, Alila, Beckers and Toews, 2002), one is a single watershed pre- and post- disturbance study (Wei and Davidson, 1998), and three are paired watershed studies. Of the paired watershed studies, one compares a disturbed and an undisturbed watershed post-treatment (Cheng, 1989; Moore and Scott, 2005) and two have both a pre- and post-disturbance monitoring period in treatment and control watersheds (Cheng and Bondar, 1984; Winkler et al., 2004). Only one of these paired watershed experiments continues, UPCr.

The Study Area

The UPCr watershed experiment includes the watersheds of 240, 241 and Upper Dennis Creeks. Each watershed is approximately 5 km^2 in size and is gentle to steeply sloping over an elevation range of 1600 to 2150 m. The area and is forested with lodgepole pine (*Pinus contorta* Dougl.) and mixed stands with Englemann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt). In the stands of lodgepole pine, trees are generally evenly spaced whereas trees in the spruce-fir stands generally have a more clumped distribution. Canopy densities vary from 35 to 50%. Trees are over 100 years old and up to 26 m tall. The area is underlain by coarse-grained granitic rocks covered by glacial till and overlain by glacio-fluvial sand and gravel in the lower reaches. Soil textures are coarse sandy-loam over loamy-sand. All soil horizons are low in clay and high in coarse fragments with low water holding capacity and are well drained. The forest floor is generally less than 4 cm thick.

The mean annual precipitation is 690 mm, about half of which falls as snow. By late winter, the snowpack is 1 to 1.5 m deep depending on forest cover, the year, and location in the watershed. There is substantial year-to-year and site-to-site variation in snow accumulation and melt. Differences between years are often larger than those between forest cover types (Winkler and Moore, 2006). Summer forest transpiration plus soil evaporation averages 2 mm d^{-1} when the soil is moist (Spittlehouse, 2002, 2006). Winter air temperatures occasionally drop to -20 ºC. In summer, daytime high temperatures can reach 25 to 30 ^{o}C.

Annual water yield ranges from 0.8 to 3 million m^3 yr^{-1} from each watershed, which is approximately 30 to 60% of the total annual precipitation. The highest daily flows occur in May during mid- to high-elevation snowmelt and may reach 1.5 m^3 s^{-1}. August through April low flows are sustained by groundwater and rain, and are often less than 0.01 m^3 s^{-1}. Soil water levels along hillslopes at upper elevations are highly responsive to precipitation input. At mid to lower elevations, water levels are less variable throughout most of the year. Streamflow is highly correlated with water levels in mid to low elevation riparian zones (Kuraš, Weiler and Alila, 2007). Deep groundwater recharge to bedrock is significant in terms of the overall water budget in the experimental watersheds. Early results from well data and modelling suggest that groundwater flow from these high elevation recharge areas to the valley bottom aquifers may also be significant (Voeckler, in progress).

Chemical water quality is high with many parameters at concentrations consistently below the laboratory detection limit. The exception is colour, which is high in all three streams where total colour units range from 0 to 70. Pre-treatment physical water quality was also generally high with sediment concentration never exceeding 20 mg L^{-1} and most frequently are less than 1 mg L^{-1}. Water temperatures in the study streams average 9 °C during the snow-free season and range from just above 0 °C in late fall through spring to an hourly maximum of 25 °C in summer. Diptera dominate the aquatic invertebrate communities of 240 and 241 Creek.

Methods

The UPCr Watershed Experiment (Winkler et al., 2004) follows a paired watershed design, which includes pre- and post-treatment sampling periods in both the logged watersheds and in the unlogged control. Watershed-scale measurements of water yield and quality are coupled with stand-scale and site-specific hydrologic process research including measurements of net precipitation, interception, evaporation, transpiration, soil moisture, and groundwater. The effects of changing hydrologic processes on streams and aquatic habitat are being assessed through stream channel and aquatic invertebrate monitoring. Hydrologic modelling builds on the field measurements to determine watershed-scale effects beyond the scope of the study including alternative logging treatments, additional variables such as peak flow magnitude and frequency, and a broader range of weather scenarios including climate change.

From 1984 to 1995, the watersheds remained undeveloped with the exception of a small area of blowdown salvage in 1992 near the outlet of 241 Creek. Road construction and conventional clearcut logging began in late 1995. By late winter of 1996, 6% and 10% of the 241 and Upper Dennis Creek watersheds had been clearcut, respectively. A second logging pass was completed by late winter of 1999 bringing the area clearcut to 18% and 21% of the 241 and Upper Dennis Creek watersheds, respectively. In 1999, a major spruce beetle outbreak killed most of the Engelmann spruce in the Dennis Creek watershed. These trees were salvage logged and by spring 2000, 52% of the Upper Dennis Creek watershed had been clearcut. A third logging pass increased the area cut in the 241 Creek watershed to 28% by late winter 2003. The final logging pass in the 241 Creek watershed was completed by late winter 2007 so that the total clearcut area was 47%, similar to that of Upper Dennis Creek. This level of cut is intended to represent the highest levels of harvest likely to be considered operationally in most watersheds. To simplify the discussion, the progressive levels of cut will subsequently be referred to as 10%, 20%, 30% and 50%. All road construction, logging, and reforestation were completed according to the operational standards of the day. Logging was done in late fall and winter, on snow, using feller bunchers and ground-based skidding. Planting was in accordance with provincial species selection guidelines and stocking standards for the specific ecological units harvested. All non-essential roads were deactivated following logging and planting.

Since 1992, a network of six weather stations have continuously monitored rainfall, air temperature, soil temperature, relative humidity, solar radiation, wind speed, snow depth, and snow temperature. Detailed snow surveys are completed at seven sites every two weeks from early March until the end of snowmelt. Root zone water content was measured during the summers of 1997 to 2006 in forest, clearcut and regenerating stands. Streamflow has been measured continuously since 1985 at a Water Survey of Canada gauge site on each of 240, 241, and Upper Dennis Creeks. Water samples for chemical analysis have been collected at the streamflow gauge sites every two weeks during the ice-free season since 1992. Water samples for physical analyses have been collected daily with automated water samplers since 1996. Two deep (30 m and 50 m) wells were drilled at upper elevation in the 241 Creek watershed in 2007 and are being continuously monitored. Other variables are measured using methods specific to each study. Streamflow in 240 and 241 Creek has been well simulated with a distributed hydrological model (Thyer, Beckers, Spittlehouse, Alila and Winkler, 2004).

Overview of Results

Taking into account weather-related changes in streamflow over the study period, no significant changes in water yield, seasonal or annual, were detected at harvest levels up to 20%. Year-to-year variability in flow and the accuracy of measurement techniques makes the detection of small changes at these harvest levels difficult. Preliminary analyses suggest that clearcut logging approximately 30% and 50% of the 241 Creek and Upper Dennis Creek watersheds, respectively, has resulted in statistically significant changes in water yield over the snowmelt season. These changes are likely due to increased snow accumulation in the openings relative to the forest at low and mid elevation. High flows also appear to be occurring earlier in spring at these levels of harvest, most probably due to the earlier onset of snowmelt in the open relative to the forest and synchronisation of snowmelt runoff from mid-elevation openings with that at lower elevation. Streamflow modelling suggests that changes in peak flows may also be observed once logging extends over more than 30% of the watershed area and that increases in spring flows are unlikely to exceed 50%, on average, regardless of logging extent unless runoff is concentrated by roads (Schnorbus, Winkler and Alila, 2004).

Increases in water yield can, at least in part, be attributable to changes in the water balance post-harvest. Maximum snow accumulation expressed as water equivalent (SWE) in clearcuts averages 10% and 23% greater than in the mature pine and spruce-fir forests, respectively (Winkler, 2001). The exception to this occurs along steep, upper elevation, south-facing slopes in the 241 Creek watershed where higher SWE is measured in the forest than in the open before the onset of melt. This is likely due to periodic snow disappearance in the open during windy and warm weather prior to the main melt season. These losses potentially mitigate the effects of increased SWE at other sites across the landscape. Snowmelt in clearcuts occurs up to 10 days earlier than in the forest (Spittlehouse and Winkler, 2004) resulting in the synchronization of melt from higher elevation clearcuts with that from lower elevation forests. In stands typical of the Okanagan Plateau, including those at UPCr, surveys show that maximum SWE decreases by approximately 6% for every 10% increase in crown closure up to a maximum crown closure of 55% (Winkler and Roach, 2005). Depending on the weather, 25 to 30% of the summer rainfall is intercepted by the forest canopy (Spittlehouse, 1998). Once logged, interception of precipitation in the new clearcut becomes negligible.

Evaporation rates from a wet, bare, soil surface, such as a new clearcut, are as high as those from the forest (2 to 3 mm d^{-1}) (Spittlehouse, 2002, 2006). During dry weather, evaporation rates from the clearcut drop rapidly to less than 0.5 mm d^{-1}. Consequently, summer evaporation from a clearcut is about 30% less than that from the forest. Lower evaporation rates combined with a substantial reduction in interception loss results in moist soil and a potential increase in water available for streamflow (Spittlehouse, 2006). Ten years of weather data, precipitation interception and soil moisture measurements, combined with a physically based water balance model, gave an average annual evaporation from the forest of 400 mm y^{-1}, of which 43% was from intercepted rain and snow. Clearcut annual evaporation was 200 mm y^{-1}. Drainage from the site followed a reverse pattern with the clearcut averaging 500 mm y^{-1} and the forests 190 mm y^{-1}. The increase in the clearcut was mainly a result of the reduction in interception loss. Inter-annual variability of evaporation is mainly a function of variation in summer precipitation, while drainage variability depends on winter precipitation.

Chemical water quality remains high in all three study watersheds with concentrations of study parameters well below the drinking water standards throughout all phases of logging. Over 67% of the nitrate plus nitrite, phosphorus, and sulphate measurements were below the detection limit. Statistically significant ($p<0.05$) increases in magnesium, potassium and sodium were detected in both 241 and Dennis Creeks, as well as in organic and inorganic nitrogen in Upper Dennis. The magnitude of these changes, however, is small and changes have also been observed in 240 Creek, the unlogged control (Winkler and Nemec, in progress). These changes appear to occur in response to snowmelt, individual rainstorm, or disturbance events. Concentrations quickly return to background levels following the event. Since concentrations are low, changes in individual chemical water quality parameters as a result of logging are not readily distinguishable from a general upward trend in parameter concentrations observed in all streams including the control. However, when all chemical water quality parameters are considered together, preliminary results of an ongoing analysis suggest that a shift in water quality described by groups of variables began post-20% cut (Winkler and Nemec, in progress). Two to three years post-20% harvest, nitrate nitrogen concentrations in Upper Dennis Creek increased noticeably in the spring, just prior to the peak in streamflow. This is a result of increased losses of nitrogen in soil water drainage in the first few years post-harvest (30 to 60% higher in the clearcut than the forest), particularly during snowmelt. However, losses of all forms of nitrogen from the root zone are extremely small (<0.1% of the total available). As a result, even at their highest measured values, nitrogen concentrations remain very low in stream water (Hope, 2008).

These small watersheds appear to be sediment poor and any sediment available to the creek is rapidly moved through the system. Elevated concentrations of suspended sediment were observed during the spring freshets immediately following logging. Slightly elevated turbidity continues through the summer and fall and in some cases increased turbidity may occur for as long as three years following harvest. The length of time that elevated readings are observed is the result of delayed delivery to the creek from the hillslope sources and may also be related to the proximity of the source to the sample collection location. The creeks appear to lack the streampower, both in terms of strong peak flows and duration of the elevated flows, to move coarser sediment (sand size and larger) through the watershed to the weir in one season. Stream channels in the Dennis Creek watershed are controlled by bedrock ridges. The main channel is dominated by large boulders with woody debris forming jams, steps and pools. In 240 Creek, the upper portions of the watershed have few channels and these cross the structure of the bedrock. In the centre of the watershed there is a large flat area where the main stem channel forms as the feeder channels leave the hillslopes. The channel then passes through a bedrock controlled valley for over a kilometre to the weir. The 241 Creek watershed has tributaries flowing through bedrock controlled draws in the steeper upper portions of the watershed. These come together along the base of the hillslope on the remnants a large glaciofluvial floodplain and flow across gentle ground to the weir. Despite the differences in the three watersheds, there has been very little change in any of the stream channels. The channel banks and beds have remained stable with only minor changes in wood inputs.

Aquatic invertebrate communities were found to be resilient to logging when slash was kept out of the stream channel. The number of invertebrates sensitive to change and invertebrate biodiversity stayed the same or increased post-logging, depending on the site. The proportion of shredders (invertebrates eating leaves) decreased. These results differ from those at another study location where fine logging slash left in the stream had a large deleterious effect on the aquatic insect community.

Understanding regional aquifer systems within mountainous regions requires an understanding of groundwater flow in the adjacent mountains where most of the recharge occurs. Lineament density (the number of bedrock fractures per unit area) mapping throughout the Okanagan Basin showed that fracture density in the 241 Creek watershed is relatively low (Voeckler and Allen, 2008). Based on pumping and monitoring well responses, the average transmissivity of the aquifer is estimated at 4.24×10^{-6} m^2 s^{-1} and the storativity value, 0.001. Using these values in Discrete Fracture Network modelling the preliminary estimate of the bulk fractured bedrock hydraulic conductivity within the 241 Creek watershed is on the order of 10^{-6} to 10^{-7} m s^{-1}. The downward movement of groundwater in the bedrock, or recharge, is estimated to be in the order of 5.77×10^{-9} m s^{-1} or 182 mm per year. This amounts to approximately one-third of the total annual precipitation, a significant portion of the overall annual water budget (Voeckler, in progress).

Relevance to Water Resource Management

Field measurements combined with modelling at UPCr provide information directly relevant to water resource management in the Okanagan Basin. As forest cover is lost to over 50% or more of small upland watersheds, changes in water yield, particularly in spring, can be expected. This finding provides an indication of the potential effects of natural disturbance such as mountain pine beetle (MPB) and subsequent salvage logging on water yield from upland watersheds. The results of snow surveys across the study area show that, when planning logging operations, opportunities exist for mitigating the synchronization of snowmelt from mid-elevation openings with that from lower elevation sites as well as the importance of considering the spatial variability in hydrologic processes across watersheds. The relatively small changes in streamflow measured over the short period of record at UPCr may be more significant during wetter or drier years than occurred during this study, or when variables such as event extremes and frequencies are considered, as has been demonstrated by modelling. Measurements in regenerating stands suggest that if future water availability is calculated based on streamflow from highly developed (harvested) watersheds, long-term water supplies may be overestimated if subsequent hydrological recovery due to forest re-growth is not taken into account. Building on the existing long-term database, continuing research in the Okanagan at UPCr and Camp Creek

(Moore and Scott, 2005) is directly measuring the rate of hydrologic recovery post-harvest. These data can be used to parameterize hydrologic models in order to estimate streamflow changes across the broader landscape of interest to down-stream water users.

Work at UPCr has also shown that extensive clearcut logging can directly or indirectly affect the water quality from small upland watersheds typical of the Okanagan Plateau. Where surface runoff patterns have not been affected, where channels remain intact, and where erosion does not occur, these changes appear to be short-term, persisting through a single, or several seasons, of high flow events. Where the stream channels and banks remain relatively undisturbed by clearcutting aquatic invertebrates are not adversely affected. Identification of sediment sources, minimising stream crossings, yarding away from creeks, and limiting or avoiding areas in or leading directly to the active riparian zone, all contribute to minimising the effects of logging in headwater streams. These recommendations applied to logging through the headwaters of the Okanagan Basin and in particular where extensive pine beetle salvage is anticipated, will help to protect both water supplies and aquatic habitat downstream.

Early research results throughout the Okanagan Basin have shown that groundwater processes at high elevation in mountainous regions can be significant, but are often overlooked due to lack of data or lack of consideration for their importance. Recharge to the deep bedrock at UPCr is evident in the sustained baseflow throughout the summer and early fall season. Even though shallow soil piezometers are mostly dry during the mid to late summer months, there is measurable flow of water in 241 Creek, suggesting that streamflow derives at least partly from deeper groundwater sources. Given the high potential for groundwater recharge at high elevation, there may be a significant groundwater flow component to aquifers in the Okanagan Valley bottom (Voeckler and Allen, 2008). These results highlight the importance of groundwater contributions from upland watersheds and suggest that changes in the surface and near-surface water balance through forest disturbance could potentially also affect downslope and downstream groundwater supplies.

The long-term database provides the foundation for future research into the water resource implications of forest land use, natural disturbance, climate change and increasing water demand. The next phase of the UPCr watershed experiment will focus on hydrologic processes in young stands and the effects of reforestation on water supplies. Work will continue to develop and improve hydrologic models for watersheds typical of the Okanagan Plateau including the incorporation of deep groundwater. The long-term data legacy at UPCr also allows us to answer questions about issues that have emerged since the experiment was initiated, such as the potential consequences of MPB-related stand mortality and subsequent salvage logging and the potential consequences of climate change on water supplies and aquatic habitat. The streamflow and weather databases at long-term research sites such as UPCr also provide a unique opportunity for future field process studies and hydrologic modelling that explore questions which we have not yet considered and provide answers which will continue to enhance stewardship of water resources in the Okanagan Basin.

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Regional Characterization of Groundwater in the Okanagan Basin

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Abstract

A significant goal of the Phase 2 Okanagan Basin Water Supply and Demand Project is to develop an overall basin water balance that incorporates groundwater. This paper presents an overview of the groundwater portion of the water balance study, specifically the methodology used to characterize aquifers in the Basin as well as to quantify monthly flow and changes in storage over a ten year period from 1997 to 2006. When the Project began in early 2008, approximately 80 alluvial and bedrock aquifers in the basin had been identified and mapped by the Ministry of Environment, representing approximately 20 % of the geographic area. The Study Team developed a concept to assess aquifers across 100% of the basin and re-mapped alluvial and bedrock aquifers based on geology and surface water catchment relationships. As the majority of the bedrock aquifer areas lacked hydrologic and hydrogeologic data, it was necessary to conduct a regional analysis to infer key spatial water balance relationships.

Where data existed, for example at discrete observation well hydrograph locations, aquifer hydraulic data from drilling and pumping tests at well locations and at stream flow hydrograph locations, the Study Team assessed aquifer recharge and discharge relationships based on regional climate data and literature sources. This enabled spatial relationships to be developed specifically for the Basin, relating surface runoff to groundwater recharge and net water availability as a function of precipitation, elevation and evapotranspiration. The Study developed individual water balances for over 300 separate bedrock and alluvial aquifers and the sensitivity of various input parameters in the water balance calculations, including hydraulic conductivity, gradient and saturated thickness were analyzed to determine relative influence.

The output of this study increased the level of understanding of potential aquifer yield and surface water/groundwater relationships throughout the Basin. The information could be used for the development of more detailed conceptual and numerical groundwater flow models in selected areas, as well as a tool to support water management planning in the Basin.

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The International Osoyoos Lake Board of Control and the Osoyoos Lake Orders

International Osoyoos Lake Board of Control (Kirk Johnstone)

Abstract

The *1909 Treaty between the United States and Great Britain Relating to Boundary Waters and Questions Arising Between the United States and Canada* was designed to prevent and resolve disputes over our shared waters—particularly those related to water quantity. The Treaty established an International Joint Commission (IJC) comprised of three members from each country and gave it jurisdiction over the use, obstruction and diversion of those shared waters. With such an obstruction on the Okanogan River in Washington, Zosel Dam, which affects water levels in Osoyoos Lake in British Columbia, the Commission wrote an Order governing the operation of the dam and created a Board of Control to oversee the implementation of the Order. Similar to the Commission, the Board is comprised of three members from each country. The Members are water resource specialists drawn from federal, provincial and state agencies, working for the Commission in their professional capacity. The Order sets out an allowable range of water levels for winter, summer, and summer under drought conditions. Further, it establishes drought criteria for the lake based on the forecast freshet response of the Similkameen River and Okanagan Lake. It also sets a conveyance standard for the outlet of the lake to assure that Zosel Dam remains in functional control of water levels. The Osoyoos Lake Order is one of few IJC Orders that has an expiry date: February 22, 2013. The Board of Control is currently working to provide the Commission with information that will inform a replacement Order.

The Boundary Waters Treaty

1909: Canada and United States, being equally desirous to prevent disputes over their shared boundary waters, ratified the Boundary Waters Treaty. Two issues were particularly notable at the time: the diversion of the Niagara River and its affect on the level of Lake Erie; and the apportionment of the Milk and St. Mary Rivers for irrigation in Montana, Alberta and Saskatchewan. The Treaty set out solutions to these two matters and, perhaps more significantly, established an International Joint Commission to deal with future cases of obstruction or diversion of shared waters.

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The Commission is comprised of six members: three appointed by the President of the United States and three appointed by the Governor in Council for Canada. At present, the Commissioners are Irene Brooks (co-chair), Allen Olson and Sam Speck for the United States, and the Rt. Hon. Herb Gray (co-chair), Jack Blaney and Pierre Trépanier for Canada.

The Commission operates under the principle that each country, on its own side of the boundary, has equal and similar rights to the use of boundary waters. The 1909 Treaty provides guidance on an order of precedence for use: first for domestic and sanitary purposes, second for navigation, and third for power and irrigation. In addition to ruling on obstructions and diversions, the Commission may deal with issues that are referred to it by either country. The issue may be referred either for examination and reporting or, in cases involving the rights, obligations or interests of either country in relation to the other, for decision. This last role, referral for decision, has never been used.

West of the Great Lakes, our shared waters are *transboundary* in nature, rather than *boundary*. While the Treaty fails to define ‘transboundary waters’, it clearly addresses them. Paraphrased, Article II says:

> Each country reserves, subject to existing treaties, the exclusive jurisdiction and control over the use and diversion of waters on its own side of the line which in their natural channel flow across the boundary. *But* if any interference or diversion results in injury on the other side of the boundary, the injured party is entitled to the same rights and remedies as if the injury took place in the country where the diversion or interference occurred.

Article IV, again paraphrased, says:

> Each country agrees that, except by special agreement, they will not permit the construction or maintenance of dams or obstructions downstream of the boundary in rivers flowing across the boundary, the effect of which is to raise the water level in the upstream country, *unless* the construction or maintenance is approved by the Commission. Further, waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other.

The International Joint Commission has approved numerous obstructions in boundary and transboundary waters along the length of our common border using a mechanism known as an *Order of Approval*. Orders of Approval give an *Applicant* to the order conditional approval to construct, operate and maintain the obstruction. West of the Rockies, there are several cases where the Commission has written orders for obstructions on transboundary rivers, most notably Grand Coulee Dam on the Columbia in Washington, Corra Linn Dam on the Kootenay in British Columbia, and Zosel Dam on the Okanogan in Washington. In each case, the dam has the capacity to raise the water level in the upstream country.

An Order from the Commission is not exclusive permission to construct a stream obstruction. Proponents must also meet the requirements of their own country. For example, in Canada the Department of Foreign Affairs administers the International Boundary Waters Treaty Act, which requires that a dam or obstruction on a stream that affects the water level upstream in the United States must be licenced by the Minister.

The Osoyoos Lake Orders

Osoyoos Lake is the lowest in a chain of lakes that characterize the Okanagan River in south central British Columbia and north central Washington. It sits straddling the international boundary in a near-desert setting, largely surrounded by the towns of Osoyoos and Oroville and territory belonging to the Osoyoos Indian Band. The lake is a major tourist destination, a haven for boaters, water-skiers and sun-lovers. It is also a key connection in the uppermost salmon-producing tributary of the Columbia River system. A few kilometres downstream of the lake, the Okanogan River is joined by the much-larger Similkameen. The combined water flows south another 100 kilometres before conflux with the Columbia just downstream of Chief Joseph Dam.

Zosel Dam, a couple of kilometres below the lake, was originally built in 1927 to form a mill pond for the Zosel Lumber Company in Oroville, Washington. When, in 1946, it became apparent that the dam and associated upstream sandbars could alter the level of Osoyoos Lake in Canada, the Commission issued its first Osoyoos Lake Order of Approval to the Applicant, the State of Washington. The Order required that the dam be altered and maintained in such manner as to increase its discharge capacity. Further, it established the *International Osoyoos Lake Board of Control* to supervise this alteration and maintenance.

By the 1980s, the original wooden dam structure had fallen into substantial disrepair. The Applicant and the Province of British Columbia were in agreement that the structure needed to be completely rebuilt. To reconstruct the dam, a new Order was needed. It followed in 1982 and came with significant conditions related to the operation of the dam in relation to lake levels. But it did not specify a transboundary flow regime. The 1982 Order was supplemented in 1985 with an Order that allowed a change in the planned design and location of the project, and it set out a conveyance requirement for the river above and below the dam. The new Zosel Dam was finally completed on February 22, 1988.

The Osoyoos Order of Approval lays out a seasonal lake level regime with allowances for adjusting to drought conditions. In the winter, from November through March, the lake must be held within the range of 909.0 to 911.5 feet as measured at the gauge in Oroville, Wa. In the summer, that is April through October, this range is reduced to 911.0 to 911.5 feet, but occasional exceedences due to high flows into the lake or blockage of the Okanogan River by the flood waters of the Similkameen are anticipated. In drought years, particularly to benefit irrigators, the summer range is increased to 910.5 to 913.0 feet to facilitate greater storage and drawdown. Unfortunately, water at levels above 912.5 feet tends to encroach on beaches and lakeside property. To alleviate this problem, the Province of BC and the Applicant try to manage the whole Okanagan system to avoid the need to use this upper half foot of storage on Osoyoos Lake.

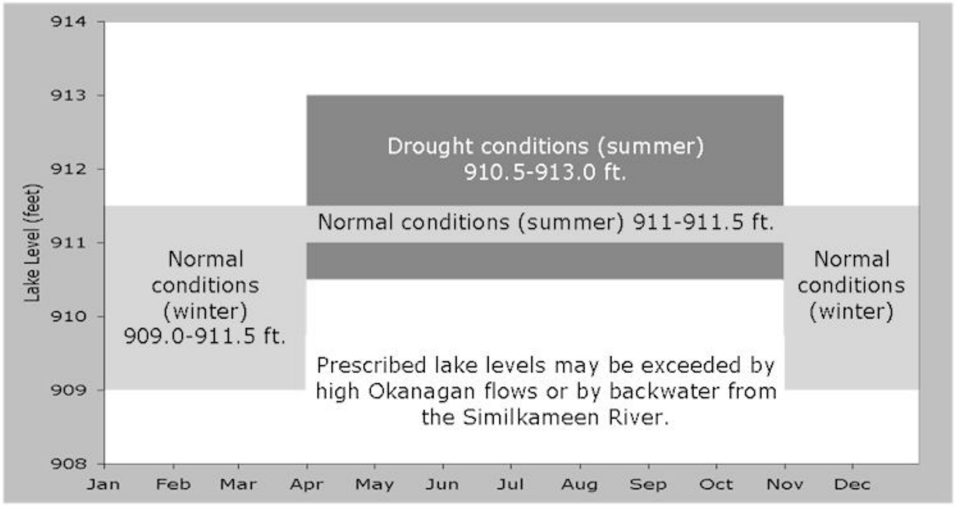

Figure 1: Osoyoos Lake allowable water levels.

The Order sets out three criteria to identify a drought year, any one of which triggers drought summer operation. These criteria may be either forecast or actual conditions: the Similkameen River discharging less than a million acre-feet from April through July; Okanagan Lake having inflow less than 195,000 acre-feet from April through July; and Okanagan Lake failing to reach an elevation of 1122.8 feet in June or July. Drought operation has been in effect for 10 of the 22 seasons since the new dam was built.

Tonasket Creek flows into the Okanogan River just upstream of the dam. It is capable of building a considerable delta in the river. To address such stream morphological processes in the stretch of river between the lake and the dam and downstream, the Order sets a conveyance requirement for the Applicant. By demonstration or calculation, the river and dam must be capable of passing 2500 cubic feet per second at a lake elevation of 913.0 feet. This offers assurance that the dam, rather than the stream channel, remains in control of lake levels.

A notable aberration to the level of Osoyoos Lake is that in freshet, the Similkameen River, even though it joins the Okanogan downstream of the lake, not only can restrict the outflow of the lake through the dam, but also can reverse the flow of the river through the dam and back into the lake. Under such high runoff conditions, lakeside property encroachment or even flooding are bound to occur.

The Osoyoos Lake Order is one of very few orders that have an expiry date. The Order stands for 25 years from the completion of the new dam construction, and hence expires on February 22, 2013. The State of Washington Governor's Office has indicated that the State intends to apply for a replacement licence in due course.

The Osoyoos Lake Board of Control

To oversee its approval orders or lead its studies, the Commission may appoint accredited officers, advisory boards, study boards, task forces, or, most commonly, boards of control. The Osoyoos Lake Board of Control, as re-established in the 1982 Order, is tasked with ensuring the

Applicant's compliance with the terms of the Order, keeping the Commission updated on all relevant matters, reporting any violations, and reporting as necessary on hydrological, operational and maintenance issues related to the dam. The Board consists of three members from each country, each a water resource specialist and each acting in their personal professional capacity rather than as representatives of their parent agency. Kirk Johnstone and Cindi Barton are the respective Canadian and American co-chairs, with Canadian members Glen Davidson and Brian Symonds, and American members Kris Kauffman and Col. Anthony Wright. These six members are drawn from Environment Canada, United States Geological Survey, BC Ministry of the Environment, Washington Department of Ecology, and the US Army Corps of Engineers.

Reissuing the Orders

A key task for the Board is to ensure the Commissioners are sufficiently informed about Osoyoos Lake issues as they write the new order. Many issues have come up during the Board's current tenure. They include concerns about high water levels, drought conditions, and water quality.

In 2006, the Commission approved the Board's Plan of Studies for the Renewal of the Orders. The Board is now in the process of implementing these studies, with completion scheduled for early 2011, thereby allowing the Commission two years to prepare the new Order. The Plan of Study describes eight prioritized studies. Where appropriate, these studies will utilize the results of the Okanagan Basin Water Board's Okanagan Water Supply and Demand Project to ensure work is not repeated and outcomes are consistent.

In response to concerns about water levels that exceed 912.5 feet, the first study will investigate the most suitable range of lake levels during drought years. It will forecast future water volume requirements for the lake and suggest optimum water levels to achieve that volume of storage, with consideration of the acceptability to all stakeholders. The next study follows by examining the drought criteria. Under the present Order there is no qualification to drought; it is all or nothing. The investigator will look at degrees of drought severity in relation to water needs and offer methods of redefining drought in the Okanagan basin context.

The third study will review the dates for switching seasonal operations of the lake. At present, with a separate designated water level range for summer and winter, the lake does not follow a typical water level cycle with a natural decline following the spring freshet. This may potentially affect biological processes in and around the lake. The investigator will look at the pros and cons of moving the two transition dates, and consider the benefits of ramping the transition. Proposed alternatives will take into account flood control, irrigation and domestic use, and ecosystem benefits.

For many local citizens who have communicated with the Board of Control, water quality is a serious concern. While the lake quality appears stable, it is not particularly good. Residents complain that quality issues such as algal blooms detract from their enjoyment of the lake. Study four considers these water quality concerns, looks at the basis of the various issues, and investigates controlling environmental factors. In particular the study will determine if the dam's operation and control of lake level and flow regime can be adjusted to improve conditions without unduly compromising other needs such as flood control and water availability. This work is complementary to study five, which investigates how ecosystem requirements in and around the lake can best be addressed in the new Orders.

Study six is intended to ascertain the impacts of climate change on the basin hydrology over the duration of the new Order. Looking at the past drought response of the Okanagan system along with model simulations of the future, the investigator will offer ways to incorporate in the new Order climate change as presently predicted and ways the make the Order sufficiently adaptive to future climatic conditions as they develop.

With the presence of Zosel Dam, there is often a tendency to believe that humans have absolute control over Osoyoos Lake levels. It is perhaps intuitive that if water levels were drawn down prior to a freshet or flood then the lake would have more capacity to absorb the additional water volume and reduce flood risk. The natural hydraulic obstruction to Okanogan flows caused by high Similkameen flows at the confluence along with the relatively small area of the lake combine to reduce the flood water storage capacity of the lake. Study seven looks at factors that govern lake levels during flood conditions, seeking to explain and communicate any potential practicality of dam operation to ameliorate impacts.

The final study, study eight, is simply an examination of the methods used to assure the conveyance capacity of Okanogan River above and below the dam.

While these eight studies provide one avenue to inform the Commissioners as they write a new Order, there is ample opportunity for stakeholders to bring their interests to the attention of the Commission. In particular, the Commission will hold public hearings prior to writing and issuing the Order, and will invite written submissions. As always, the Board of Control holds annual public meetings each fall that many individuals use to air their concerns.

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Water Management and Use Study

Don Dobson

Abstract

The Water Management and Use Study is the first project in Phase 2 of the *Okanagan Water Supply and Demand Project*. This paper summarizes the “state of the basin” regarding current water use and how it is managed.

The study objectives were:

1. To develop a thorough understanding of water use and management in the Okanagan Basin and prepare a report that describes the current state of the basin in this regard; and
2. To develop a database reflecting water use and management at each node in the Okanagan Basin (i.e. 81 points of interest) on a weekly basis for 1996 to 2006.

The results from the study were to be used to support a water balance model to be developed for the Basin.

There are 3,981 active water licenses in the Basin, 493,236 ML for off-stream use, 26,550 ML for instream (conservation) use, and 212,236 ML for storage. The total surface water used in 2006 was approximately 238,410 ML. In 2006, irrigation use was 63% and domestic use was 37% of the licensed volumes.

Groundwater use data were compiled for 24 water suppliers that operated 72 active wells. The groundwater use in 2006 was 19,083 ML.

Water use for 2006 was determined for six end-uses: agriculture, golf courses, parks/open space, domestic (indoor and outdoor), institutional, commercial, and industrial (ICI), and unaccounted for water (losses).

It was recommended that:

- The water license system be reviewed and revised.
- The water license system should reflect the way water is used in the basin.
- There should be a standardized system for the collection, review and archiving of water data.
- The hydrometric/climate network in the Basin requires immediate upgrading.

To manage water effectively in the Basin in the future will require a commitment by the agencies and water managers to collect better water data and more water and climate data in a consistent manner and to an established standard. The quality of the output from the Water Balance Model will only be as good as the input data.

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Introduction

In response to increasing concerns regarding the sustainable use of water in the Okanagan Basin, the Okanagan Basin Water Board (OBWB) and its federal, provincial, and Okanagan Nation partners (the Working Group) have undertaken a multi-phase project, titled the *Okanagan Water Supply and Demand Project* (the Project). The overall goal of the Project is to determine the current and future supply and use of water in the Okanagan Basin. The first phase of the project (Phase 1) was completed by Summit Environmental Consultants Ltd. (Summit) in 2005 and included a summary of existing information and data as well as data gaps, development of an information database, and development of a strategy to meet following goals:

- determine the current supply and use of surface water and groundwater in the Basin;
- develop a model to route water through the Basin to examine water management alternatives; and
- identify potential future changes in both water supply and use resulting from changes in the population, economy, climate.

The OBWB issued a Request for Proposals for the Water Management and Use component (the study) in June 2007. In July 2007, Dobson Engineering Ltd. (Dobson) was awarded a contract to complete the Water Management and Use (WMU) study. This study involved the compilation and analysis of a large body of relevant data and information on water management and use in the Okanagan. This paper provides a summary of this information and describes the current state-of-the-basin with regards to water management and use in the Okanagan.

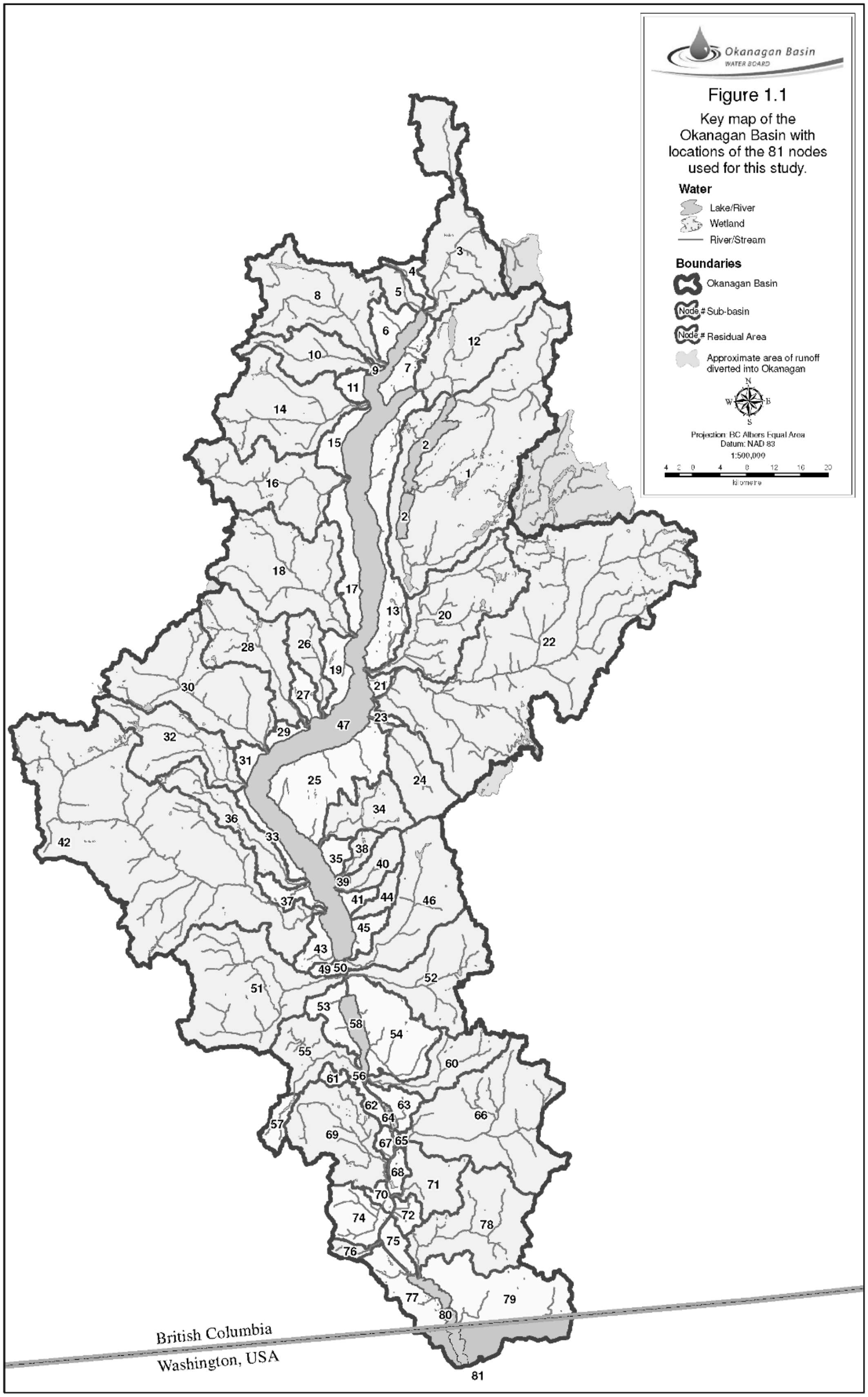
Scope of the Project

Spatial Scale

The geographic boundaries of the study area include the entire Okanagan River watershed upstream of Zosel Dam near the outlet of Osoyoos Lake (Figure 1.1) and are consistent with that used in the 1974 Okanagan Basin Study. The total watershed area to the Zosel Dam is 8,046 km^2. Zosel Dam and the southern portion of Osoyoos Lake are situated within Washington State but the watershed area within the USA is relatively small (~73 km^2).

The Basin was subdivided into five zones:

- Zone A: The watershed for Vernon Creek upstream of the outlet of Kalamalka Lake,
- Zone B: The watershed between Vernon Creek at the outlet of Kalamalka Lake and the outlet of Okanagan Lake at Penticton,
- Zone C: The watershed between Okanagan River at the outlet of Okanagan Lake and Okanagan River at Okanagan Falls,
- Zone D: The watershed between Okanagan River at Okanagan Falls and Okanagan River near Oliver, and
- Zone E: The watershed between Okanagan River near Oliver and the Zosel Dam downstream of Osoyoos Lake.


Okanagan Basin
WATER BOARD
Figure 1.1
Key map of the Okanagan Basin with locations of the 81 nodes used for this study.
Water
Lake/River
Wetland
River/Stream
Boundaries
Okanagan Basin
Node # Sub-basin
Node # Residual Area
Approximate area of runoff diverted into Okanagan
N
W
E
S
Projection: BC Albers Equal Area
Datum: NAD 83
1:500,000
4 2 0 4 8 12 16 20
kilometre
British Columbia
Washington, USA

The Basin was further divided into 32 sub-basins representing tributary watersheds, 40 residual areas, i.e. land parcels of interest, but not constituting watersheds, the five mainstem lakes, and four key locations on the mainstem of the Okanagan River. These constitute the 81 nodes used in the water balance framework (Table 1). The nodes also define the spatial resolution of this study, that is, the study focus is at the sub-basin/residual area scale and larger. The exceptions are the water suppliers in the Basin. For the purposes of this study a water supplier was defined as an entity that supplies domestic and/or irrigation water to a defined community area with water licenses totaling 123 ML or more per year.

Temporal Scale

Water use in the Basin is influenced by population, climate impacts, land use, changes in irrigation practices and water distribution systems. A task of this study was to define a standard time period that *reasonably* reflected both the current average water use as well the current variability of water use in the Basin. An 11-year time period from 1996 to 2006 was chosen for this study. This period provided a basis to estimate the recent variability of water use in the Basin and includes 2006, the most recent Canada Census year that also (by chance) represents an average year in terms of water use. In addition 2006 was the most recent year for which there was a complete dataset available from all the water suppliers in the basin, and a review of the Environment Canada climate summaries for the period 1948-2006 suggests that 2006 was a reasonably average year overall for precipitation and temperatures.

Weekly data were estimated from the actual available water use data to provide sufficient temporal resolution for the proposed water balance model. Since water use data are typically collected on a monthly basis by most suppliers, not on a weekly basis, this time step presented its own challenges.

Study Objectives

The two primary objectives of the Water Management and Use Study were:

1. To develop a thorough understanding of water use and management in the Okanagan Basin and prepare a report that describes the current state of the basin in this regard; and
2. To develop a database reflecting water use and management at each node in the Okanagan Basin (i.e. 81 points of interest) on a weekly basis for 1996 to 2006.

The water balance parameters addressed in this study deal with surface water and groundwater and are:

- $Q_{R\ i,t}$ – upstream reservoir component of streamflow;
- $RF_{S\ i,t}$ – surface component of return flow, e.g. sewage treatment plant releases;
- $Q_{T\ i,t}$ – rate of water transfer into the basin or between sub-basins;
- $E_{S\ i,t}$ - Volume extracted from surface sources within node;
- $R_{H\ i,t}$ - Recharge to aquifer due to human activity, e.g. septic/irrigation throughflow;
- $D_{P\ i,t}$ - Groundwater pumpage within node.

Table 1: The 81 nodes adopted for this study (from north to south).

Zone	Node No.	Description	1.1.1.1.	Node No.	Description
A	1	Vernon Creek at outlet of Kalamalka Lake		42	Trout Creek
	2	Kalamalka Lake & Wood Lake		43	Residual area W-13
	3	Deep Creek	B	44	Turnbull Creek
	4	Residual area W-1		45	Residual area E-9
	5	Irish Creek		46	Penticton Creek
	6	Residual area W-2		47	Okanagan Lake
	7	Residual area E-1		48	Okanagan River at Penticton
	8	Equesis Creek		49	Residual area W-14
	9	Residual area W-3		50	Residual area E-10
	10	Naswhito Creek		51	Shingle Creek
	11	Residual area W-4		52	Ellis Creek
	12	Vernon Creek (at mouth)		53	Residual area W-15
	13	Residual area E-2	C	54	Residual area E-11
	14	Whiteman Creek		55	Marron River
	15	Residual area W-5		56	Residual area W-16
	16	Shorts Creek		57	Residual area W-17*
	17	Residual area W-6		58	Skaha Lake
	18	Lambly Creek		59	Okanagan River at Okanagan Falls
	19	Residual area W-7		60	Shuttleworth Creek
	20	Mill Creek		61	Residual area W-18*
	21	Residual area E-3		62	Residual area W-19
B	22	Mission Creek		63	Residual area E-12
	23	Residual area E-4		64	Vaseux Lake
	24	Bellevue Creek		65	Residual area E-13
	25	Residual area E-5	D	66	Vaseux Creek
	26	McDougall Creek		67	Residual area W-20
	27	Residual area W-8		68	Residual Area E-14
	28	Powers Creek		69	Park Rill
	29	Residual area W-9		70	Residual area W-21
	30	Trepanier Creek		71	Wolfcub Creek
	31	Residual area W-10		72	Residual area E-15
	32	Peachland Creek		73	Okanagan River near Oliver
	33	Residual area W-11		74	Residual area W-22
	34	Chute Creek		75	Residual area E-16
	35	Residual area E-6		76	Testalinden Creek
	36	Eneas Creek		77	Residual area W-23
	37	Residual area W-12	E	78	Inkaneep Creek
	38	Robinson Creek		79	Residual area E-17
	39	Residual area E-7		80	Osoyoos Lake
	40	Naramata Creek		81	Okanagan River at Oroville, Washington
	41	Residual area E-8			

Notes: * These areas are considered terminal basins that have no surface water connection to Okanagan River.

The focus of this study was to determine how much water is actually used in the Okanagan Basin during the period 1996-2006 (principally water balance variables $E_{S\ i,t}$ and $D_{P\ i,t}$), and to identify not only the average water use, but also the range of water uses between “dry” and “wet” years. The following six water use categories were identified:

1. Agriculture,
2. Golf courses,
3. Parks and open-space,
4. Domestic,
5. Institutional, commercial, and industrial (ICI), and
6. Losses or unaccounted for water (UFW) (e.g. system leakage and other unaccounted for losses).

The results of this study are intended to provide a comprehensive update of the water use studies summarized in the 1974 Okanagan Basin Study Report (Consultative Board, 1974). It is intended that this report and the accompanying data be used in subsequent studies of surface water and groundwater supply, water management, and instream flows, and to provide the basis for examining current and future water management and use alternatives.

Overview of Water Management in the Okanagan Basin

Okanagan Basin Study (1974)

In 1974 the Canada-British Columbia Consultative Board released the 15-volume report on the results of a four-year study of water resource management in the Okanagan Basin. The objective of the study was to prepare a comprehensive framework plan for the development and management of water resources for the social and economic betterment of the Okanagan community to the year 2020. The Okanagan Basin Study was a new approach to water management that combined the skills of experts in water quantity, water quality, waste treatment, socio-economics, limnology and fisheries. The product from the four years of detailed work was a landmark study with scope and breadth unlike any other previously developed worldwide. Even now, 34 years later, the 1974 Okanagan Basin Study is still a remarkable piece of work and a tribute to the efforts of the scientists who produced it.

The key recommendations in the 1974 report regarding water quantity were:
For the mainstem:
"That the water available be managed such that, without large scale importation of water, all present and projected future water uses around Okanagan Lake and along Okanagan River are satisfied; recognizing that during a prolonged drought cycle, increased drawdown of Okanagan Lake and some cut-back in releases to Okanagan River for non-consumptive uses may be necessary.”

For the tributary streams:
"That major conflicts in water use between irrigation and fishery requirements in tributary streams be avoided by managing Mission, Equesis and Trepanier Creeks for fisheries and irrigation purposes, and developing other major creeks primarily for domestic and agricultural water use.

The WMU study expands on the studies reported in 1974 that focused on eight selected major tributaries and addresses the water management for the 81 nodes previously described.

Overview of Water Suppliers in the Okanagan Basin

Water Licenses

There are 3,981 active water licenses in the Basin. These include 493,236 ML for off-stream use - (149,038 ML Waterworks Local Authority + 344,197 ML Irrigation), 26,550 ML for instream (conservation) use and 212,236 ML for storage. Nearly 70%, or 344,197 ML of the off-stream licenses are allocated for irrigation. The remainder (149,039 ML) is allocated for waterworks (domestic use). The 57 water suppliers identified in the Basin account for 422,494 ML or 86% of the total issued licensed quantity for off-stream use. The developed upland storage in the 36 larger reservoirs totaled 132,589 ML or 62% of the total licensed storage in the Basin.

Water Suppliers

Within the Okanagan Basin, water is extracted from surface and groundwater sources by a diversity of water suppliers and individuals. Water extraction ranges from single points of diversion on streams or shallow groundwater wells to large municipal waterworks with high capacity pump stations and deep wells. According to the Phase 1 Water Supply and Demand Study, at least 57 water suppliers are located in the Basin (Table 2). This includes water suppliers that provide the bulk of the water used in the Okanagan, usually to supply communities with domestic water and/or irrigation water.

Surface Water Management

The surface water component of this study focused on compiling water management and water use data from water suppliers and to determine the four water balance parameters; Q_T, the rate of water transferred between basins and sub-basins, Q_R, the upstream storage component, E_S, the volume of water extracted from surface sources, and RF_S, the surface water component of return from sewage treatment plant. In addition the water use was to be determined for the six end uses.

The first 17 suppliers in Table 2 account for 60% of the total surface water use in the Basin. The management of water by these suppliers ranges from complex to simple depending upon the extent of development and use. For example, Greater Vernon Water is probably the most complex of all the suppliers since it extracts water from three sources within the sub-basin as well as storing and diverting water from the Duteau Creek watershed in the Shuswap River basin into the Okanagan. Water is distributed in three sub-basins and two residual areas. In addition sewage is collected from two sub-basins and one residual area, treated, and the treated effluent water applied as irrigation water in one residual area and one sub-basin. Further, there is throughflow from irrigation and septic systems in a node with water that may originate outside of the node and outside of the Basin.

Table 2: List of Known Water Suppliers in the Okanagan Basin.

Water Supplier No.	Water Supplier	Water Supplier No.	Water Supplier
1	City of Kelowna	32	Canyon Waterworks District
2	Greater Vernon Water	33	Eagle Rock Waterworks District
3	City of Penticton	34	Grandview Waterworks District
4	Black Mountain Irrigation District	35	Highlands Park WWD
5	Westbank Irrigation District	36	Landsdowne Waterworks District
6	District of Summerland	37	Larkin Waterworks District
7	Glenmore Ellison Improvement District	38	Otter Lake Waterworks District
8	Lakeview Irrigation District	39	Stardel Waterworks District
9	Rutland Waterworks	40	Steele Springs Waterworks District
10	District of Lake Country	41	Lower Nipit Irrigation District
11	District of Peachland	42	Sun Valley Irrigation District
12	A. Town of Oliver B. Town of Oliver (rural)	43	Traders Cove Waterworks District
13	South East Kelowna Irrigation District	44	Wilson's Landing Utilities Inc.
14	City of Armstrong	45	Casa Loma
15	Kaleden Irrigation District	46	Jennens Road Water Users
16	A. Town of Osoyoos B. Town of Osoyoos (rural)	47	Westbank First Nation
17	West Kelowna Estates (RDCO)	48	Penticton Indian Band
18	Naramata Water Utility (RDOS)	49	Okanagan Indian Band
19	Sunnyside Water Utility (RDCO)	50	Osoyoos Indian Band (Vincor)
20	West Bench Irrigation District	51	Meighan Creek
21	Alto Utility	52	Woodsdale Utility
22	Okanagan Falls Irrigation District	53	Lakepine Utility
23	Osoyoos Water Utility (RDOS)	54	Eastside Utility Ltd.
24	Sunset Ranch Water Utility (RDCO)	55	Greystoke Improvement District
25	Falconridge Water Utility (RDCO)	56	Skaha Estates Improvement District
26	Pritchard / Shanboolard Water Utility (RDCO)	57	Meadow Valley Irrigation District
27	Rolling Hills Waterworks District		
28	Boundary Line Irrigation District		
29	Lakeshore Waterworks District		
30	South Okanagan Mission Irrigation District		
31	Vaseux Lake Improvement District		

Source: Table adapted from Summit (2005).

The Kaleden Irrigation District is an example of a less complicated supplier. Its only source of surface water is Skaha Lake, and water is used within the one residual area W-15. In a number of the smaller sub-basins and residual areas, e.g. residual area W-19, there is no water supplier and surface water may be limited to individual water licensees that divert water for domestic and/or limited irrigation use.

Storage reservoir management

There are 36 large upland storage reservoirs operated by the water suppliers in the Basin for which detailed storage and release estimates are provided for the water balance model variable Q_R. The total developed storage volume for these reservoirs is 132,589 ML. The developed storage volume may not be the same as the licensed volume, the developed storage could be more but is normally somewhat less. The general criteria for determining appropriate storage volumes for water suppliers in the Basin is to have sufficient storage to meet projected water use in the event of three consecutive years of drought.

The water balance model requires weekly data for both water stored and water released from storage. Although some of the water suppliers have recently installed continuous water level recorders on their larger reservoirs, there is no long-term continuous reservoir storage data for the majority of the sites.

Groundwater management

Groundwater is used throughout the Okanagan valley primarily for municipal domestic consumption and commercial agricultural irrigation. In this study, it was determined that 24 water suppliers (with a total of 72 active wells) control the bulk of groundwater pumped and managed for human use in the valley. Based on the data provided by those water suppliers that provided information, the total annual volume of groundwater pumped in 2006 was approximately 19,083 ML. The table does not include private wells used for individual water supplies.

Overview of Water Uses in the Okanagan Basin

The 2006 water use by the six end-use categories for water extracted from surface and groundwater sources in the Basin are summarized in Table 3. The total water used is estimated to be 238,410 ML. Irrigation water use (including use on agricultural lands, golf courses, parks/open spaces) amounts to 150,482 ML or 63%. Domestic indoor use was 26,787 ML or 11%, domestic outdoor was 46,238 ML or 19%, ICI was 3,793 ML or 2% and losses were approximately 11,365 ML or 5%.

The actual water use in 2006 for irrigation was 150,482 ML or 44% of the licensed quantity (344,197 ML) and for waterworks, i.e. domestic use was 76,574 ML or 51% of the licensed quantity (149,038 ML).

Table 3: Water Use 2006 for the Okanagan Basin.

Water User	End Use Category/End Use Volume (ML)							
	Agriculture	Golf Courses	Parks/ Open Space	Domestic Indoor	Domestic Outdoor	ICI	Losses	Total Use
Water Suppliers	92697	5386	3263	23990	39519	3793	8368	177016
Others	46554	2084	498	2797	6475	0	2985	61393
Total ML	139251	7470	3761	26787	45994	3793	11353	238410
Percent	58	3	2	11	19	2	5	100

The following sections provide a brief description of each end-use category of the water use by category and a summary of the estimated water use for 2006.

Agriculture (Irrigation)

The water used for agriculture is defined as irrigation water. The volume used for irrigation varies by crop, irrigation system type, soil and climate. Nearly all of the water suppliers provided data for irrigation and domestic water use. There was limited data specific to irrigation use from any supplier for the standard period since metering irrigation water at point of use was almost non-existent for most of the period. The total estimated irrigation water use in 2006 was 139,251 ML or 58% of the total water use in the Basin.

Golf Courses

Many of the golf courses in the Okanagan are not supplied with water by the large water suppliers, but rather have their own source of supply. Most courses will divert water into storage 24 hours a day during the golf season but only irrigate for 8 – 10 hours at night when the courses are not being used. The water use by the golf courses was based on the area of golf course within the node at a typical irrigation application rate for that node. The total area for golf courses was estimated at 1,065 ha with an estimated total water use of 7,470 ML or 3% of the total water use in the Basin.

Parks and Open Space

The area in parks and open space was provided from the Ministry of Agriculture and Lands (*Land Use Model*). The water use for parks and open space was considered to be similar to agricultural land in the node. The pattern of water use would be similar to a golf course, however the annual volume would likely be less. There were approximately 604 ha of irrigated parks and open space using a total of 3,761 ML of water or 1.6% of the total water used in the Basin.

Domestic (indoor and outdoor)

Domestic indoor use is that water used for all indoor uses including cooking, bathing, drinking, laundry, and toilets. Since point of use water meters were not commonly in use for the standard period from most water suppliers and since meters were not commonly in use throughout most of the basin during the standard period, indoor water use is best represented by the winter water use less the unaccounted for losses since there is no irrigation water use from November through March. Where data were not readily available, the domestic indoor use was estimated using the water supplier population from the Census data and an average per capita use of 250 liters per day. The estimated domestic indoor use in 2006 for the Basin was 26,787 ML or 11% of the total water use for the year.

Domestic outdoor use is also not metered for many utilities and was estimated. The method used to do this was similar to the domestic indoor to use but using an average value of 1,200 liters/per person per day for the six month period from May to October. This value should be reasonably consistent throughout the valley since most water suppliers have active water conservation programs. The volume will be slightly less in the north and more in the south. The estimated domestic outdoor use in 2006 for the Basin was 45,994 ML or 19% of the total water use for the year.

Institutional, Commercial, and Industrial (ICI) Water Use

Water use for industrial, commercial and institutional (ICI) is typically that water used in schools, hospitals, care facilities, businesses and any industrial operations, for drinking, toilets, etc. The water use volumes, with the exception of hospital and care facilities, are typically low. As with most other water uses there was very limited point of use data for the standard period for most of the water suppliers. Based on the available data, the water use has been estimated at an average value of 0.75 ML/unit/year. It is estimated that there were 5,126 ICI connections in the Basin in 2006 using approximately 3,793 ML of water or 1.6% of the total water.

Unaccounted for Water (UFW)

Unaccounted for water or UFW is the amount of water that is lost throughout the water distribution system from the intake to the last user. It includes leakage in the main delivery system, leakage in point of use systems, and water theft. Few water suppliers keep actual records of this volume. Based on the analysis of a number of systems throughout the Basin, the recommended average volume for all unaccounted losses averages 5% of a suppliers total annual water use (R. Hrasko, Agua Consulting Ltd.). Based on this value the total UFW water for the Basin for 2006 the UFW water totaled approximately 11,353 ML.

Methods and Assumptions

Study Tasks

The main focus of the Water Management and Use Study was to determine the key parameters associated with management and use of water in the Okanagan Basin. In order to identify these parameters the following tasks were undertaken:

Task 1: Review of the Phase 1 Water Supply & Demand Study and Relevant Background Information;
Task 2: Recommend Standard Period for the Phase 2 Study;

Task 3: Refine Strategy to Collecting New Information;
Task 4: Compile Water License Information;
Task 5: Acquire Water Use and Management Data;
Task 6: Reduce Data and Develop Study Database;
Task 7: Reviewing Raw Data and Filling Data Gaps in Water Supplier Records;
Task 8: Estimation of Water Use by Water Use Category;
Task 9: Summarize Water Balance Parameters;
Task 10: Prepare the State of the Basin Report.

Assumptions and Simplifications Used

In order to fill data gaps, extend records, and disaggregate data to smaller areas or shorter time-steps it was necessary to adopt a number of assumptions and simplifications. The general assumptions and simplifications used in developing the estimates of the six water balance parameters are outlined below.

Upstream Reservoir Component of Streamflow ($Q_{R\ i,t}$)

The South East Kelowna Irrigation District was the only supplier that could provide long-term continuous records of reservoir levels and releases data for the McCulloch Reservoir. While most water suppliers do keep records of releases, this information is noted in the operator's logbooks and was not readily available and therefore $Q_{R\ i,t}$ was estimated using the South East Kelowna Irrigation District data as a guide.

Surface Component of Return Flow ($RF_{S\ i,t}$)

Treated wastewater return flows were available for the larger municipal wastewater treatment plants. To estimate wastewater effluent used to irrigate crops, it was assumed that the annual volume from the plant was applied as irrigation during the period April 1 – October 31.

Rate of Water Transfer into a Sub-Basin or Residual Area ($Q_{T\ i,t}$)

None of the water suppliers have continuous records of inter-basin or sub-basin-to-sub-basin transfers of water. Most do have records on volumes of water diverted from a surface source, but do not have detailed records on volumes transferred between sub-basins or residual areas.

To determine $Q_{T\ i,t}$ is was assumed that the rates of inter-basin diversion of water are similar to the requirements of the water licenses held by the water suppliers that divert water, and the rate of water diverted to/from sub-basins/residual areas was estimated by apportioning the volumes based on area of irrigated land and by estimating the population based on cadastral data for the number of lots and the Canada Census data.

Volume Extracted from Surface Sources ($E_{S\ i,t}$)

All available data on the volume of water extracted from surface sources was obtained from the water suppliers. Seldom were these data available in digital form and in only one case was it available as daily data. Water suppliers typically record water extracted from surface sources on a monthly basis, so it was necessary to develop a method to disaggregate the data into weekly time periods.

Since only a few of the water suppliers have end-use water metering in place, the distribution of water use for the various use categories also required several assumptions based on professional experience and knowledge of the Basin.

Recharge to Aquifer due to Human Activity ($R_{H\ i,t}$)

Aquifer recharge due to human activity is associated with septic system throughflow and irrigation losses to groundwater. Since little information specific to the Okanagan was available, a number of assumptions were made. The number of septic tanks within a sub-basin or residual area was estimated based on number of households not connected to sewer systems as inferred from municipal and regional district information, cadastral data, and census data. Septic system throughflow was assumed to be 250 liters per day per person.

Irrigation throughflow was assumed to be 20% of the total irrigation use for the irrigation season for each year (T. Van der Gulik, pers. comm. 2008). This will over estimate throughflow for areas with heavy soils such as clays and under-estimate the throughflows for porous soils especially where high volume irrigation equipment is used.

Groundwater Pumpage ($D_{P\ i,t}$)

Records for groundwater extraction were difficult to compile since there were limited records available. In many cases data were recorded as an annual volume only. In some cases it was recorded monthly and in many cases groundwater was used to supplement flows in distribution systems during periods of high demand for sporadic periods of time depending on the demand. Groundwater use was presented in the form that it was received. Missing periods were not estimated.

Data Quality

The data quality and reliability ratings were provided to the study team based on concepts developed by ESSA Technologies, who was responsible for the design of the Project database. For each water balance variable, the team assigned a *Data Quality* value and a *Data Error Value* to the data entered into the database for each water supplier.

Data quality was assigned a qualitative value from 0 to 5 in one of five categories with a range of ratings for each category. A value of 0-1 was assigned to low quality data based on estimates and a value of 4-5 was assigned to high quality accurate data from measurements.

Data were also assigned a value for the *Data Error Value*. This value represented an estimate of the standard error of the data. As with the data quality system there were five categories but with a discrete value for each category from 1 (uncertainty >100%) to 5 (uncertainty <=10%).

The quality of the water use data available from the water suppliers ranged from good to poor. Generally the quality for 2006 for the majority of the suppliers was good but the quality typically deteriorated rapidly with each previous year. Overall for the Basin the data quality was considered to be poor when evaluated over the 11-year period simply because the technology to easily record and store accurate data was not commonly used. The average data error, considering all the data over all the period may be in the >10% - 25% range but this was only because of the efforts of the team and the review team to correct data where there were obvious errors.

Summary

The two objectives of the Water Management and Use Study were to develop a thorough understanding of water use and how it is currently managed in the Okanagan Basin, and to develop a database for the six water balance parameters that contains the actual water use for each parameter at each of 81 nodes on a weekly basis for the period 1996-2006. The database will be used to calibrate a water balance model for the Basin. The database includes weekly data for the 11-year period for each of the six water balance parameters.

The Water Management and Use Study initially focused on the primary water suppliers in the Basin and assembling the available data on water diverted from surface and groundwater sources. The data from the water suppliers was used to develop the database for the required model parameters. The study determined how much water was diverted from all the licensed surface sources and from groundwater wells, and then apportion the water to the six end-uses.

Water license data were available online from the Ministry of Environment using the Water License Information System. There were 3,981 active water licenses in the Basin as of September 2007, the authorized the use of 149,039 ML of water for Waterworks Local Authority (domestic use, 344,197 ML for Irrigation, 26,550 ML for Conservation, and 17,533 ML for Storage

An accurate GIS spatial database was developed for the Basin to manage the mapping requirements for the study and to link data spatially and provide the spatial analysis support. The results of the GIS spatial analyses were entered into the MS Access™ database and used in the computations of the six water balance parameters.

The maps produced for the report include an overview map of the Basin with the zones and the nodes added, plus a second map that illustrates where water is diverted into the Basin and how water is transferred between sub-basins. There is also an Internet link to a Google Earth™ map of the node area that can be activated from the digital version of the report. This feature allows one to see an aerial image of the watershed and its features.

The standard period 1996-2006 was used that reflected recent water data. The period happened to include the three Canada Census years of 1996, 2001 and 2006. The period also included a wide range of water runoff and water use. The years of 1996, 1997, 2004 and 2005 were wetter years with higher runoff and lower water use. The years of 1998, 2002 and 2003 were much drier with 2003 being a record dry year. The years of 2000, 2001 and 2006 were considered normal years with normal runoff volumes and normal summer temperatures resulting in average water use.

The 57 water suppliers that represented the main body of water use in the Basin were contacted to collect water use data. The final data set of actual water diverted was compiled for only the first 17 water suppliers noted in Table 2.

After assembling the collected data it was entered into an MS AccessTM database. As the data were checked it was also reviewed for data quality and an estimate made of the accuracy. All supplied data was rated for quality and accuracy using the rating system provided by ESSA Technologies. Overall, the quality for the 11-year period was considered to be poor due to the lack of continuous actual data. For individual water suppliers the data quality and the data accuracy ranged from good to poor. There was clearly room for improvement in what data that should be collected and how it should be collected, reviewed and archived.

The results of the surface water use distribution were then used to estimate the water use for those areas not included within a water supplier for each node and the results summarized. The estimated total surface water use in the Basin in 2006 was 238,410 ML. Table 3 summarizes the water use by end use for the 57 water suppliers listed in Table 1 and for all users.

Groundwater records for water use were even more difficult to collect since groundwater is currently not licensed. It was determined that there were 24 water suppliers that operated 72 active wells in the Basin. Data was supplied for 2006 regarding the total groundwater pumped totaled 19,083 ML.

In addition to surface and groundwater extraction, the volume of water returned to surface and ground by wastewater treatment plants, septic tanks and irrigation throughflow was estimated. The estimated total water returned to surface and ground from municipal wastewater treatments plants was 15,596 ML, and to ground from septic tanks was 9,798 ML and irrigation throughflow was 30,096 ML for 2006. The irrigation throughflow is a likely an over estimate and should be revised using the results from the MAL model when data is available.

The full data set was then analyzed to apportion the water diverted by the supplier to each of the six end uses. The results at the Basin level are summarized in Table 4.

Table 4: Water Use for the Six End-use Categories for 2006 for the Okanagan Basin.

Water Use	End-use	Volume (ML)	Percent Total Use
Irrigation	Agriculture	139251	58
	Golf Courses	7470	2
	Parks/Open Spaces	3761	3
Domestic	Domestic Indoor	26787	11
	Domestic Outdoor	45994	19
	ICI	3793	2
	Losses	11353	5
Total		**238410**	**100**

The report summarizes how water is managed and used in the Okanagan Basin and the actual (or estimated actual) use for the 11-year period from 1996-2006. Analysis of the actual use for 2006, the most recent full year of record, that illustrates the current use and patterns of use, indicates that the water use is less than the licensed for Waterworks Local Authority, i.e. domestic use (51% of the licensed volume used in 2006), and for irrigation use (44% of the licensed volume in 2006). These data do not suggest that water managers should reduce efforts to reduce water use, nor do they suggest that there is an abundance of unused water. It is apparent that the climate in the Basin is changing and that supplies could be reduced in the future. It is important to note that as urbanization increases, the potential increase in water use is being offset by increased conservation measures. The future focus should be on measures to conserve water used for agriculture and outdoor domestic use.

To manage water effectively in the Basin in the future will require a commitment by the agencies and water managers to collect better water data and more water and climate in a consistent manner and to an established standard. The quality of the output from the Water Balance Model will only be as good as the input data.

Recommendations

Water management requires reliable accurate data on water supplies and water use. It was apparent to the study team that reliable accurate water data were not readily available except for the most recent years. Recognizing that there have been substantial improvements in technology in the last few years and that the data logging equipment is now readily available and affordable, there is no longer any reason for any of the water suppliers not to collect water use data electronically.

The following key recommendations are provided that would improve water management in the Okanagan Basin:

Water Licenses:

- The water license system must be reviewed and revised since it is cumbersome to use and very difficult to interrogate to derive accurate water license data.
- The water license system should reflect the current actual water use in the basin.

Water data:

- Water suppliers should be required to improve the collection of continuous water use data within their supply areas and distribution systems.
- There should be a standardized system for the collection, review of data quality and archiving of water data that all water suppliers are required to comply with. The system should be web-based and provide input fields for multiple water uses.

Climate Data:

- The province and the water suppliers should improve the hydrometric/climate network in the Basin to provide accurate long-term data to understand regional hydrology and for improved water management.

For More Detail

The full report can be found on the Okanagan Basin Water Board website at http://www.obwb.ca/ .

Potential Impacts of Climate Change on Life History Events of Okanagan Salmonids

Kim Hyatt, Margot Stockwell, and D. Paul Rankin

Abstract

The Intergovernmental Panel on Climate Change (IPCC) has made a compelling case that atmospheric warming is well underway and virtually certain to affect all regions of the globe within less than a single human generation. Warming is expected to be especially pronounced in the north-temperate zone in which the Okanagan basin is situated. Global Climate Models (GCM's) are commonly used in association with regional data sets to provide plausible projections of future conditions with respect to annual or seasonal temperature and precipitation in a given location. GCM projections of future conditions have been used in recent studies to explore the impacts of climate change on agricultural production and water consumption in the Okanagan. We are currently using projections from the same suite of GCM's (HadCM3-A22, CGCM2-A21 and CSIRO MK2 A21) centred on the year 2050 to assess potential, climate change impacts on key life history stages of important coldwater fishes (sockeye and kokanee salmon, lake whitefish) resident in river and lake habitats of the Okanagan valley. Climate change impacts have been assessed by comparing observations of the frequency of occurrence, timing or magnitude of a given life history event during a base period (1961-1990) versus projected outcomes for the same events during the future 2050's period (i.e. 2035-2065). Results from our analysis are highly consistent across all GCM projections and suggest: (a) adult migration delays for Okanagan sockeye salmon will increase from an average of 40 days (base-case) to an average of between 71-81 days (2050 case); (b) 2050 spawn timing for salmonids may be delayed by 2-3 weeks relative to current timing; (c) 2050 egg hatch will occur 1-2 weeks later; (d) 2050 fry emergence will occur 1-2 weeks earlier; and (e) the frequency and severity of climate induced losses of seasonal rearing habitat for juvenile sockeye and adult whitefish in Osoyoos Lake will increase greatly. We conclude that interactions among climate change and life history events identified here will exert a profound influence on future production trends, manageability and the probability of long-term persistence of salmon and other coldwater fishes in British Columbia's southern interior.

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Climate Surfaces for the Okanagan Basin Water Supply Demand Project

Guy Duke, Denise Neilsen, Bill Taylor, Alex Cannon, Ted Van der Gulik, Nathanial Newlands, Grace Frank, and Scott Smith

Abstract

The diverse terrain of the Okanagan Basin has a strong localizing influence on climate. Model development for water supply and demand requires climate data inputs that reflect this complexity. The Okanagan Climate Data Model has been developed to provide climate information at a suitable scale for modelling climate dependent processes. Using GIS interpolation methodology and all available climate data from a number of sources, basin-wide 500m x 500m gridded surfaces for daily minimum, maximum temperatures and precipitation have been generated for the period 1960 to 2000. Future daily climate data, up to the year 2100, have also been generated using output from six Global Climate Models (GCM) and three SRES scenarios reflecting high and low greenhouse gas emissions. GCM output has been downscaled to climate grid cells using a combined synoptic map typing and weather generator approach.

The Okanagan Climate Data Model has been used to drive the Okanagan Irrigation Water Demand Model, which provides calculations of Penman Monteith reference ET and a range of agro-climatic indices for each climate grid cell in addition to crop and terrain based irrigation water demand.

Introduction

The terrain of the Okanagan Basin is diverse and has a strong influence on climate. Water supply and demand models require climate data inputs that reflect this complexity, but climate stations are few and located mainly in the valley bottom. Consequently, spatial interpolation at a suitable scale is required to fill in gaps in temperature and precipitation data. A number of approaches have been used previously to develop models which incorporate spatial correlation and topographic effects on climate data. These include GIDS (Gradient plus Inverse-Distance-Squared) which weights predictions derived from a multiple regression equation with the inverse distance to nearby climate stations within a specified search radius (Nalder and Wein, 1998) and

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PRISM (Parameter-elevation Regressions on Independent Slopes Model) Daly *et al.* (1994) with a search neighbourhood limited to climate located on the same topographic facet (i.e., a common aspect). Other approaches include DAYMET (DAilY METeorology) (Thornton *et al.*, 1997) which uses weighted observed climate values within a search radius using a Gaussian filter with a shape parameter and ANUSPLIN (Australian National University SPLINe) Hutchinson (1995, 1999) which uses a thin plate spline algorithm to fit a smooth surface through data values. Each of these methods has shortcomings in mountainous regions where terrain variations have a substantial effect on local climate.

To account for temperature inversions, efforts have also been made to utilize two atmospheric layers when deriving gridded temperature datasets. Using PRISM, Daly *et al*. (2003) divided meteorological point data into two sets and used weighting factors to limit the ability of stations above an inversion to influence the climate parameters within the mixed layer. A standard inversion height (based on radiosonde data) and predefined inversion locations were specified (Daly *et al*., 2003). The PRISM two layer approach has been successfully applied across North America (Daly *et al*., 1994, 2003; Simpson *et al*., 2005).

In addition to terrain, large water bodies can also influence climate patterns significantly. Daly *et al*. (2003) accounted for coastal proximity by assembling a cost grid which accounts for distance from the coast, terrain blocking, and preferred wind directions to model coastal climate modifications. Perry and Hollins (2005) used the surface area of water within a 5 km radius of each climate station as a predictive variable for gridding monthly climate surfaces for the United Kingdom. Incorporating the area of surface water around each climate station in the regression-interpolation methodology worked well in all seasons, with the exception of the summer months

In this study, we have created an interactive model for deriving gridded estimates of daily T_{min} (minimum temperature), T_{max} (maximum temperature), and precipitation for the Okanagan Basin (Figure 1). An inverse distance weighting (IDW) interpolation algorithm similar to GIDS was utilized in conjunction with regional linear and non-linear regression to generate the climate surfaces from point data. Spline interpolation was not implemented because steep temperature gradients (i.e., differences in T_{max} of 4-5 ^{o}C between stations located 500 m apart) resulted in the model creating hot and cold temperature pockets causing very large errors in the resulting temperature surfaces. This drawback of splining was also noted by Daly (2006) in a review of suitability guidelines for spatial climate datasets. In addition to latitudinal and elevation influences on temperature and precipitation, temperature inversions are accounted for using a two-layer method and lake effects are modeled by establishing the average long term temperature modification on station T_{max} values.

This study builds on past work that investigated the impacts a warmed climate could have on water resources in the Okanagan Basin (Cohen and Kulkarni, 2001; Neilsen *et al.*, 2001; Cohen *et al.*, 2006; Neilsen et al., 2006). The climate surfaces used in these studies were based on the monthly climate grids produced using PRISM. At a spatial scale of 4 and 1 km, the PRISM grids were too coarse to differentiate valley and mid-slope locations (Neilsen *et al.*, 2001; 2006).

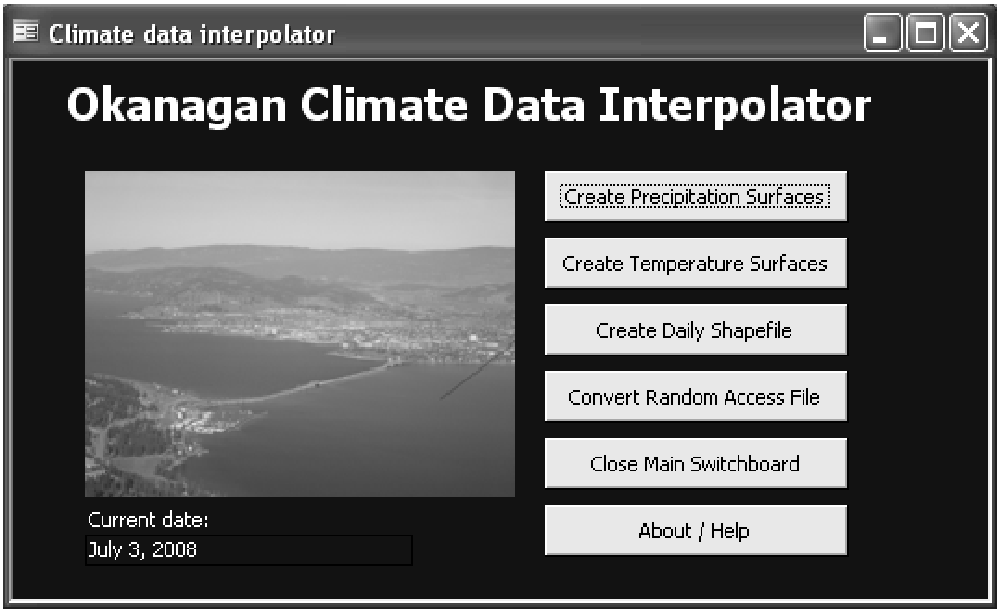

Figure 1: The Okangan Climate Data Interpolator Model splash screen.

Geographic Region

The Okanagan Basin encompasses approximately 8,000 km^2 in the southern interior of British Columbia, Canada between 48^o 56' and 50^o 30' North latitude and 118^o 37' and 120^o 22' West longitude (Figure 2). Okanagan Lake (350 m ASL) and a number of smaller 'main-stem lakes' bisect the watershed. The elevations of the surrounding mountains range from approximately 1,600 – 2,000 m asl. The region has a dry, continental climate due to its location in the rain shadow of the Coast (and Cascade) mountain ranges. On average, 88% of the 550 mm of mean annual precipitation is lost through evaporation and sublimation (Hall *et al.*, 2001). Basin averages such as those reported by Hall *et al.* (2001) mask the strong elevational and north-to-south climate gradients that extend up the 160 km valley. The southern extent of the basin is much warmer and drier than the north. There is an obvious orographic effect as average annual precipitation ranges from just under 300 mm to just over 400 mm south to north in the valley bottom, but up to 770 mm in sub-alpine regions.

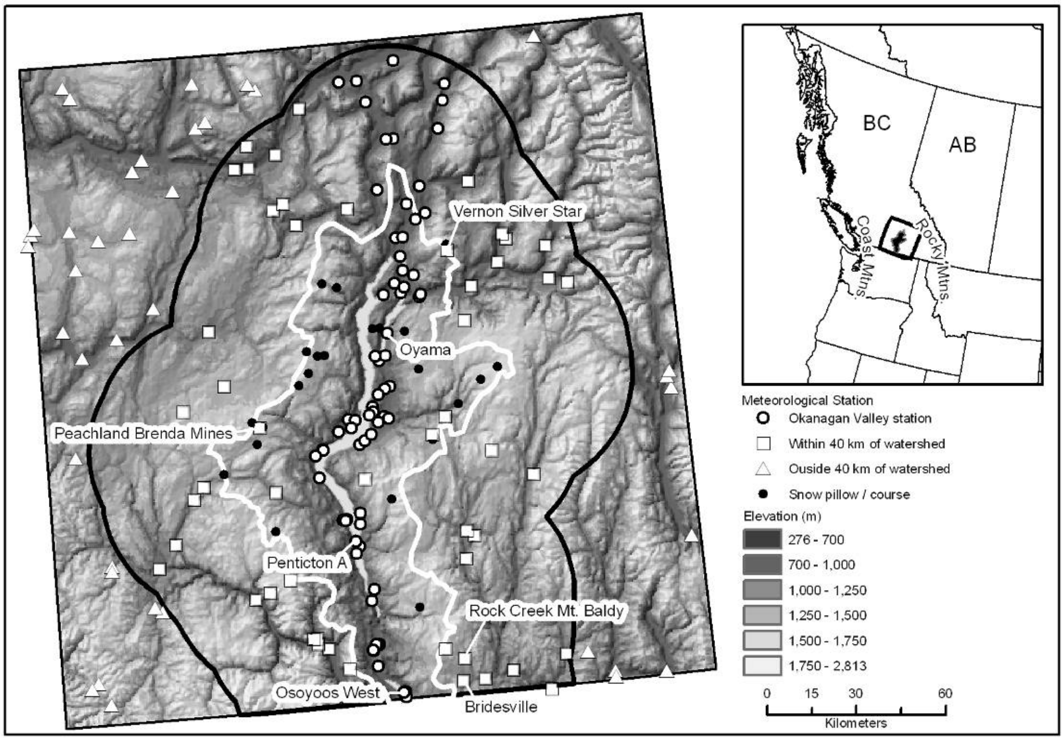

Figure 2: Okanagan valley watershed base map and study area location. Stations with labels used for cross-validation.

Climate Data

Meteorological data were acquired from the Canadian Daily Climate Data - Temperature and Precipitation CD for Western Canada (Environment Canada, 2000). In total, data from 168 stations (66 within the basin and 102 within approximately 70 km) were extracted from the data CD and used to generate a 41 year meteorological database of daily T_{max}, T_{min}, and precipitation (1960 - 2000). Since the analysis described here, data up to 2006 have been included in the model. The lack of mid-high elevation meteorological stations in the Okanagan Basin necessitated the incorporation of the stations surrounding the Okanagan valley (Figure 2) and data from other weather data networks including the BC Environment Snow Pillow stations; BC Ministry of Transportation Highways Network and the BC Ministry of Forests Fire Weather Network.

Digital Elevation Data

A digital elevation model (DEM) with a 100-m grid cell size was created as a mosaic from DMTI Spatial's (Markham, Ontario) digital database. A sensitivity analysis of grid cell size on model error indicated that the optimal spatial resolution for the climate interpolation model was 500 m. Thus, to increase computing efficiency and reduce disk storage requirements, while maintaining model integrity, the 100 m DEM was re-sampled to a grid cell size of 500 m using bilinear interpolation.

Modelling Methods

The spatial analysis involves accounting for spatial, elevation, lake effect, temperature inversion, and latitudinal variability in the meteorological data. Interpolation by inverse distance weighting (IDW) was undertaken using the Spatial Analyst feature of ArcGIS (ESRI, Redlands, CA).

Historic Temperature Grids

Daily maximum and minimum temperature grids were created using step-wise regional regression in which daily residuals of T_{max} and T_{min} are interpolated using IDW. Following the interpolation, the effect of the explanatory variables (elevation and latitude) is re-introduced to the interpolated residual grid, thereby creating a spatial representation of each variable on a daily basis. The model can be represented using Equation 1. Interpolating these climate variables after removing the effect of elevation and latitude reduces the spatial bias errors that can occur with simple regression models (e.g., Goovaerts, 2000) and incorporates a spatial interpolation component for the unexplained component of the regression models (i.e., residual data values).

$$T = (a_{(i)} \times E_{(jk)}) + (b_{(i)} \times L_{(jk)}) + y_{(i)} \tag{1}$$

Where:

$T_{(i)}$ = Daily temperature (either T_{max} or T_{min}) on day *i*
$a_{(i)}$ = Slope of elevation regression equation on day *i*
E = Elevation at grid cell *jk*
$b_{(i)}$ = Slope of latitude equation on day *i*
L = Latitude of grid cell *jk*
$y_{(i)}$ = Model error (residual value from interpolated grid) on day *i*

The elevation regression is applied if the trend is significant (p<=0.05) and the R^2 value is greater or equal to 0.25. The R^2 cut off was implemented to enhance the ability to detect inversions, and subsequently apply the two-layer model. Instead of extrapolating daily calculated lapse rates the constrained lapse rate approach of Stahl *et al*. (2006) was applied. Using the constrained approach default lapse rates, averaged by month, were used for grid cells in which the elevation is greater than the highest meteorological station that reported on any given day. The monthly default lapse rates were taken from Stahl *et al.* (2006) and were calculated using paired stations (Vernon Silver Star Lodge [1572 m] and Vernon Cold Stream Ranch [482 m]).

While the elevation-temperature regression are calculated using all stations within 40 km of the watershed, the latitude-temperature regression is completed using stations located along the Okanagan valley only . The remaining stations located outside of the 40 km buffer are used to reduce the likelihood that the basin boundary extends beyond all meteorological stations that reported on any given day, thereby minimizing the potential for interpolation artifacts along the watershed boundary.

Prior to the daily regression analysis the T_{max} data are adjusted to remove the average cooling/heating effect of surface water bodies for all stations within 5 km of a water body. In our study area, daily lapse rates and the occurrence of temperature inversions in the Okanagan

Valley are strongly affected by Okanagan Lake. T_{min} surfaces did not take lake effects into account because T_{min} temperatures are typically measured around 5:00 am and are a function of local topography (Bolstad *et al*., 1998; Yoshikado and Kondo, 1989). Monthly lake induced temperature change per 10 km^2 of lake area within 5 km of the meteorological stations were derived by regressing lake area with daily observed T_{max} values using data from 1960 – 2000 (Figure 3). The approach adopted provides a simplified method to produce a conservative quantification of T_{max} modification as a result of surface water bodies.

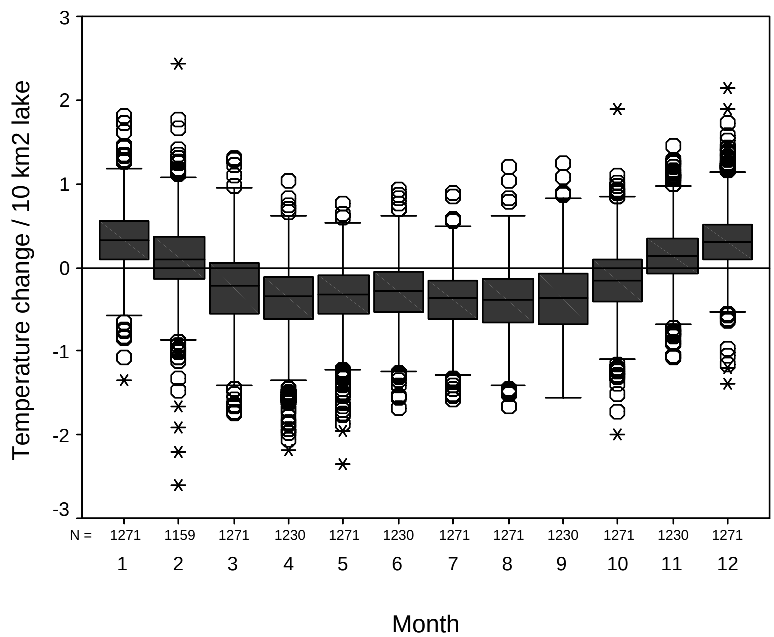

Figure 3: Predicted T_{max} difference for every 10 km^2 of adjacent lake area (January 1, 1960 – December 31, 2000). Outliers (shown with circles) are cases with values between 1.5 and 3 box lengths from the upper or lower inter-quartile range. Extremes are shown as a star.

Also of particular importance are temperature inversions that typically develop at night during clear sky conditions in mountainous terrain (Whiteman *et al.*, 2004). Using earlier versions of the model large temperature simulation errors occurred due to temperature inversions. As a result, the model incorporates a two-layer approach in which inversions (either T_{max} or T_{min}) are detected by fitting a second order polynomial to the observed data and comparing best-fit statistics with the linear regression model (Figure 4). If an inversion is detected, the observed temperature data are subset into two groups, including: 1) stations within the mixing layer (i.e., below the inversion), and 2) stations at elevations greater than the inversion height. The mixing height is defined as the elevation at which the derivative of a best-fit second order polynomial is zero. After the data are subset, the regular regression-interpolation approach is applied to the stations below the inversion. For the upper layer component a simple IDW interpolation is applied to the raw data. If fewer than 4 stations are included within the inversion the average air temperature is assigned to all locations above the inversion height.

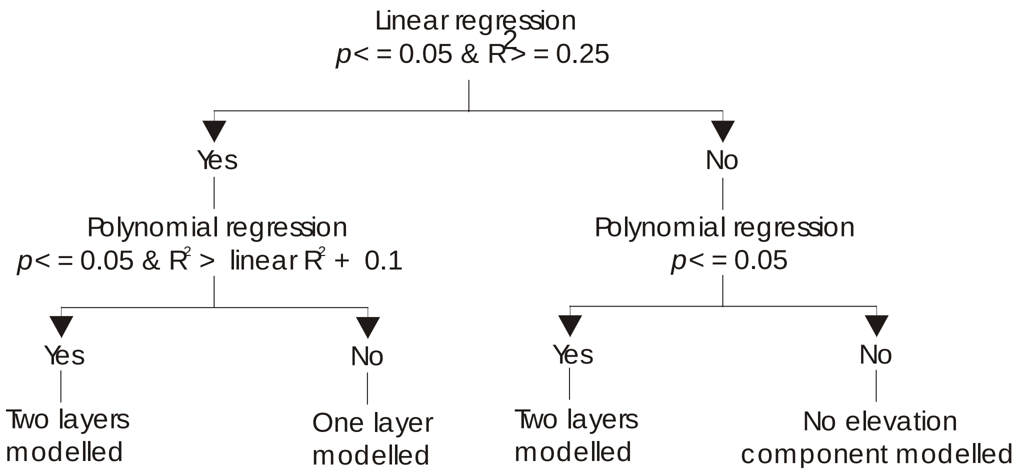

Figure 4: Model decision structure for T_{min} and T_{max} inversion and elevation-trend detection.

Historic Precipitation Grids

Gridded mean filter analysis was employed to match the scale of orographic processes in the region with the appropriate terrain representation. This analysis was completed by regressing the 41 year (1960 – 2000) average winter and early spring precipitation (December, January, February, and March) with elevation using a series of increasingly generalized DEMs. The ensemble of DEMs was generated from the average elevation within a moving grid cell window with dimensions ranging from 3-by-3 to 99-by-99 grid cells. Based on this analysis, the elevation value used should represent the average elevation surrounding each meteorological station (Spreen, 1947; Barros and Lettenmaier, 1994; Daly *et al.*, 1994; Marquinez *et al.*, 2003). Using the average elevation around each station avoids situations in which stations in narrow mountain valleys record more precipitation than their point elevations would suggest (Barry, 1981). Similarly, stations located on narrow peaks may not accumulate as much precipitation as their elevation would suggest because the blocking effect of the peak is insufficient to generate uplift and hydrometeor formation.

Daily precipitation grids were created using Equation 2. Prior to the spatial interpolation, the data were de-trended for the north-to-south precipitation gradient and the orographic component of precipitation. Again the north-to-south precipitation gradients were calculated using the Okangan Valley stations only (Figure 2). The precipitation model differs from the temperature model in that the regressions are based on monthly precipitation totals. To derive daily surfaces using monthly elevation-precipitation and latitude-precipitation relationships required the calculation of the percent of monthly precipitation at each station for each day.

$$\mathrm{Pr}_{(i)} = ([a_{(i)} \times E_{(jk)}] \times P_{(ijk)}) + ([b_{(i)} \times L_{(jk)}] \times P_{(ijk)}) + y_{(i)} \qquad (2)$$

Where:

$\mathrm{Pr}_{(i)}$ = Precipitation on day *i*
$a_{(i)}$ = Slope of elevation regression equation on day *i*
E = Elevation at grid cell *jk*

P = Percent of monthy precipitation observed at cell *jk* on day *i*
$b_{(i)}$ = Slope of latitude equation on day *i*
L = Latitude of grid cell *jk*
$y_{(i)}$ = Model error (residual value from interpolated grid) on day *i*

Two spatial interpolations are utilized, one for the residual values from the regression analysis and another to interpolate the percent of monthly precipitation on each day. Following the interpolation of daily precipitation percentages and regression model residuals using IDW, Equation 2 is reversed to create daily precipitation grids. In contrast to the one-step regression-interpolation procedures developed by Daly *et al.* (1994), Thornton (1997), Nalder and Wein (1998), and Hutchinson (1999), the spatial dependences of latitude and elevation were removed before the spatial interpolation because the daily adjustments of each observed precipitation value were based on monthly precipitation totals. The month-based approach for precipitation was favored over daily regression analysis because with so few high elevation stations, single station anomalies at a daily time-step can affect the elevation-precipitation relationship significantly. These daily anomalies could be caused by localized terrain attributes and / or atmospheric phenomenon that may not be representative over the entire study area.

Cross-validation of the interpolated climate surfaces was performed as follows. Six sites (Table 1, Figure 2) and were removed from the analysis one station at a time. The climate surfaces were derived using the remaining stations, and the interpolated data were checked against the observations for the removed stations. The mean error (ME) (predicted-observed), mean absolute error (MAE) (average of absolute values of predicted-observed), root mean square error (RMSE) (standard deviation of the ME), and linear regression statistics (simulated versus observed) were determined on a daily basis at each of the six sites for maximum daily temperature, minimum daily temperature, and precipitation for a one-year time period (July 1, 1989 – June 30, 1990). Cross-validation of the precipitation surfaces was also performed on a monthly basis because the elevation-regression models were based on monthly precipitation totals.

Table 1. Meteorological station attributes for six locations used to cross-validate the interpolated temperature and precipitation surfaces.

Station Name	Latitude	Longitude	Station Elevation (m)
Vernon Silver Star	50° 21’	119° 03’	1,572
Oyama	50° 07’	119° 22’	440
Peachland Brenda Mines	49° 52’	120° 00’	1,520
Penticton A	49° 28’	119° 36’	344
Rock Creek Mt Baldy*	49° 07’	119° 09’	1,174
Bridesville*	49° 03’	119° 10’	1,187
Osoyoos West	49° 02’	119° 27’	297

*Only precipitation validated at Rock Creek Mt. Baldy because temperature data not observed during cross-validation period. Bridesville used as the sixth station to verify temperature data in lieu of Rock Creek Mt. Baldy.

Cross-validation of the daily and monthly precipitation surfaces showed the ME, MAE, and RMSE were largest at Vernon Silver Star and Peachland Brenda Mines (Table 2; Figure 2). The large errors at these locations were attributed to the lack of neighbouring stations on the same mountain range. Rock Creek Mt. Baldy, also a mid-elevation station, did not show a similar error due to its location nearby other mid to high elevation stations (Table 2; Figure 2). The dependency of empirical regression analysis on the few high elevation stations is well documented and a common problem in alpine environments (Running *et al.*, 1987; Daly *et al.*, 1994; Lookingbill and Urban, 2003). For the daily data the ME was closer to zero than the MAE for all stations, indicating that the errors were distributed around zero. With slopes near 1, y-intercepts near 0, and high R^2 values the monthly regression statistics for 5 out of 6 stations indicate that the precipitation error was small over the course of each month.

Table 2: Comparison of Mean Error (predicted minus observed), Mean Absolute Error (average of errors after the errors are made positive), Root Mean Square Error (standard deviation of the errors), and linear regression statistics based on daily and monthly precipitation totals for six locations.

Comparison Method	Vernon Silver Star	Oyama	Peachland Brenda Mines	Pentiction A	Rock Creek Mt. Baldy	Osoyoos West
Daily						
ME (mm)	-0.9	0.1	0.2	0.0	0.2	0.2
MAE (mm)	1.7	0.5	1.6	0.9	0.9	0.5
RMSE (mm)	3.7	1.1	3.2	2.3	2.2	1.9
Slope	0.58	0.88	0.87	0.63	0.78	1.07
Y-intercept	0.37	0.19	0.46	0.41	0.54	0.18
R^2	0.58	0.84	0.53	0.60	0.68	0.69
Monthly						
ME (mm)	-25.3	2.0	6.0	-0.8	5.0	7.5
MAE (mm)	25.9	3.9	12.1	5.4	9.1	7.8
RMSE (mm)	23.6	4.7	13.8	8.2	9.9	9.4
Slope	0.66	1.03	1.17	0.90	0.95	1.13
Y-intercept	4.24	1.19	-4.57	2.97	7.36	-2.40
R^2	0.88	0.97	0.89	0.91	0.93	0.98

Cross-validation of the predicted temperature surfaces indicates that, on average, the daily maximum temperature surfaces were more accurate than the minimum temperature surfaces (Table 3). The higher T_{min} error was likely because there were more days when no distinguishable minimum temperature lapse rate was found (Figure 5). The weak relationship between minimum daily temperatures and elevation is likely due to the drainage of cold air from mid and high elevations into valley bottoms, which leads to the formation of atmospheric inversions (Cox, 1920; Barry, 1981; Whiteman *et al.*, 2004). The negative ME, low regression slope, and negative y-intercept for T_{min} at the high elevation stations Vernon Silver Star and Peachland Brenda Mines indicates that the predicted minimum temperatures were lower than observed, which would contribute to conservative snow pack melt rates. The relatively small ME for the low elevation stations (i.e., Oyama, Penticton A, Osoyoos West) is an indication that the 500 m grid cell size used in this study is an advantage over the 4 and 1 km temperature grids that were used for the crop water demand study conducted by Neilsen *et al.* (2001;2006).

Table 3: Comparison of Mean Error (predicted minus observed), Mean Absolute Error (average of errors after the errors are made positive), Root Mean Square Error (standard deviation of the errors), and linear regression statistics based on daily maximum and minimum temperatures for six locations.

Comparison Method	Vernon Silver Star	Oyama	Peachland Brenda Mines	Penticton A	Bridesville	Osoyoos West
Max. Daily Temp.						
ME (°C)	1.0	-0.1	0.8	-0.2	1.5	0.9
MAE (°C)	1.7	0.7	1.5	0.7	1.8	1.0
RMSE (°C)	2.0	1.0	1.8	0.9	1.5	0.8
Slope	0.99	1.01	0.98	1.03	0.99	1.04
Y-intercept	1.09	-0.18	0.96	-0.56	1.69	0.25
R^2	0.96	0.99	0.96	0.99	0.98	0.99
Min. Daily Temp.						
ME (°C)	-2.0	-1.1	-1.8	0.4	1.0	-0.1
MAE (°C)	2.5	1.2	2.4	1.2	1.7	0.6
RMSE (°C)	2.5	1.0	2.3	1.4	1.9	0.9
Slope	0.87	0.96	0.87	0.95	0.90	0.97
Y-intercept	-2.20	-0.90	-1.9	0.59	0.91	0.08
R^2	0.90	0.97	0.89	0.96	0.93	0.98

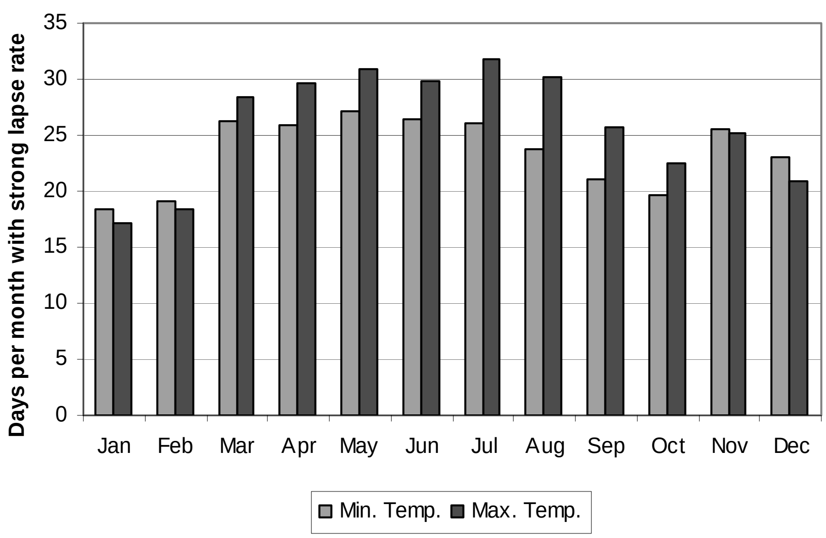

Figure 5: Average monthly frequency of strong lapse rates (*p*<=0.05 and $R^2 \geq 0.25$) observed using linear regression analysis of daily temperatures and climate station elevation from August 1, 1960 – July 31, 1990.

Future Climate Surfaces

Future daily temperature and precipitation surfaces were developed using multiple Global Climate Models (GCMs) and 3 IPCC greenhouse gas emissions scenarios (SRES). The six GCMs used were CGCM2, CGCM3, CM2.1, ECHAM5, HadCM3, PCM1. The SRES scenarios included A2 which describes a very heterogeneous world with high population growth, slow economic development and slow technological change; B1 which describes a convergent world, with a global population that peaks in mid-century with rapid changes in economic structures toward a service and information economy and B2 which describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. No likelihood has been attached to any of the SRES scenarios (IPCC, 2008).

Data were downscaled to 500 x 500m grid cells using TreeGen (Cannon, 2008) a model which combines a synoptic variable classification scheme (Cannon et al., 2002) with a weather generator. In this way, observed synoptic-scale atmospheric predictor variables are related to observed surface weather variables, and then, based on these relationships, realistic series of weather variables are generated from GCM synoptic scale variables. Algorithm details are given in Stahl *et al.* (2008, Appendix A). Predictors in the classification model were mean sea-level pressure surface air temperature, and surface precipitation data from the US NCEP/NCAR model reanalysis (Kalnay *et al*., 1996). Daily mean maps from 1948-2006 were obtained for a region covering western North America and the North Pacific Ocean (30°N-70°N; 160°W-110°W). Data were sub-sampled from the 2.5° by 2.5° resolution grid to a 5° by 7.5° grid to facilitate later use with coarser spatial resolution GCM data. Synoptic-scale fields matching those from the NCEP/NCAR Reanalysis were obtained from transient greenhouse gas plus aerosol runs of were CGCM2, CGCM3, CM2.1, ECHAM5, HadCM3, PCM1 for simulated years 1961–2100 with forcing variables from the A2 SRES scenario and one of the B1 or B2 SRES scenarios. Concurrent daily weather conditions in the Okanagan Valley were represented by precipitation amounts, mean temperatures, and diurnal temperature ranges at major surface stations. The "stations" in this case are a subset of points from the gridded climate field. Derived climate normal variables at all points in the basin were first clustered and were used to split the area into a series of homogeneous climate regions. Finally, the grid points nearest to the cluster centroids served as stations in the downscaling.

The Okanagan Climate Data Model (Figure 1) has been used to drive the Okanagan Irrigation Water Demand Model, which provides calculations of Penman Monteith reference ET and a range of agro-climatic indices for each climate grid cell in addition to crop and terrain based irrigation water demand.

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Okanagan River Restoration Initiative (ORRI)

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Abstract

The Okanagan River Restoration Initiative will return part of the channelized river back into a natural meandering path connected to its historic floodplain. Dykes will be set back, river meanders will be restored, and pool/riffle sequences will be created. On the re-established floodplain, riparian vegetation will be restored. The creation of complex and diverse natural habitat will provide high quality spawning habitat for all species and rearing for steelhead, rainbow trout and possibly Chinook. Reconnection with the floodplain should decrease silt loads in the main channel. Egg to fry survival is expected to increase dramatically and rearing sites will be established where there are presently none. The project is designed to be self-sustaining and ecosystem based.

Background

Biological Importance of Okanagan River

The Canadian portion of the Okanagan River supports approximately half of the total sockeye salmon (*O. nerka*) production in the Columbia Basin. Additionally, it supports remnant runs of Upper Columbia River summer steelhead (*O. mykiss*); naturally spawning summer/fall Chinook (*O. tshawytscha*); resident rainbow trout (*O. mykiss*); kokanee (*O. nerka*); mountain whitefish (*P. williamsoni*) and 13 other fish species (Basok, 2000; NPCC, 2004). Several of those species are listed threatened or endangered in Canada and in the United States (COSEWIC, 2008; FWS, 2008).

The river is also home to a wide variety of animals and plants that depend on the few riparian areas that remain. Several species are listed as threatened or endangered. For example, Yellow-breasted Chat (*I. virens*), Western Screech Owl (*M. kennicotti*), Tiger Salamander (*A. tigrinum*), Great Basin Spadefoot Toad (*S. intermontana*) and the Rocky Mountain Ridged Mussel (*G. angulata*) (COSEWIC, 2008).

Furthermore, Okanagan is the region with the most endangered, threatened and rare species in British Columbia. In total, the South Okanagan has 30% of BC's Red-listed wildlife species (extirpated, endangered or threatened species) and 46% of the province's Blue-listed species (species considered vulnerable) (MOE, 2008). The Okanagan River is listed as one of the most

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endangered rivers in British Columbia (ORC, 2008) and the Upper Columbia area is considered the highest priority area for recovery efforts according to National Marine Fisheries Service (NPCC, 2004).

Need for Restoration

Natural wildlife linked to the Okanagan River has been negatively impacted. The River has lost 90% of its riparian vegetation and wetland habitat (Bull & al. 2000). The result has been a loss of habitat for the various birds, amphibians and other wildlife species. Lost natural bank vegetation also generates other negative impacts such as a destabilization of streambanks, an increasing of erosion, a reduction of the natural water purification, a reduction of shading, and a rising of water temperatures. In addition, the river has been cut off from its natural floodplain and doesn't allow the same benefit from spring flood storage.

Fish production in the Okanagan River has also been severely impacted by flood protection works constructed in the mid-1950s. Only 16% (4.9 km) of the river remains in a natural or semi-natural state. Approximately 84% (30.4 km) of the river has been channelized, straightened, narrowed and dyked (Bull, 1999; NPCC, 2004). As a result, the entire length of Okanagan River has been reduced by 50 % (Bull et al., 2000). There are just a few meanders, pool/riffle sequences and habitat features suitable for species that require rearing areas such as rainbow trout, steelhead, Chinook and mountain whitefish.

Habitat quality declined as well as quantity. Studies show that sockeye egg to fry survival is only half as successful in channeled reaches as it is in the more natural areas (Long, 2004). This is likely due to the lack of natural flushing and consequential build-up of fines. Decreased egg to fry survival is only one example of the impacts of channelization; loss of rearing is another. Inventories in 2005 and 2006 found rainbow trout juveniles throughout the natural sections of river but no juveniles at all in the channeled reaches (Matthews, 2005, 2006). Likewise, Phillips (2005) found that Chinook only spawned at historic crossover points in the river.

Project Proponent

Okanagan River Restoration Initiative is sponsored by the Canadian Okanagan Basin Technical Working Group (COBTWG). COBTWG is a tripartite group dealing with technical issues associated with management of salmon and resident fish stocks and their associated habitat requirements in the Canadian portions of the Okanagan River basin. Participants in the COBTWG include Fisheries and Oceans Canada (DFO), Okanagan Nation Alliance Fisheries Department (ONAFD) and B.C. Ministry of Environment (MOE).

ORRI includes various partners sharing different roles:

- *Canadian Okanagan Basin Technical Working Group* – Direction and guidance
- *British Columbia Ministry of Environment* – Project Lead and funding partner
- *Okanagan Nation Alliance* – Project Administrator
- *Fisheries and Oceans Canada* – Regulatory approval
- *BC Ministry of Environment, Water Management Division* – Regulatory approval

- *Okanagan Region Wildlife Heritage Fund Society* – Landowner approval
- *Environment Canada* – Participation in restoration of the riparian zone
- *BC Habitat Conservation Trust Fund, BC Ministry of Environment, BC Ministry of Transportation and Highways, Bumwrap, Cocymela, Canadian Wildlife Service, Douglas County Public Utility District, Grant County Public Utility District, HCP Tributary Fund, Nature Trust BC, Okanagan Helicopters, One Wild Earth Photography, Priest Rapids Coordinating Committee, and The Land Conservancy of BC,* – funding or in-kind contributions

Project description

Project Goals and Objectives

The goal of the ORRI restoration work is to regain some of the habitat quality and quantity that has been lost. This project would return 1,087 meters of channelized river back to a more natural condition. The work involves relocating the dikes, lengthening the channel by 150 meters, re-establishing four meanders and four pool/riffle sequences, reconnecting the river to 3.9 ha of contiguous floodplains and replanting riparian vegetation (Bezener & Wood, 2005; Newbury Hydraulics, 2005). The long term purpose of project is to create more complex and diverse habitat for fish and wildlife in order to increase habitat quality. It particularly strives to increase the quality of the spawning and rearing habitats for salmonids. Figure 1 shows what the habitat currently looks like and what is envisioned at the completion of the program.

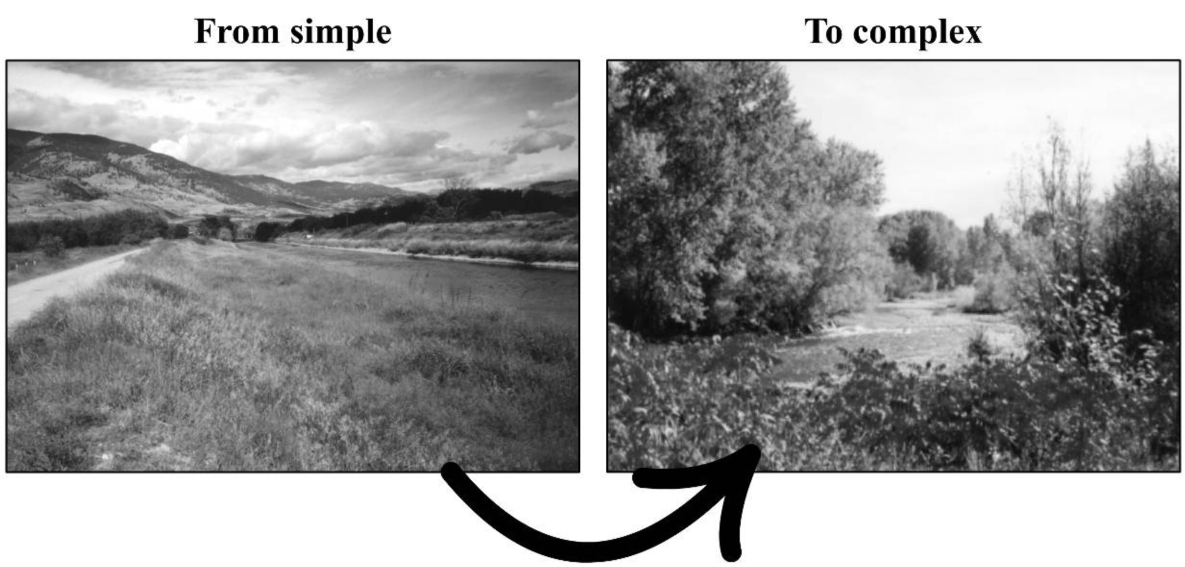

Figure 1: Restoration vision.

Project Location

The project is located on the mainstem of the Okanagan River in British Columbia, approximately 17 km upstream from Osoyoos Lake. Two properties situated on the west bank of the Okanagan River adjacent to the northern boundary of the Town of Oliver, BC were purchased specifically for this project. The southern property is named Nemes and the northern is named Lougheed after the previous owners. Figure 2 shows the location of the project and Figure 3 is an aerial photograph of the restoration site.

This site was chosen based on the channel gradient characteristics and its connectivity to productive habitats in order to maximize the habitat restoration potential. The slope of the river in this area will allow for re-creating river characteristics like riffles and runs. Furthermore, this section of the river is located immediately downstream of a natural portion and provides connectivity with the river's existing primary salmonid spawning grounds (Bulls et al., 2000; Gaboury, 2004; Phillips et al., 2005). The connection to this upstream productive habitat will provide greater overall benefit to salmon, trout, amphibian, bird and other wildlife species. This area corresponds to the section of Okanagan River where habitat restoration would have the most significant benefit to the greatest number of species.

Ecosystem based approach

ORRI is conducted within an "ecosystem based management framework". Ecosystem based management is a process that integrates biological, social and economic factors into a comprehensive strategy. ORRI's strategy aims to protect and enhance the sustainability, diversity and productivity of our natural resources considering human and ecological components.

Furthermore, the ORRI project meets the ecosystem criteria: i.e. this project not only serves a single species but also provides benefits at the ecosystem level to other species. It also involves risk assessment as one component of benefit-cost analysis. Finally, it follows an adaptive management process with a commitment to assessment and monitoring and improvement if required.

The Okanagan Subbasin Plan and several other studies indicate that a major factor contributing to the decline of anadromous salmon populations in the Okanagan Basin is river and riparian habitat alteration or destruction (NPCC, 2004). COBTWG agrees that ecosystem-based approaches, such as conservation, protection and restoration of habitats that support naturally producing populations of anadromous salmon hold the best promise for maintaining these populations.

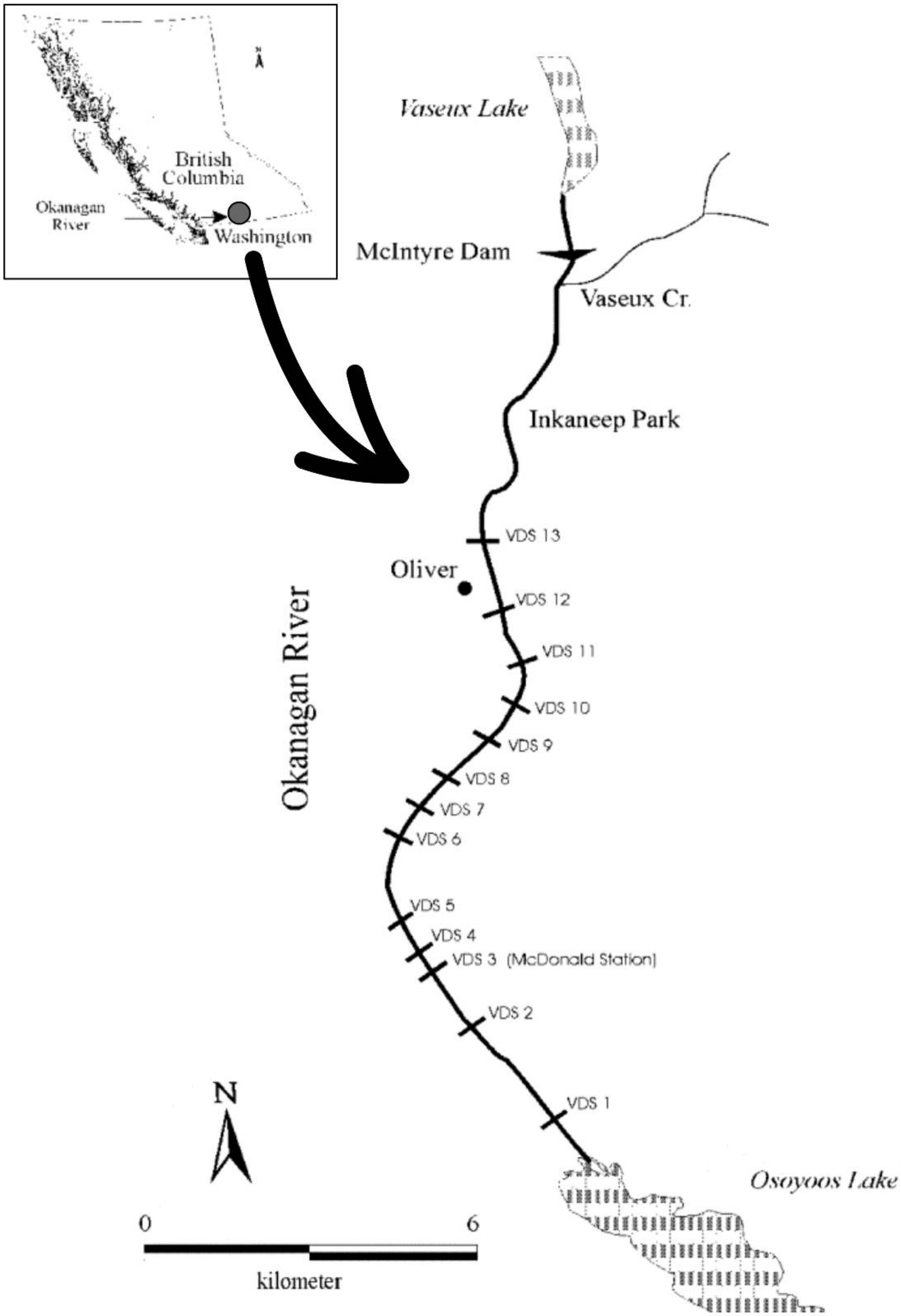

Figure 2: Location of the ORRI worksite.

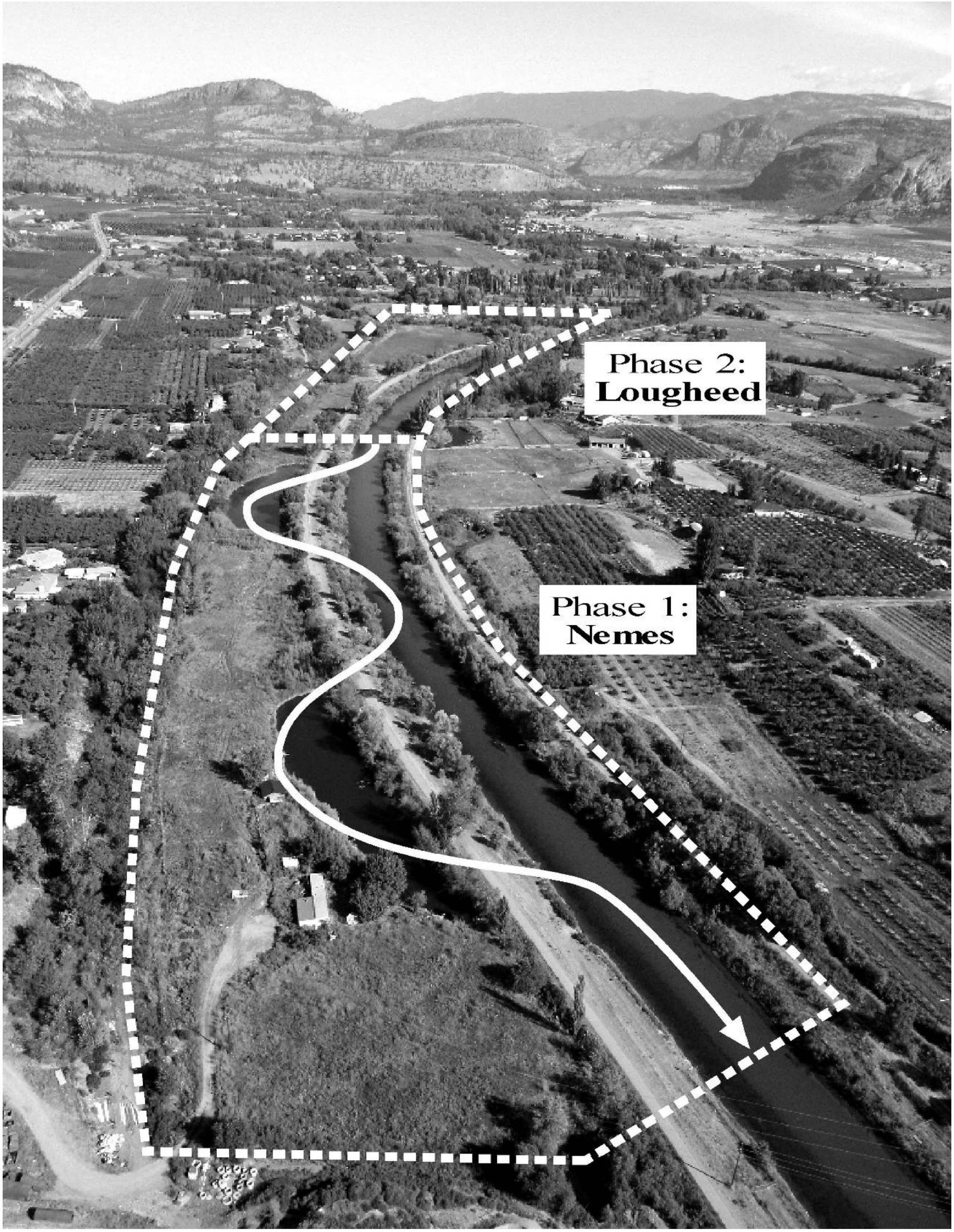

Figure 3: Aerial photo of the ORRI worksite. (Adapted from: Flight courtesy of Canadian Helicopters Ltd. and photograph courtesy of Michael Bezener of One Wild Earth Photography)

Process

Phases and Timeline

The main activities of ORRI for the restoration of Nemes property are planned to continue until at least 2013. But, the restoration of this section of Okanagan River must be seen as one of the first steps of a larger initiative that started in 1999 and that will continue in further years to regain some of Okanagan River's ecosystem functions, enhance the potentials of adjacent conservation/private properties, and serve as a strong benchmark for what restoration can be achieved in the region.

Table 1 presents the five phases of ORRI and the schedule for the main activities. Some activities are not presented in this table, but are intrinsically part of ORRI's project. First, the founding research is an on-going process even though the principal research occurred during the Phase I: Planning. Also, in ORRI's approach, each phase is submitted to a Risk Assessment. Finally, various outreach and consultation activities are present at each step of the project.

Conceptual design

To maximize the chances of success while ensuring a fiscally responsible approach, three different channel designs have been considered (described by Newbury, 2007). The ORRI Steering Committee decided that the most effective option would be the one that most closely resembled the river prior to channelization (this is called the "FSP" option in the report by Newbury).

Regulatory approvals

The major approving authorities (Fisheries and Oceans Canada, BC Ministry of Environment, and Okanagan Nation Alliance) have agreed to the concept and they jointly sponsor the project. However, this does not rule out the need to go through the formal approval processes. ORRI's project includes approvals under the BC Water Act, the BC Dyke and Maintenance Act, the Land Act, the Fisheries Act, and the Navigable Waters Act. Approvals were also obtained from the Okanagan Nation Alliance's Cheif Executive Council and the Osoyoos Indian Band Council. Exemptions were obtained from the Regional District's Environmentally Sensitive Development Area permit and the RDOS Water Development Permit.

Construction

The construction will be phased to reduce the costs in any single fiscal year and to provide a model to guide further work. In a first Phase, construction will be limited to the southern property (Nemes). When this Phase has been achieved and stabilized, the restoration will be extended to the northern property (Lougheed).

Table 1: ORRI's phases, main activities and timeline.

Phases			Main Activities	Schedule
I	Planning		Survey and prioritize the areas of Okanagan River	2000
			Research funding & Launch project	2002-2004
II	Property Acquisition		Aquire proprieties	2003-2004
			Prepare Conceptual Design & Risk Assessement	2005-2006
III	Engineering Design		Develop Engineering Methodology and Design	2006-2008
			Consult authorities for Regulatory approvals	2006-2008
IV	Construction	Site Preparation	Clean the proprieties	2006-2007
			Inform stakeholders and the general public (outreach)	on-going
			Realign the dyke	2008
			Remove & Salvage plant materials on site	2008
			Plant & Stabilise disturbed areas	
		Phase 1: Nemes	Inform stakeholders and the general public (outreach)	on-going
			Re-establish 2 meanders	2009
			Construct 4 pool/riffle sequences	2009
			Add habitat complexity features (Large Woody Debris & Excavation of wetland habitats)	2009
			Replant suitable native riparian species & Stabilise disturbed areas	2009
V	Monitoring		Monitor the aquatic responses (pre & post treatment)	2008-2013
			Monitor the wildlife and riparian responses (pre & post treatment)	
	Evaluation & Adaptive Management		Evaluate the project in phase1: Nemes	on-going
			Extend what we learn from Planning, Engineering, Construction & Monitoring to Phase 2: Lougheed	future

Site Preparation: Realign the Dyke

There is a dyke (paved emergency right-of-way and hiking/biking trail) that extends along the eastern river side of the Okanagan River for approximately 7 kilometers. During the construction phase, the 1 km portion of the dyke adjacent to the project site will to be relocated to the outside western edge of the restoration site. Much of the excavated soils from the actual dyke will be re-used to construct the new dyke pathway as well as to add complex habitat features and topography to the site. The dyke will be realigned for both properties in Phase 1 to save money by avoiding the need to repeat the construction steps later on. Constructing the entire dyke will also allow vegetation to be re-established along the entire hiking/biking route as soon as possible.

Re-meander the Channel

In the Nemes property, the river will be re-connected with its two historic meander loops. The excavation work will follow the original meander pathway. The two isolated oxbows will be eliminated by a reconnection to the mainstem (Figure 3). Excavated soils and material will be used to fill the new channel. The remaining material from this operation will be used to add topographic complexity to the site or will be accumulated in an area located in the south-eastern area of Nemes property. The uniform bottom that exists presently in the channel will be replaced by four pool/riffles sequences.

Erosion and Sediment Control

ORRI includes an Erosion and Sediment Control plan to reduce sedimentation and erosion associated with the construction steps. This plan has been developed according to the *Standards and Best Practices for Instream Works* (MWLAP, 2004) and includes:

- A rapid stabilisation and revegetation of disturbed areas;
- A water quality monitoring program during all construction steps;
- An Appropriately Qualified Professional present on site during the works.

Riparian Habitat Rehabilitation and Biodiversity Optimization Strategy

The goal is to repair the ecosystem with respect to its integrity and health. *Integrity* is defined in terms of biodiversity – particularly species composition, community structure and ecological functions. *Health* is defined in terms of vigour, organization and resilience. Resilience refers to the degree to which the system expresses a capacity for learning and adaptation (Walker et al. 2002 in Emery, 2008). To ensure natural biodiversity, various suitable native plants, shrubs and trees will be planted in selected riparian and floodplain areas such as cottonwood, waterbirch, willow, dogwood and wild rose (Bezener & Wood, 2005).

Emphasis will focus on providing native vegetation to river bank areas, excavated wetland perimeters and newly created floodplain habitats in order to initiate early bank stabilization in these areas and provide shade, cover and potential food sources for fish and other wildlife species.

Outreach

All stakeholders plus the general public are involved at the different steps of the project. A communication plan has been developed and provides on-going information to local government, neighbors and the general public. The outreach activities include consulting the stakeholders, distributing information handouts, installing signs during the construction phases, presenting the project to the local groups, participating in various public events and receiving coverage through press releases and newspaper announcements.

Monitoring, Evaluation and Adaptive Management

The short, medium and long term reaction of the ecosystem to the river modifications will be assessed through both aquatic and terrestrial monitoring.

Aquatic Monitoring

The aquatic monitoring plan aims to evaluate various aquatic responses such as the stream channel morphometry, hydrological change, and changes to water quality and fish habitat. Various aquatic parameters are being monitored in a pre- and post-treatment plan. This plan includes the assessment of:

- Channel morphology;
- Surface water elevation;
- Sinuosity and slope;
- Cross sectional dimensions (river widths and depths);
- Habitat quality and quantity:
  - habitat features (LWD, SWD, human impacted areas etc)
  - area of pools, riffles and glides;
- Water and sediment chemistry;
- Water velocities and temperatures;
- Substrate composition and quality (fine sediment accumulation, substrate gravel sizes);
- Fish holding and rearing habitat;
- Redd counts and distribution;
- Spawning enumeration (sockeye, Chinook, steelhead);
- Egg incubation success;
- Benthos characterization (invertebrate monitoring).

Eight years of pre-treatment sockeye inventories are available for the treatment area and control areas upstream and downstream. Two years of pre-treatment inventory are also available for Chinook and steelhead/rainbow. Similar inventories will be carried out for at least 10 years after treatment within a larger initiative.

Wildlife and Vegetation Monitoring

The wildlife and vegetation monitoring plan directs the evaluation of the responses in the riparian condition and in the wildlife habitats. The newly planted and colonizing vegetation will be monitored as well as the wildlife responses to the newly formed habitat (Emery, 2007, 2008). The monitoring plan includes the assessment of:

- Plant stem heights;
- Plant crown diameters;
- Ungulate browse;
- Planted vegetation survivorship;
- Natural re-vegetation and colonization;
- Floodplain soil formation and moisture;
- Point Count Surveys (avian, reptile, amphibian and small mammal population/ diversity/usage measures);
- Point Count Station Vegetation Assessment;

- Additional Vegetation Assessment Plots;
- Reptile and Amphibian surveys.

Pre-treatment plant and wildlife inventories are available.

Impacts

Ecological Impacts

From an aquatic point of view, ORRI expects to benefit mainly salmonids species (Bull, 2005):

- Okanagan Sockeye (spawning and egg incubation stages);
- Evolutionary significant unit (important stock) of Upper Columbia River Steelhead (spawning, egg incubation and fry rearing stages);
- Evolutionary significant unit of Upper Columbia summer/fall Chinook (spawning, egg incubation and fry rearing stages).

The restoration of Nemes and Lougheed properties will provide about 24,000 square meters of high quality spawning and rearing habitat for all these salmonids species (Bull, 2005):

- The re-created meanders and the added habitat features will provide a more natural, complex and suitable habitat;
- The created pools will provide rearing, resting and feeding areas and will also help the fishes to avoid predation from predatory birds like ospreys and eagles;
- The created riffles will provide spawning areas and will add oxygen to the water.

Furthermore, the reconnection with the floodplain will permit the deposition of fine sediments, like silt and sand, on the floodplain during periods of high water flows. This will:

- Decrease silt loads in the main channel;
- Reduce redd scour;
- Increase (double) the egg to fry survival of sockeye salmon;
- Increase egg to fry survival of fall Chinook;
- Increase egg to fry survival of steelhead and/or resident rainbow trout;
- Increase survival of juvenile Chinook and steelhead and juvenile/adult rainbow trout;
- Help maintain the populations in long term.

From a terrestrial point of view, the re-vegetation of the banks and of the floodplain with a diversity of native plants and shrubs and trees will help to:

- Stabilize the banks and reduce erosion;
- Provide more shade, keeping water cooler and offering fish cover from predators;
- Contribute to water purification by natural ecological process;
- Enhance the quality of the habitat for wildlife species;
- Reduce the potential for undesirable plant species to become established on the site;
- Increase the biodiversity of the region;
- Help the recovery of endangered or threatened species, such as the Yellow-breasted Chat;

Socio-Economic Impacts

In addition to the ecological long term positive impacts, ORRI will benefit in a human perspective. First, the reconnection of the mainstem with the original floodplain will reduce flooding risks for the adjacent lands. Second, the restoration will provide a more natural environment and enhance the visual quality and aesthetics. Finally, the ecosystem will recover its intrinsic value, providing a more diverse and indigenous vegetation and wildlife.

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Hydrologic Networks in the Okanagan

Bruce Letvak and Don Dobson

Abstract

This presentation will review hydrologic networks in the Okanagan, with emphasis on the hydrometric network. Content will include:

- Uses of monitoring networks in the Okanagan,
- The recently completed review of hydrometric network requirements for the Okanagan, including method and results,
- Climate monitoring stations: uses, linkage with hydrometric network, current project to coordinate climate networks,
- New provincial funding for hydrologic monitoring, relation to Okanagan
- Thoughts on future management of networks.

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Fish Passage at McIntyre Dam, Okanagan River

John van der Eerden and Duane Hendricks

Abstract

Over the last half century, man-made structures built for flood control purposes along the Okanagan River have deprived a number of fish species access to their native habitat and spawning grounds. This paper presents work conducted by the Okanagan Nation Alliance and Associated Engineering to design fish passage solutions for the McIntyre Dam.

McIntyre Dam, constructed in 1954, is located on the Okanagan River approximately 1.8 km south of Vaseaux Lake, and approximately 19 km north of Osoyoos Lake. McIntyre Dam is a barrier to upstream fish migration. Should the dam be decommissioned or altered to facilitate fish passage, a net gain of approximately 9 km of fish habitat in the Okanagan River will be realized, including Vaseaux Lake. The next upstream barrier to fish passage is the Skaha Lake Outlet dam at Okanagan Falls.

Fish passage in an upstream direction is prevented by high flow velocities exiting under the dam's vertical lift gates. Fish passing through the dam in a downstream direction also experience very high velocities under the existing gates. Furthermore, a drop of about 40cm onto a downstream array of energy dissipating concrete baffle blocks causes a further hazard and fish mortality.

The Okanagan Nation Alliance secured funding from the Habitat Conservation Plan Tributary Funds to retrofit the existing dam. The retrofits involve replacing the existing vertical lift gates with overshot gates. This will reduce the high flow velocities experienced by downstream migrating fish. However, overshot gates on their own will not resolve the hydraulic drop and potential fish impact on the baffles downstream of the dam. Construction of a downstream rock riffle will increase the tail water level at the dam outlet. This will reduce the hydraulic drop onto the concrete baffle blocks and reduce the need for energy dissipation at the base of the dam. The backwater riffle will also create a deeper plunge pool downstream of the dam. This is beneficial for both upstream and downstream fish migration. Design of the dam retrofit is currently underway.

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Introduction

Over the last half century, man-made structures built along the Okanagan River for flood control and irrigation purposes have deprived a number of fish species access to their native habitat and spawning grounds.

Much of the Okanagan River was straightened and dyked in the mid 1950s. In addition to reducing the length of the river, this converted the natural riffle/pool nature of the river to a more uniform flow regime. For flood control purposes, a number of vertical drop structures and dams were built along the length of the Okanagan River. These structures were, in some cases, impassable by fish. The McIntyre Dam is one of these structures.

McIntyre Dam is located on the Okanagan River approximately 1.8 km south of Vaseaux Lake and approximately 19 km north of Osoyoos Lake. Should the dam be made passable by fish, a net gain of approximately 9 km of fish habitat in the Okanagan River will be realized, including Vaseaux Lake. The next upstream barrier to fish passage is the Skaha Lake Outlet Dam at Okanagan Falls as shown in Figure 1.

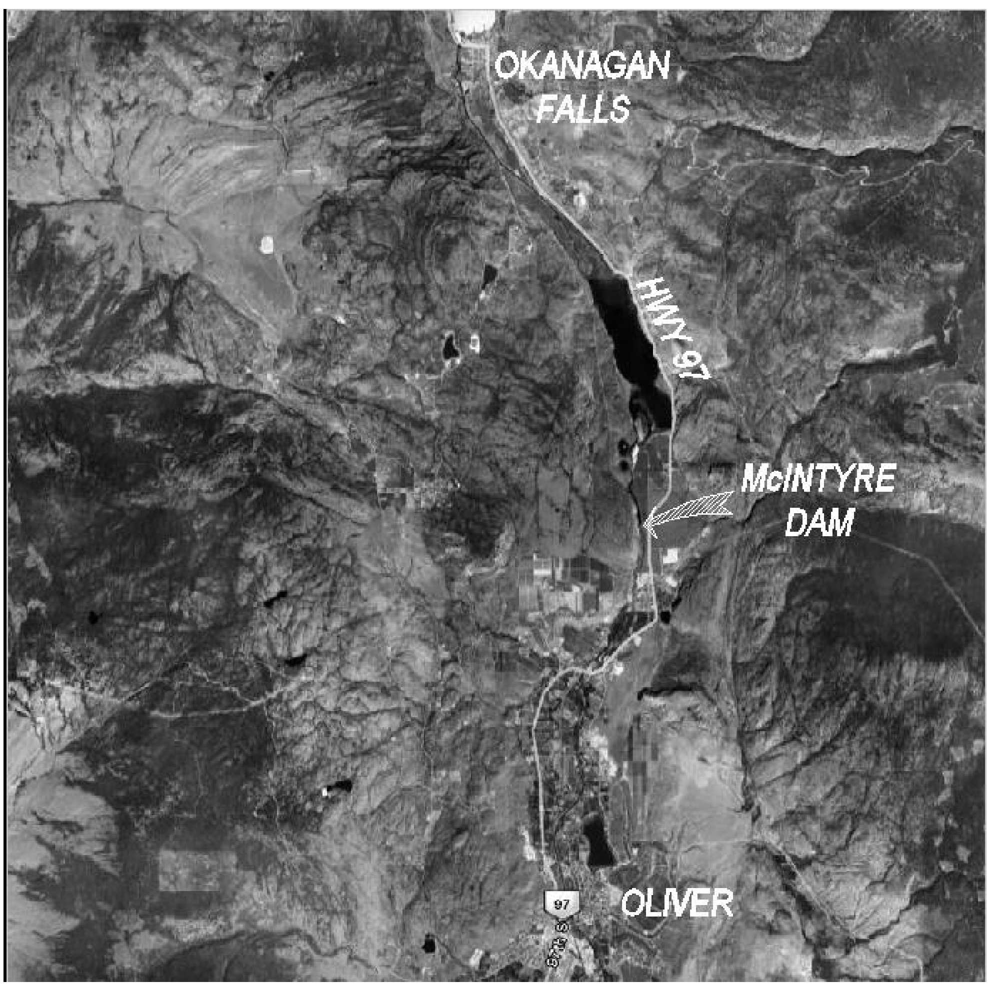

Figure 1: Location plan.

Fish passage in an upstream direction is prevented by high flow velocities exiting the underflow gates at the McIntyre Dam. Fish passing through the dam in a downstream direction also experience very high velocities through the underflow gates. Furthermore, a drop of about 40 cm onto an array of energy dissipating concrete baffle blocks, immediately downstream of the gates, causes a further hazard as shown in Figure 2.

Figure 2: McIntyre Dam looking upstream.

The objective of this study was to render the McIntyre Dam passable by fish in both an upstream and downstream direction. This was to be achieved by replacing the existing underflow gates with overshot gates and installing a downstream riffle(s). Previous studies (Summit Environmental Consultants, 2006) investigated various fish passage options. Some of these options included dam removal, while other options proposed retaining the dam for water level management. The McIntyre Fish Passage Committee selected an option that retains the dam and replaces the existing five underflow gates with overshot gates.

Installation of overshot gates will reduce the high velocities experienced by downstream migrating fish. However, overshot gates on their own will not resolve the hydraulic drop and potential fish impact on the baffles downstream of the dam. The recommended option also includes construction of a downstream riffle to increase the tail water level at the dam outlet. This will reduce the hydraulic drop onto the concrete baffle blocks and reduce the need for energy dissipation at the base of the dam. The backwater riffle will also create a deeper plunge pool downstream of the dam. This is beneficial for both upstream and downstream fish migration.

Hydraulic Constraints

Prior to flow regulation on the Okanagan River, the historic range of water levels on Vaseaux Lake was approximately 325.9 m to 327.5 m (Newbury Hydraulics, 2005). The present Vaseaux Lake water level range is between 327.3 m to 327.93 m. The desired operating range is reportedly 327.4 m to 327.6 m.

Mould Engineering (2001) reports that, at a reported peak flow rate of 85 m^3/s, the maximum allowable water level on Vaseaux Lake is reached, while the existing McIntyre Dam gates are fully open and the water level upstream of the dam is 327.2 m.

The Ministry of Environment (MOE) specified our proposed backwater riffle and gate alterations must not cause any water level increase above those currently experienced upstream the McIntyre Dam at the design peak flow rate.

The Oliver irrigation canal intake is immediately upstream of the McIntyre Dam. The minimum canal intake water surface elevation to achieve its maximum design flow is 327.14 m (Mould, 2001). Our design must minimize fish jump heights from the downstream side of the dam, while maintaining this water surface elevation on the upstream side of the dam.

The existing gate opening invert, or the dam sill, is 325.82 m.

Fish Species and Constraints

Sockeye salmon are the primary species identified for achieving fish passage. However, it is also desirable to promote passage of other species including rainbow trout and steelhead.

Two primary concerns for fish travelling upstream are jump heights and flow velocities. Eiserman et al. (1975) indicated the need for a plunge pool depth of 1.25 times the distance between the crest of the waterfall to the water level of the plunge pool. Reiser and Peacock, (1985) state the maximum jumping height of average size adult sockeye salmon to be 2.1 m.

During low flow conditions, the overshot gates would be maintained in an elevated position to achieve the required upstream water level to serve the Oliver Irrigation Canal intake. To achieve fish passage, the migrating fish must be capable of jumping the height from the downstream plunge pool.

The riffle and the concentrated flow over an overshot gate may cause local increases in stream flow velocity. The fish must be able to swim through these higher flow velocities.

Gate Configuration

Several options exist to incorporate new overshot gates into the existing McIntyre Dam. For each option, consideration must be given to constructability, cost, seal effectiveness, and effects on the hydraulic opening.

Achieving fish passage does not require every gate be replaced. Replacing a minimum of two gates with overshot gates is sufficient to meet our objectives. A minimum of two overshot gates also allows for easier control of the upstream water levels than do the existing underflow gates.

We initially considered several options to mount the gates directly against the existing concrete pilasters. This configuration presents several difficulties due to the irregular and rough condition of the existing concrete pilaster surface, including achieving an effective side seal and wear on the side seals. Due to the above challenges, we did not further consider options mounting the gates directly against the existing concrete pilasters.

Incorporating steel side plates into the gate configuration provides a smooth surface to seal the gates against. This improves the seal effectiveness and reduces wear on the rubber/neoprene side seals. Steel side plates also simplify construction. The gates can be fabricated as a unit and lifted into place with a crane. The side plates act as formwork for any concrete required to tie the gates into the existing structure. As well, since the gates are located downstream of the existing pilasters, the full hydraulic opening can be maintained.

The gate configuration is illustrated on Figure 3.

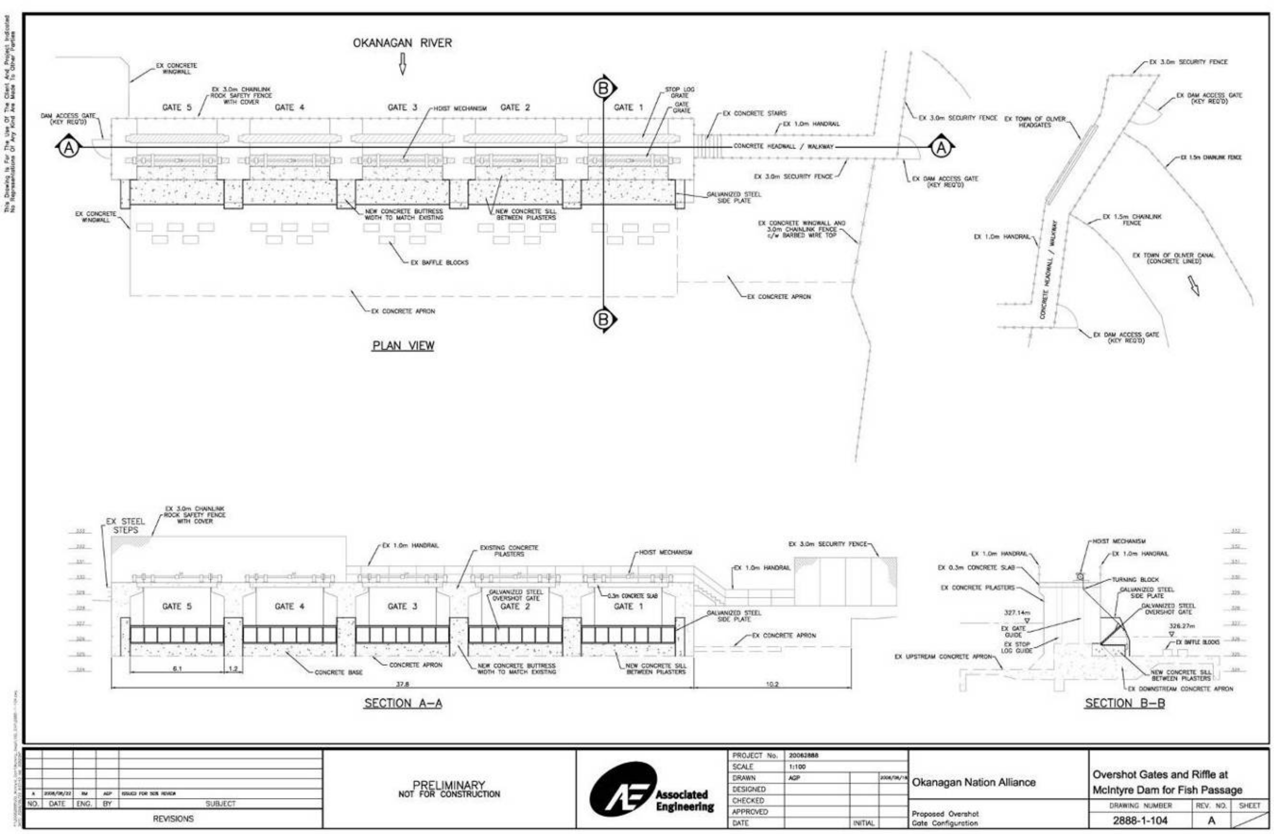

Figure 3: Overshot gate configuration.

Model Construction

We constructed our hydraulic model based on a detailed hydrographic survey downstream of the McIntyre Dam and on 1980 surveyed river cross sections upstream of the dam to Vaseaux Lake. The latter sections were provided by the Ministry of Environment.

The hydrographic survey, completed as part of this assignment, covered a 200 m reach of the Okanagan River downstream of the McIntyre Dam. We imported this data into GIS to create a digital terrain model of the river bed downstream of the dam. This data allowed us to complete a detailed hydraulic model downstream of the dam. Our model upstream of the dam is more skeletal, as 11 river cross sections describe approximately 1.9 km of river.

We estimated roughness coefficients based on the river bed material and the observed vegetation on the overbank areas. The river bed downstream of the dam contains large boulders. The river reach upstream of the dam to Vaseaux Lake is slow flowing and contains Eurasian milfoil.

We modelled the existing McIntyre Dam as a weir with five in-line sluice-gate structures. We assigned a coefficient appropriate to broad-crested weir flow over the bottom of the open sluice gates.

Model Results

Design Flow Rates

We calculated a 200-year design flow rate based on historical gauged flow data. We identified a number of flow gauges upstream and downstream of the dam site. Table 1 shows the identified flow gauges.

Table 1: Flow gauges.

Gauge Number	Gauge Name	Location	Record Years	Comments
08NM085	Okanagan River Near Oliver	17.9 km downstream of McIntyre Dam	1944-2003	A number of tributaries add flow between McIntyre Dam and this gauge
08NM002	Okanagan River at Okanagan Falls	10.8 km upstream of McIntyre Dam	1915-2003	Shuttleworth Creek is only tributary between gauge and McIntyre Dam
08NM006	Shuttleworth Creek Near Okanagan Falls	Downstream of Okanagan Falls	1921-1964	Tributary to Okanagan River upstream of McIntyre Dam
08NM149	Shuttleworth Creek at the Mouth	Downstream of Okanagan Falls	1969-1971	Tributary to Okanagan River Upstream of McIntyre Dam

Gauge 08NM085 is located south of Oliver. A number of tributaries contribute flow to the Okanagan River between the McIntyre Dam and this gauge location. As such, this gauge overpredicts flows experienced at the McIntyre Dam.

Gauge 08NM002 is located near the south end of Skaha Lake, at Okanagan Falls. Although this gauge is upstream of the McIntyre Dam, Shuttleworth Creek is the only significant tributary that contributes flow between the gauge and the dam. Ignoring the attenuation effects of Vaseaux Lake, adding gauge 08NM002 flows to Shuttleworth Creek flows, may provide a reasonable prediction of flows at the McIntyre Dam.

HYDAT includes two gauges located on Shuttleworth Creek. These gauges existed during different time periods.

We analyzed gauged flows at Okanagan Falls (08NM002) to determine a 200-year flow rate. We undertook this analysis with Environment Canada's Consolidated Frequency Analysis program. Dam construction on the Okanagan River altered the flow regime. Okanagan Falls Dam was constructed in 1950 and McIntyre Dam was constructed in 1954. We thus included only gauged Okanagan River flows after 1950 in our statistical analysis, yielding an estimated 200-year flow rate of 84.1 m^3/s.

We analyzed gauged flows on Shuttleworth Creek (08NM006) yielding an estimated 200-year flow rate of 7.5 m^3/s. Okanagan River dams do not affect the Shuttleworth Creek flow regime.

Based on this statistical analysis, we adopted a 200-year design flow rate of 92 m^3/s. Minimum summer flow rates were estimated at 8 m^3/s (Mould, 2001).

Model Calibration

We had little data with which to calibrate our model. Model calibration requires knowledge of flow rates, water levels, and McIntyre Dam gate openings for a particular event. However, we used the available data to make a cursory assessment of our model predictions.

The 2006 Summit Report presented a graph of Vaseaux Lake water levels gauged between 1991 and 2003. From this graph we chose periods of high water levels. We identified peak instantaneous flow events for these periods as recorded at the WSC Okanagan Falls gauge (08NM002). However, we had no information of McIntyre Dam gate opening heights or Shuttleworth Creek flows for these events.

To overcome this data shortfall, we examined typical ranges of Shuttleworth Creek flows. As the Okanagan River is a large dam controlled system, high flow events do not necessarily correspond directly to high local runoff events. Thus, high Shuttleworth Creek flows would not necessarily be expected during high flow events recorded at the Okanagan Falls gauge.

As Shuttleworth Creek flows are small compared to Okanagan River flows, we estimated a suitable Shuttleworth Creek flow for each chosen Okanagan River flow event. We ran the cumulative flow through the model with the assumption of fully open gates at the McIntyre Dam. Table 2 presents our results.

Table 2: Model calibration.

Date	OK Falls Flow (m^3/s)	Assumed Shuttleworth Creek Flow (m^3/s)	Estimated Total Flow (m^3/s)	Observed Vaseaux Lake WL (m)	Predicted Vaseaux Lake WL (m)
13-Jun-96	72.6	4.4	77	327.94	327.92
6-Jun-97	76.8	4.2	81	327.93	327.97
31-Aug-93	58.7	3.3	62	327.79	327.70

We predicted Vaseaux Lake water levels on June 13, 1996 and June 6, 1997. Observed Vaseaux Lake water levels were above the desired operating range during those events. We thus assume the McIntyre Dam gates were fully open in an effort to reduce Vaseaux Lake water levels. This lends credibility to our modelling the gates fully open during those events.

We underpredicted the Vaseaux Lake water level on August 31, 1993. As the observed lake water level, during this event fell within the desired lake operating regime, the McIntyre Dam gates may have been partially closed. This partial gate closure would bring the lake water levels higher than those we predict with fully open gates.

Our calibration results are sensitive to the assumed Shuttleworth Creek flows and assumed McIntyre Dam gate opening levels. However, based on the available data, we believe our modelled predictions to be reasonable.

Existing Situation

We ran our existing condition HEC-RAS model to establish the existing flow regime. We then established a benchmark against which to compare hydraulic conditions resulting from the proposed gate and riffle configurations. Figures 4 and 5 illustrate the existing flow regime.

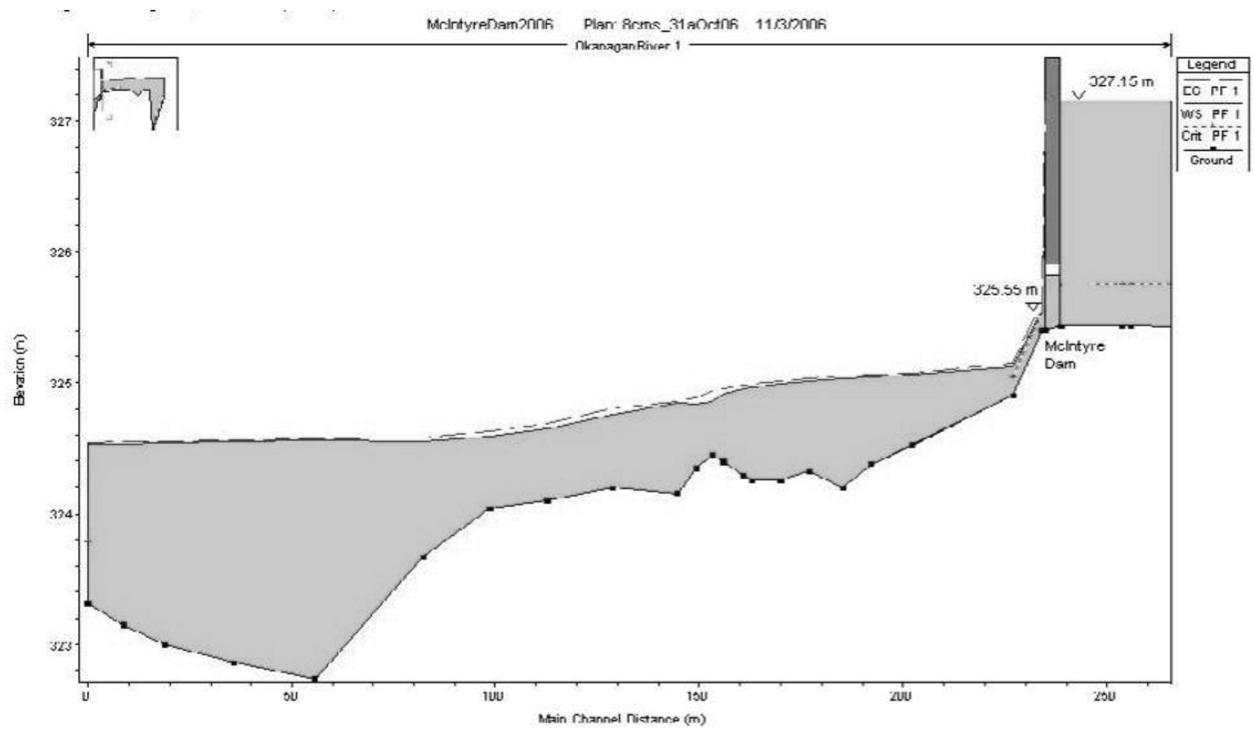

Figure 4: Existing flow regime, low flow (8 m^3/s).

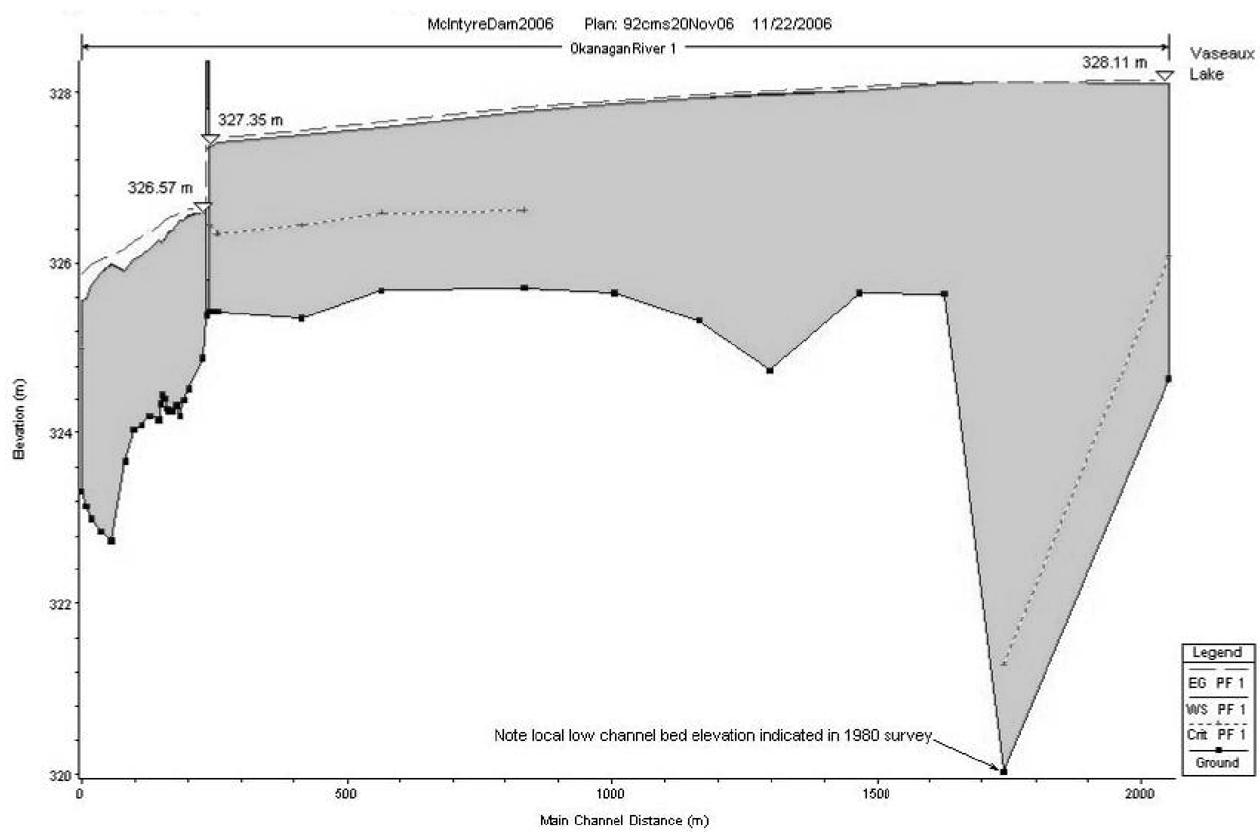

Figure 5: Existing flow regime, Vaseaux Lake to McIntyre Dam (92 m^3/s).

Riffle Configuration

We examined our river bed digital terrain model to determine the location of any naturally occurring riffle. We propose constructing a riffle at a natural riffle location.

We located two naturally occurring riffle locations. We illustrate this on our digital terrain model in Figure 6. The first is located approximately 55 m downstream of the dam. The second is located approximately 78 m downstream of the dam. These locations are apparent in the existing river profile illustrated in Figure 6.

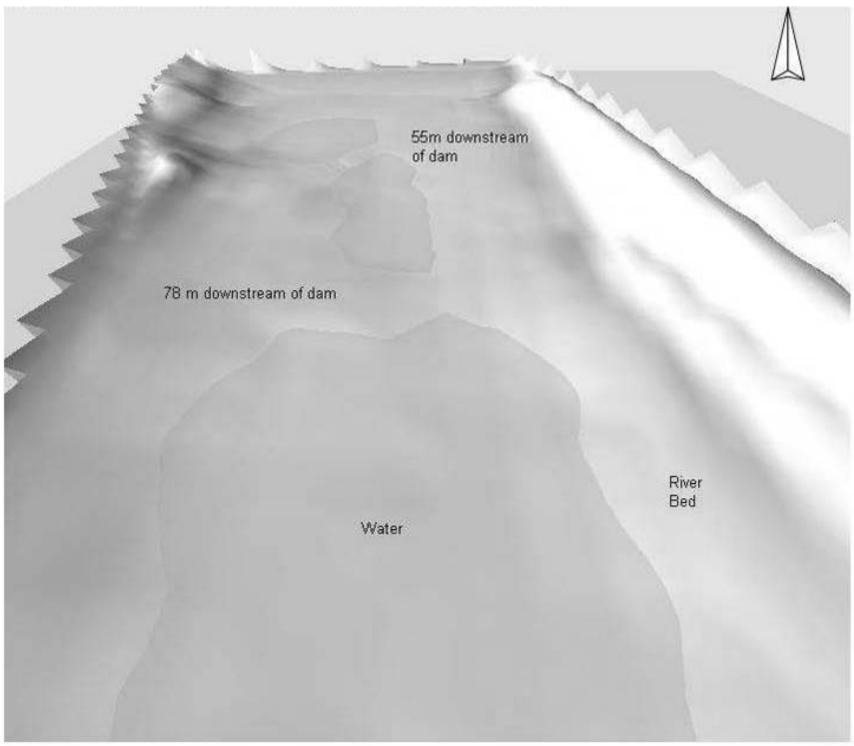

Figure 6: Digital Terrain Model.

The first riffle is located at a natural narrowing of the channel downstream of the dam. This location may thus provide the most logical location for the downstream boundary of a plunge pool. However, the natural spacing of riffles averages approximately two or five to seven times the channel width (Dr. Robert Newbury, 2003). Our main channel width ranges from about 40 m to 30 m in the area of the first and second proposed riffles, respectively. The minimum distance from the dam to the proposed riffle could arguably be 80 m, based on the natural spacing. This suggests locating the riffle at the second location. We thus modelled the riffle about 78 m downstream of the dam.

Natural riffles typically rise from the river bed at a steep slope of 2:1 and then slowly taper back to the bed level at a shallower 20:1 slope on their downstream face (Reference 3). We modelled the riffle with a front slope of approximately 3:1 and a downstream slope of approximately 20:1.

We modelled the riffle crest with two configurations. In the first instance, we modelled a flat riffle crest, with the same crest elevation across the width of the riffle. In the second instance, we modelled a V-shaped riffle crest. We raised the outer edges of the riffle by 0.25 m to achieve this V-shape. We sloped the crest elevation linearly down from the outer edges to the centre of the riffle crest. The V-shape concentrates low flows to the centre of the riffle, providing a higher flow depth for upstream migrating fish.

We determined suitable rock sizing for riffle construction. Based on our predicted peak flow velocities and the various angles of flow impingement over the riffle, we recommend 50 kg class riprap. This equates to a D50 size of approximately 335 mm.

Water Surface Elevations

Based on the reasoning described above, we modelled the riffle at a location 78 m downstream of the dam. We sized the riffle to backwater the dam to the sill elevation (325.82 m) at low flow conditions. We maintain free outfall conditions by not submerging the gate openings. At the same time, we modelled the dam gates partially closed to maintain an upstream water surface elevation required by the Oliver irrigation canal intake (327.14 m). We illustrated this concept in Figure 7.

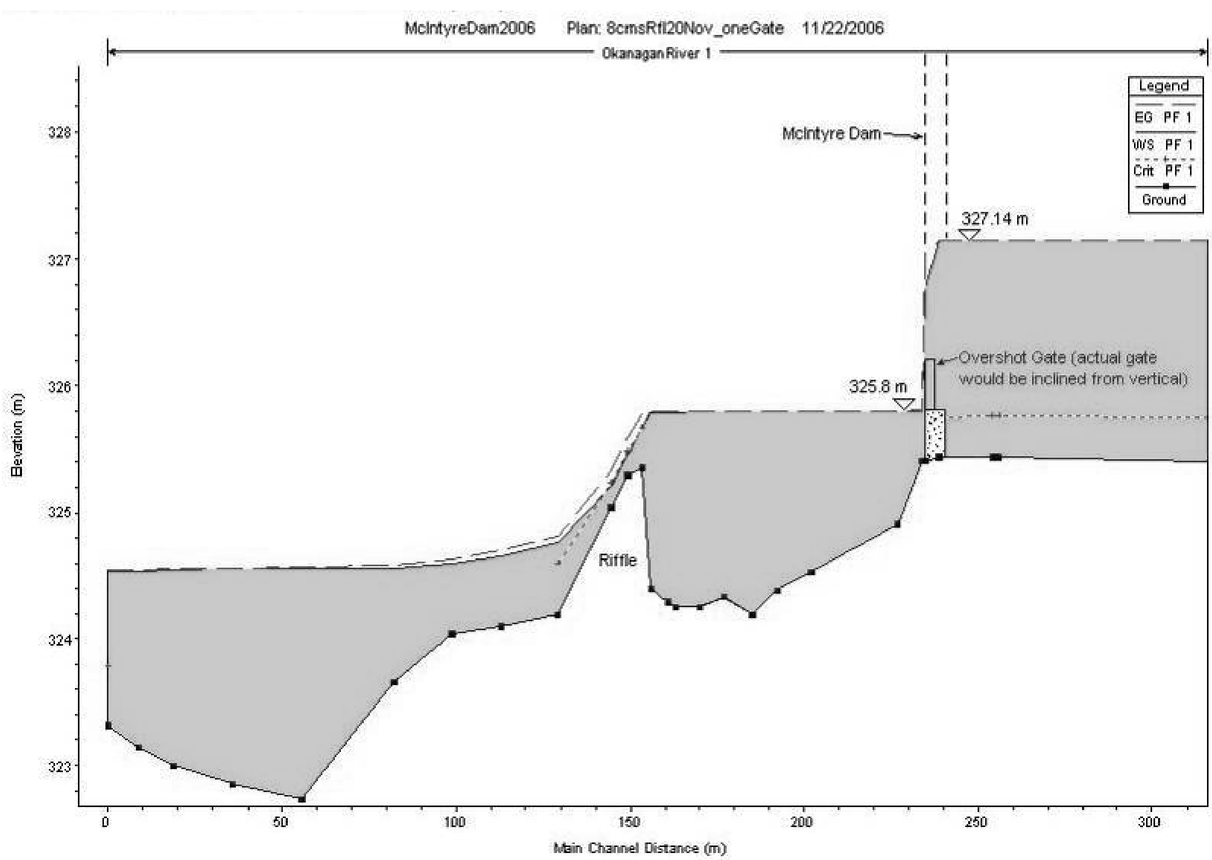

Figure 7 – Riffle 78 m downstream of Dam, low flow conditions (8 m^3s/).

We tested this riffle configuration at peak flow to compare upstream water levels with and without the riffle. We achieved our design criteria with a riffle height of 1.1 m, thus a riffle crest elevation of 325.49 m. Our V-crest riffle has a mid-channel crest elevation of 325.35 m, but a linearly increasing crest elevation to 325.6 m at each outer edge.

Both riffle configurations backwater the dam to the sill during low flows, but do not increase upstream water levels during peak design flow. We present our water surface elevation results in Table 3. Figure 8 illustrates the design peak flow regime with the riffle.

Table 3: Predicted water surface elevations.

Channel	Flow Rate (m^3/s)	Flow Depth on Riffle Crest (m)	WL Downstream Dam (m)	WL Upstream Dam (m)	WL Vaseaux Lake (m)
Low Flow					
Existing	8	-	325.55	327.15	327.17
Flat Crest Riffle	8	0.2	325.81	327.14	327.16
V-Crest Riffle	8	0.32	325.8	327.14	327.16
200-year Flow					
Existing	92	-	326.57	327.35	328.11
Flat Crest Riffle	92	0.98	327.08	327.35	328.11
V-Crest Riffle	92	1.1	327.06	327.35	328.11

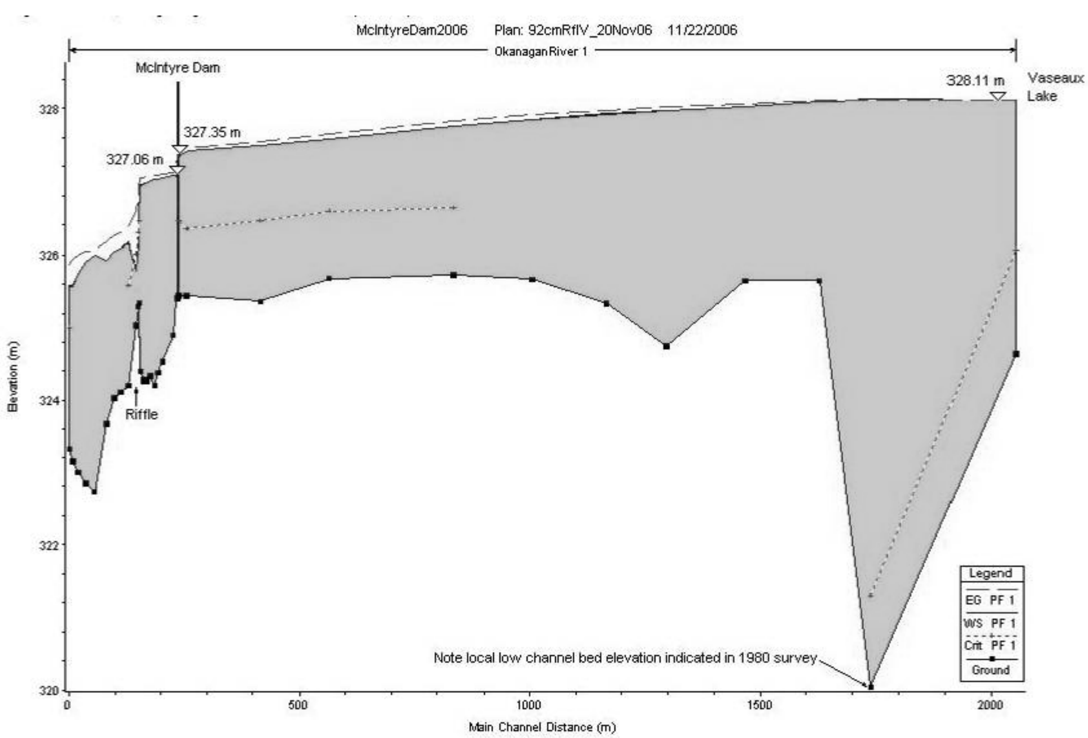

Figure 8: Proposed riffle, 200-year peak flow conditions (92 m^3/s).

A deeper flow depth forms on the V-crest riffle than on the flat riffle. This facilitates fish passage during low flows.

Note: we predict a 200-year Vaseaux Lake water level above the desired maximum 327.93 m level. The 200-year flow event is not recorded to have occurred since the McIntyre Dam was constructed, thus this level has not likely been recorded at Vaseaux Lake to date.

Fish Jump Heights

We assessed the feasibility of fish jumping over the proposed gates. The required fish jump height is greatest during low flows. At this time, the plunge pool top elevation is lowest and the proposed overshot gates must be raised highest.

As previously discussed, fish generally require a plunge pool depth of 1.25 times the jump height. The top of our proposed plunge pool is the backwater surface elevation formed by the riffle. The concrete apron downstream of the dam is the bottom of the plunge pool.

During low flows, the proposed riffle will backwater the dam to the sill elevation (325.82 m). The concrete apron top elevation is approximately 324.85 m. The difference between these two elevations yields a plunge pool depth of approximately 0.97 m. Based on the ratio of 1.25:1, the maximum fish jumping height from this pool depth is 0.78 m.

We assessed the elevation difference between the top of the plunge pool and the minimum water surface upstream of the dam. The Oliver irrigation canal requires a water surface elevation of 327.14 m upstream of the dam. The low flow top elevation of our plunge pool is 325.82 m. The difference between these two elevations is 1.32 m. This height is greater than our predicted fish jump height.

If upstream migrating fish can jump into the depth of flowing water above an overshot gate, we can reduce the required fish jump height. We can direct the entire flow over a single overshot gate, thus developing a significant flow depth, even at low flows. The gate may then be lowered significantly, while maintaining the required upstream water surface for the Oliver irrigation canal.

We modelled this scenario assuming, in the first instance, a weir flow coefficient for a sharp-crested weir. In the second case, we set a weir coefficient suitable for a broad-crested weir. Assuming a sharp-crested weir coefficient and 8 m^3/s flow, 1.12 m depth builds up over the open gate. This allows the top of the overshot gate to be lowered to approximately 326.02 m, while yielding a water level of 327.16 m upstream the dam. Providing the fish can jump into the stream of flow over the gate, the resulting minimum jump height is 0.21 m.

In the case of a broad-crested weir, the flow depth over the gate at 8 m^3/s is 0.93 m. This allows the top of the overshot gate to be lowered to 326.21 m, while maintaining 327.14 m water level upstream of the dam. Again, providing the fish can jump into the stream of flow over the gate, the resulting jump height is 0.4 m. We summarized our results in Table 4.

Table 4: Fish jump heights.

Flow Rate (m^3/s)	Weir Coefficient	Weir Crest (m)	Depth on Weir (m)	Jump Height (m)	Weir Flow Velocity (m/s)
8	1.071	326.02	1.12	0.21	1.16
8	1.44	326.21	0.93	0.4	1.4

Our predicted fish jump heights into the flow depth over a single open gate is within the range possible from the low flow plunge pool below the dam.

The low flow scenario above backwaters Vaseaux Lake to 327.16 m. The gates may thus be raised by an additional 0.14 m to maintain the existing Vaseaux Lake low water elevation of 327.3 m. The fish jump height range would accordingly increase, with the new range being 0.35 m to 0.54 m. This still falls within the 0.78 m low flow jump height possible from the downstream plunge pool.

Additionally, the Town of Oliver expressed a possible future need for irrigation canal forebay water levels in excess of the current minimum of 327.14 m. This is due to possible head losses across a proposed fish screen at the canal intake. A 10% return flow from the canal may also be required to return fish to the river from the upstream side of the screen.

As discussed above, maintaining the existing Vaseaux Lake low water elevations will require backwatering at the dam during low flows. This may serve to accommodate the Town of Oliver's possible future need for a canal forebay water surface elevation in excess of 327.14 m. The new overshot gates will be capable of maintaining the existing water level regime and accommodating likely water level requirements resulting from possible agreements negotiated between the MOE, the Town of Oliver, and the Department of Fisheries and Oceans.

Fish Burst Speeds

We assessed the ability of relevant fish species to swim through the flow velocities over the riffle and above the proposed overshot gate.

The riffle and the concentrated flow over an overshot gate may cause a local increase in stream flow velocity. We calculated the peak velocities resulting from our proposed gate and riffle configuration and compared them to published fish burst swimming speeds. The fish must be able to swim faster than the peak flow velocities in order to migrate upstream.

We compared fish burst swimming speeds to our calculated flow velocities in Table 5.

Table 5: Fish burst speeds.

Species	Burst Speed (m/s)	Flow Velocities (m/s) (average channel Velocity)			
		8 m^3/s 1 Overshot Gate	**92 m^3/s 5 Gates Open**	**92 m^3/s Over Riffle***	**8 m^3/s Over Riffle***
Sockeye Salmon	3.1 – 6.3	1.16 – 1.4	1.22	4.14	1.68
Steelhead	4.2 - 8.1	1.16 – 1.4	1.22	4.14	1.68
Rainbow Trout	1.8 – 4.3	1.16 – 1.4	1.22	4.14	1.68

The three species considered, all swim with sufficient burst speeds to migrate upstream over the proposed riffle and gates. During peak 200-year flows, the resulting average channel velocities over the riffle are at the upper end of rainbow trout burst swimming speeds. However, riffles are constructed to provide a non-uniform flow regime. Protruding boulders provide shelter locations and alter the flow regime in such a manner as to provide locations where the flow velocity may be lower than the average channel velocity.

Conclusions

We conducted a preliminary design to achieve fish passage through the McIntyre Dam. The selected option includes replacing the dam's existing underflow gates with overshot gates and backwatering the downstream face of the dam with a riffle.

We assessed gate and riffle configurations to create flow conditions conducive to fish passage. We based our preliminary design on constraints of fish jump heights, fish burst swimming velocities, water level management criteria, and constructability.

Based on our hydrographic survey, we determined a suitable riffle location. We concluded a suitable riffle height and crest elevation to backwater the dam sufficiently during low flows. This riffle configuration does not raise Vaseaux Lake water levels during peak design flows.

If all flow is directed over a single overshot gate, the resulting flow depth over the gate reduces the fish jump height. Resulting jump heights, ranging from 0.21 m to 0.54 m, are within the range possible from the downstream plunge pool formed by the riffle. During higher flows, the overshot gate may be lowered to provide an even lower jump height.

We determined a 1.1 m high V-shape crested riffle will satisfy our design criteria. A riffle centre crest elevation of 325.35, rising to 325.6 at the right and left bank, meets the water level and fish passage constraints. We recommend constructing this riffle at a natural rise in the existing channel bed. Such a location exists approximately 78 m downstream of the dam.

We determined that sockeye salmon, steelhead, and rainbow trout swim with sufficient burst speeds to migrate upstream over the proposed riffle. However, during peak 200-year flows, the resulting average channel velocities over the riffle are near the upper end of rainbow trout burst swimming speeds.

We evaluated physical options to mount overshot gates to the McIntyre Dam. To satisfy hydraulic constraints, and for reasons of constructability, we recommend mounting new overshot gates with integrated steel sidewalls to the downstream face of the dam.

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The Use of Stable Isotope Techniques to Assess the Regional Hydrology of the Southern Okanagan Basin

Pana Athanasopoulos, M.J. Hendry, and Leonard I. Wassenaar

Abstract

A rapidly increasing population in the Okanagan Basin is expected to put additional stress on surface water and groundwater systems in the region. As a result, important issues such as water supply and demand, surface water and groundwater protection, surface water-groundwater interaction, and water quality will need to be addressed. The use of stable isotopes, particularly when coupled with geochemical and physical parameters, is an effective method of addressing these issues in a region of complex hydrological, hydrogeological and climatological systems.

Here we present the results of two years of research conducted in the southern Okanagan Basin, where isotopic methods were used to assess the regional hydrogeology of the southern Okanagan Basin, and, in particular, to identify the source(s) of groundwater recharge in the region. Stable isotope analysis of ^{18}O and ^{2}H was conducted on: monthly precipitation samples from three sites in the basin (Kelowna, Osoyoos and Anarchist Mountain) ($n = 37$), shallow and deep groundwaters in the alluvial valley bottom ($n = 122$), groundwater in the bedrock of the upland areas ($n = 22$), and monthly samples of surface waters collected at 10 stations along the Okanagan River system (which supply irrigation water to local agricultural users) ($n = 134$). Subsequently, tritium-helium ($^{3}H/^{3}He$) age dating was conducted on shallow groundwaters in the valley bottom ($n = 9$), and enriched tritium (^{3}H) and carbon-14 (^{14}C) isotope analysis was conducted on the deep groundwater system in the valley bottom and the groundwater in the upland areas ($n = 4$), to determine the ages of the respective waters.

These data were used to: (1) create a local meteoric water line for the Okanagan Basin; (2) define the source(s) and ages of groundwaters in the southern Okanagan Basin; and (3) develop a conceptual model of flow and residence times of groundwaters in the Basin. The results of this research, conducted in one region of the valley, may be generally applicable over the entire Okanagan Basin.

Research for this project was funded by the Canadian Water Network, BC Ministry of Environment, Geological Survey of Canada, NSERC and Environment Canada.

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Endocrine Disruptors in the Okanagan Basin

P. Jeff Curtis, Tricia Brett, Rob O'Brien, Sandra Mecklenburg

Abstract

Effects of endocrine disrupting substances discharged in wastewater pose unknown risks to water supplies and ecosystems of receiving waters in the Okanagan Basin. Among urban regions of Canada, the Okanagan Basin is arguably at exceptional risk to endocrine disruptors for several important reasons. First, we have one of the smallest per capita water supplies in Canada. Thus, potential dilution of wastewater is limited. Second, much of our water use is consumptive (evaporative uses) further reducing the dilution volume. Finally, water supplies to a large portion of our population receive wastewater. In scoping the risks, we calculated worst-case levels of the most potent endocrine disruptors from wastewater – estradiols – for low flows in the Okanagan River (Penticton). Calculated concentrations were in ranges that generally cause endocrine disruption, and are within a factor of five of levels that caused fish population collapse in the Experimental Lakes Area study.

We have embarked on a study of estradiols in the Okanagan Basin wastewaters and waste receiving waters. Over the next two years, samples of wastewater will be collected from wastewater treatment plants (WWTPs) in Vernon, Kelowna and Penticton and characterized instrumentally. Wastewater is discharged by the cities of Vernon, Kelowna and Penticton into a reservoir for spray irrigation, into Lake Okanagan, and into the Okanagan River, respectively. We propose to use differences in discharge practices and receiving water properties among the Okanagan WWTPs to infer loss rates of estradiols in the environment. Because of the differences in discharge practices among WWTPs, this study might identify relatively quickly best practices for discharge, and means to mitigate estradiol risks to the water supplies and aquatic ecosystems.

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Evaluation of the hydrogeology of valley-fill aquifers in the Northern Okanagan using geochemical and modeling methods

Jianhua Ping, Craig Nichol, Adam Wei, Trina Koch, Oleg Ivanov

Abstract

Groundwater resources in the North Okanagan were investigated using an integrated physical, geochemical and numerical approach. The North Okanagan Groundwater Characterization and Assessment (NOGWCA) project began with an investigation of the geology and hydrostratigraphy of the North Okanagan region. The Deep Creek and Fortune Creek watersheds were found to contain multiple valley-fill aquifers. Seismic surveys and borehole data were used to reconstruct the aquifer system.

The main valley is composed of several confined aquifers. The first, Spallumcheen A, ranges from 30 m to 90 m depth and is 45 m to 90 m thick. This is the main aquifer utilized in the valley for domestic, municipal, commercial and irrigation supply. It is recharged from both the adjacent highlands via mountain system recharge (MSR) and via direct recharge in the valley bottom. The aquifer grades into unconfined aquifers in the Hullcar/Sleepy Hollow and Okeefe areas to the West of the main valley stem. Detailed hydrometric data from nine stations deployed on both creeks indicates groundwater recharge within the alluvial fan of Fortune Creek, and discharge to groundwater in the lower reaches of Deep Creek. Valley side recharge at alluvial fans generates artesian conditions in the valley center in the City of Armstrong area. A second continuous confined aquifer is found at depths of 200 m to 350 m. Additional discontinuous aquifers are found between 90 m and 200 m, as well as at depths below 350 m in the main valley north of Armstrong.

Groundwater and surface water geochemistry and isotopic character were used to determine the overall groundwater flow regime, and reveal that groundwater within the Fortune Creek watershed flow southwards into the Deep Creek watershed. Chloride mass balance was used to estimate recharge in the valley bottom and within the mountain bedrock system. Additional recharge information was derived from an interpolated climate dataset and from data on agricultural irrigation and wastewater irrigation. Efforts to accurately quantify and understand MSR are hampered by sparse data on the geochemical character of bedrock aquifers. Analysis of the groundwater chemistry has assisted in detailing the aquifer interactions. Conservative elements and deuterium/oxygen isotopes were used in a mixing cell model (MCM) approach to assess groundwater flow between aquifers

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FEFLOW is being used for numerical simulation of the groundwater system. The first stage of the aquifer assessment will determine steady state conditions within the system in anticipation of integrated surface water and groundwater modeling to be carried out in the future. The groundwater flow modeling will contribute to subsequent water management decisions at the watershed scale. Climate change and economic change scenarios will be considered in the integrated surface water and groundwater modeling.

Keywords: valleyfill aquifers; geochemistry; isotopes; Mountain System Recharge; aquifer properties; Feflow

Developing Performance Standards for Nutrients, Sediments and Instream Flows for Agricultural Watersheds in Canada: An Overview for the Okanagan

Daniel Peters, Donald Baird, Glen Benoy, Patricia Chambers, Joseph Culp, and Laura Maclean

Abstract

Excessive inputs of nutrients and sediments to aquatic ecosystems can result in a variety of deleterious changes in abundance and diversity of aquatic plants, invertebrates and fish. Similarly, alterations to a stream's natural flow regime via changes in land-cover, land-use and/or flow regulation can have negative consequences for riverine ecosystems. The goal of the National Agri-Environmental Standards Initiative (NAESI) Water Theme was to develop a number of environmental standards to help protect surface waters from deleterious effects of agricultural practices on nutrients, sediments, microbial pathogens, and unsustainable water use across Canada. As part of a national program to define benchmarks of ecological condition in agricultural streams, Environment Canada analyzed a combination of new and existing chemical, physical, biological and discharge data to characterize relationships between water quality and quantity and various measures of aquatic community health. Several statistical approaches were then employed, including a percentile approach and a threshold approach, to define desired performance standards for good ecological condition for agricultural streams across Canada. The purpose of this paper is to present the NAESI Water Theme program and outline the environmental performance standards with a focus on the Okanagan Valley. A number of non-regulatory agri-environmental standards are recommended for total nitrogen, total phosphorus, suspended and deposited sediments and ecological instream flow needs. Achievement of these standards is predicted to result in good ecological condition in the aquatic community in the absence of other stressors.

Introduction

The National Agri-Environmental Standards Initiative (NAESI) was a four-year program (2004-2008) led by Environment Canada (EC) in partnership with Agriculture and Agri-Food Canada (AAFC), under AAFC's Agricultural Policy Framework (APF). The aim of NAESI was to increase our understanding of relationships between agriculture and the environment, and

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develop non-regulatory national environmental performance standards that have regional application. The scientifically-defensible performance standards developed will provide useful tools to guide environmentally-sustainable agricultural practices and provide benchmarks in four thematic areas: Air, Water, Pesticides, and Biodiversity.

Water is an important component of agricultural systems, essential for crop production and raising livestock. Some agricultural activities increase the risk of water contamination or reduce the availability of water for other uses, which may be harmful to environmental and human health. Excessive inputs of nutrients and sediments to aquatic ecosystems can result in a variety of deleterious changes in abundance and diversity of aquatic plants, invertebrates and fish. Similarly, alterations to a stream's natural flow regime via changes in land-cover, land-use and/or flow regulation can have negative consequences for riverine ecosystems. The goal of the NAESI Water Theme was to develop a number of key environmental standards to help protect surface waters from deleterious effects of agricultural practices on nutrients, sediments, microbial pathogens, water availability and ecological instream flow needs across Canada.

The NAESI Water Theme collated existing data sets and conducted a three-year study to collect additional chemical, biological and hydrological data for developing stressor-response relations, defining ecological condition, and recommending environmental performance standards for streams in agricultural landscapes (Chambers *et al*., 2006; Culp *et al*., 2007). Although data currently exist on nutrient and suspended sediment concentrations and water flow in selected streams across Canada, the data are variable in their geographic cover and time span. Moreover, few sites previously sampled for chemical or physical parameters and regularly sampled abundance or composition of aquatic biota. Figure 1 presents the locations where the Water theme focused their efforts on the development of environmental performance standards. In each agricultural region, stream networks consisting of up to 15 watersheds spanned a range of agricultural land-use intensity. At each site, a consistent set of parameters was sampled at the same frequency using identical field and laboratory methods, providing national coverage for setting environmental performance standards. The purpose of this paper is to present an overview of the environmental performance standards for i) nutrients, ii) sediments and iii) instream flow needs, with a focus on the Okanagan Valley, British Columbia.

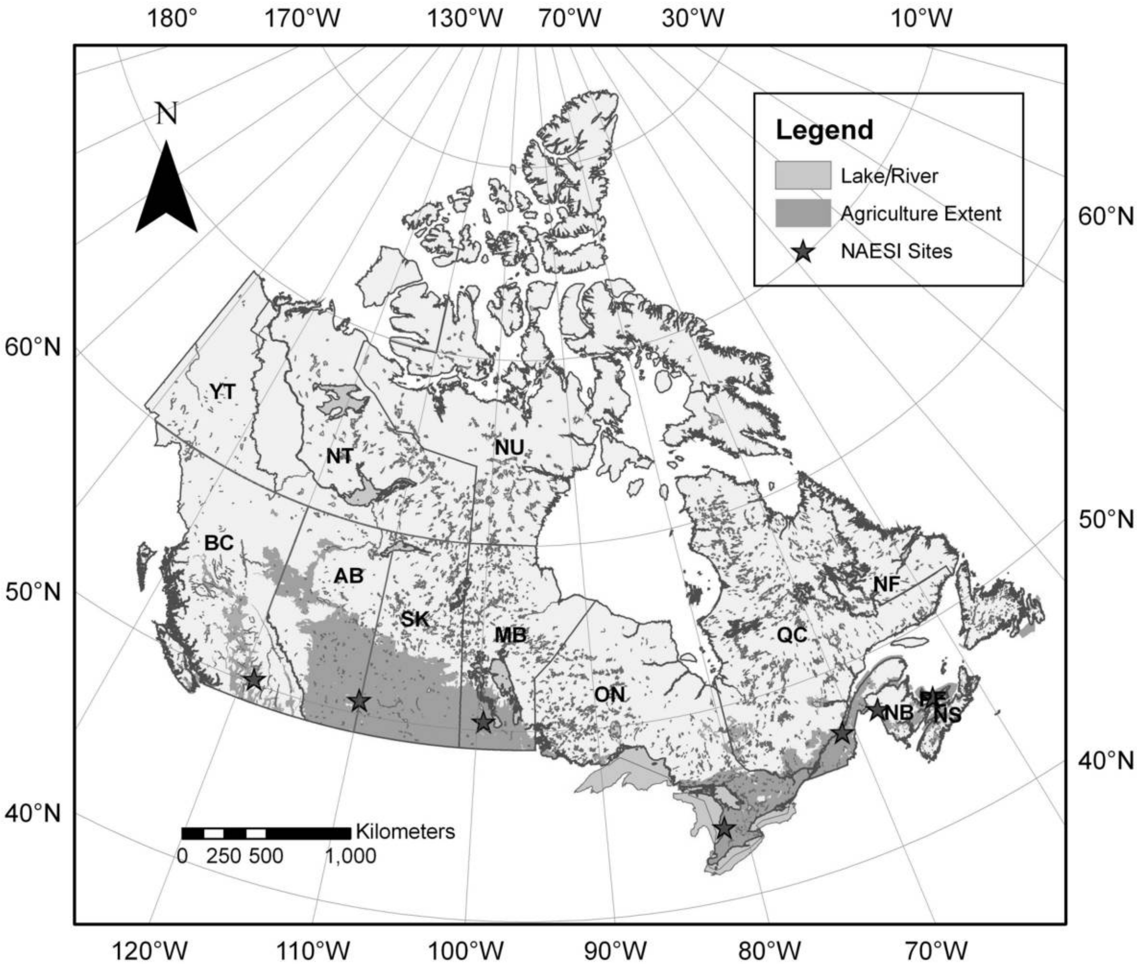

Figure 1: Location of NAESI Water Theme field study sites across Canada.

Development Environmental Performance Standards - Okanagan

A network of 15 stream monitoring sites, spanning a continuum from minimal exposure to human disturbance to intensive agricultural activities throughout the watershed, were established in the Okanagan Valley of British Columbia in 2005 (Figure 2). The watersheds included were Coldstream, Deep, Eneas, Equesis, Joe Rich, Keremeos, Leech, Mission, Shatford, and Shingle Creek. Table 1 presents basic information on these sites. At each site, a monthly sampling program collected a suite of water quality, biological and hydrological information. Benthic macroinvertebrate surveys were conducted annually at each site following the Canadian Aquatic Biomonitoring Network (CABIN) protocol. During this survey, other stream biophysical parameters were also measured, such as canopy cover, stream width, bankfull width, and stream substrate type. A full description of the national field data collection program is found in Chambers *et al*. (2006) and Culp *et al*. (2007). The main field program ended in the fall of 2007 in most watersheds, but has continued under a more intensive data collection program in Coldstream, Equesis and Eneas Creek (Peters *et al*., 2007).

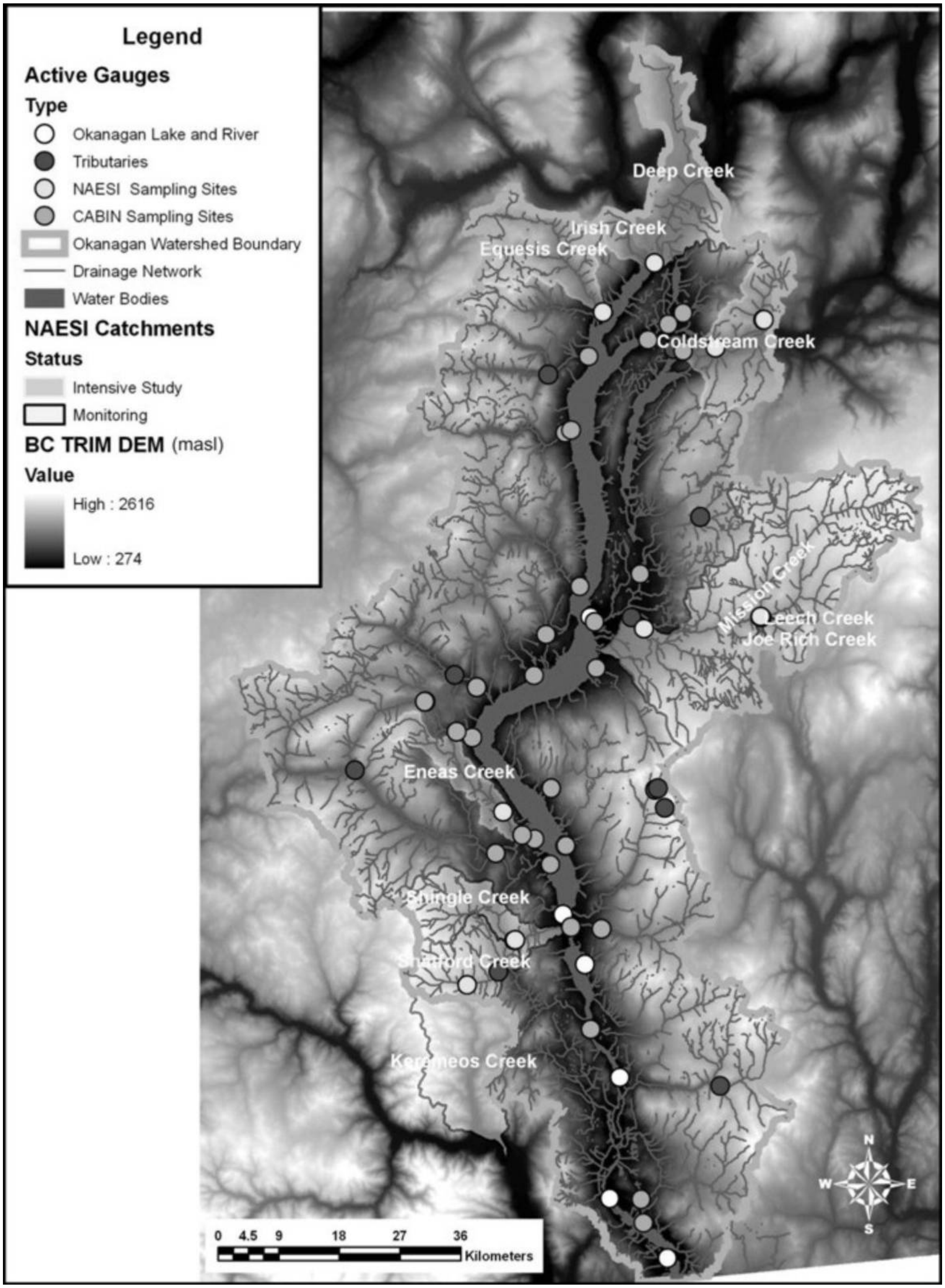

Figure 2: NAESI Water Theme study watersheds within the Okanagan Valley, British Columbia.

Table 1: Names and geographical co-ordinates of British Columbia streams selected for the NAESI monitoring network. Source: Culp *et al*. (2007)

Watershed	Site Code	Watershed Area (km^2)	Agricultural Land-use %	Latitude	Longitude	Elevation (masl)
Coldstream Creek	BCCOL01	204.0	21.2	50° 15.461'	119° 04.824'	635
	BCCOL02	204.0	21.2	50° 13.559'	119° 11.190'	476
Deep Creek	BCDEE01	245.0	41.3	50° 20.797'	119° 17.788'	341
Eneas Creek	BCENE01	89.8	13.1	49° 38.327'	119° 42.727'	522
Equesis Creek	BCEQU01	199.5	4.3	50° 17.297'	119° 24.815'	376
Joe Rich Creek	BCJOE01	44.5	4.9	49° 51.872'	119° 08.770'	809
Keremeos Creek	BCKER01	224.9	17.6	49° 21.877'	119° 48.712'	812
	BCKER02	224.9	17.6	49° 15.691'	119° 49.555'	519
	BCKER03	224.9	17.6	49° 14.328'	119° 49.389'	465
	BCKER04	224.9	17.6	49° 12.083'	119° 47.167'	404
Leech Creek	BCLEE01	4.8	0.7	49° 51.848'	119° 08.969'	840
Mission Creek	BCMIS01	795.0	5.8	49° 51.943'	119° 08.868'	819
	BCMIS02	795.0	5.8	49° 51.852'	119° 23.401'	407
Shatford Creek	BCSHA01	140.3	11.5	49° 24.853'	119° 48.990'	901
Shingle Creek	BCSHI01	143.6	13.4	49° 28.103'	119° 42.664'	606

In the case of the nutrients, sediments and eco-hydrology components, standards development focused on defining desired ecological condition by: (1) determining the potential ecological effects imposed by a stressor, be it elevated nutrient or suspended sediment concentrations or reduced water flow (i.e., developing stressor-response relationships), and (2) determining nutrient, suspended sediment and flow conditions for reference or minimally-disturbed streams. Knowing the adverse ecological effects that may occur in response to exposure to a stressor (i.e., the stressor-response relationship) as well as the best conditions that can be attained (i.e., the condition of reference or minimally disturbed sites), it is then possible to define the set of physical, chemical and biological conditions that define desirable ecological condition.

Nutrients

The information presented in this section was summarized from a peer-reviewed NAESI Synthesis report prepared by Chambers *et al*. (2008) entitled "*Nitrogen and Phosphorous Standards to Protect Ecological Condition of Canadian Streams, Rivers and Coastal Waters*"

Issue

Non-point sources of nitrogen (N) and phosphorus (P) are recognized as a major cause of eutrophication in inland and coastal waters. The addition of N and P to surface waters as a result of non-point loading can cause excessive aquatic plant growth, loss of plant species, depletion of oxygen and changes in abundance and diversity of aquatic invertebrates, fish and, possibly, birds and mammals dependant upon these habitats. Agricultural sources of N and P include chemical fertilizers and land application of manure.

Objectives

- To establish chemical and biological ideal performance standard (IPS) for nutrients that confer good ecological condition and protect against excessive eutrophication in Canadian streams, rivers and nearshore marine areas.
- To establish IPS to protect marine and freshwater life from the toxic effects of nitrate. Short-term IPS are intended to prevent the severe, acute impacts of an event such as a chemical spill, while long-term IPS values are designed to protect against any adverse effect from prolonged exposure.
- To develop and test a methodology for estimation of achievable performance standard (APS) for nutrients in streams using two targeted watersheds as demonstration sites.

Approach to Standards Development

IPS to protect against excessive eutrophication in streams and rivers:

IPS were developed using an iterative approach that involved calculation of provisional total phosphorus (TP) or total nitrogen (TN) standards using empirical methods followed by cross-calibration of these empirically-derived chemical standards with information on the biological attributes (algal and benthic macroinvertebrate abundance and composition) that these IPS values would protect. Two sources of data were used to develop IPS for TP and TN: long-term monitoring data (water chemistry only) from numerous government and non-governmental sources, and, for streams, contemporary data (chemical and biological) collected from seven study areas that comprised the national NAESI Water Theme field sampling program. Provisional TP and TN standards for rivers were derived following the USEPA percentile method. For streams, IPS were initially calculated as the average of the values produced using three different international approaches:

- the USEPA percentile approach
- the Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council percentile approach
- the Canadian Council of Ministers of the Environment percentile approach

These provisional IPS values were then compared to criteria associated with biological attributes and, if necessary, lowered to ensure that final IPS would protect stream biology. A full account of the approach for streams is available in Chambers *et al.* (2008).

IPS to protect against excessive eutrophication in nearshore coastal waters:

An approach for setting IPS was developed using relative physical susceptibility (an index of dilution and nutrient loading potential). The approach offers significant potential for developing watershed or site-specific IPS for coastal waters (coves, bays and estuaries), which behave differently than streams and rivers with respect to freshwater inputs, retention times and nutrient additions. An example of the applicability of this approach was demonstrated for the coastal waters around PEI.

APS to protect streams against excessive eutrophication:

APS for N and P were developed through non-point source water quality modeling for a targeted watershed in each of New Brunswick and Ontario. Various BMP implementation scenarios for nutrient management (e.g., diversion terraces, crop rotation, tillage practices and fertilizer application rates for NB; biodiversity conservation scenarios and variable buffer widths for ON) were modeled using SWAT (Soil and Water Assessment Tool, USDA). The APS was determined as the lowest achievable nutrient concentration for the particular watershed under an optimal BMP implementation scenario. A full account of the modeling approach is available in Benoy *et al.* (2008) and Culp *et al.* (2008).

IPS to protect against nitrate toxicity:

IPS for nitrate were developed by updating the 2003 interim CCME Water Quality Guidelines for Aquatic Life in accordance with the 2007 protocol. The revised protocol employs a species-sensitivity distribution (SSD) approach and results in concentrations protective against both short- and long-term exposure to a toxicant. A SSD is a statistical distribution capturing the variation in toxicological sensitivity to a contaminant among a set of species. As part of this project, new nitrate toxicity data were acquired for four species (rainbow trout, the Scud freshwater amphipod, the Pacific purple sea urchin and topsmelt) and used to fill data gaps in the nitrate toxicity dataset. IPS values were chosen as the 5^{th} percentile of species affected and are calculated based on the regression curve that best fits the SSD data. A full account of the approach is available in Guy (2008).

Recommended Standards

The recommended IPS and APS standards for the Okanagan region are presented in Table 2. Note that these standards are provisional until released in a NAESI Synthesis report by Chambers *et al*. (2008) entitled "*Nitrogen and Phosphorous Standards to Protect Ecological Condition of Canadian Streams, Rivers and Coastal Waters*"

Table 2: Recommended nutrient standards for the Okanagan region. Note: the standards are provisional until released in NAESI Synthesis report by Chambers *et al*. (2008) entitled "*Nitrogen and Phosphorous Standards to Protect Ecological Condition of Canadian Streams, Rivers and Coastal Waters*".

Type of Standard	Recommended Standard		
		TP (mg/L)	TN (mg/L)
IPS - Total Nitrogen (TN) & Total Phosphorus (TP) in Freshwater Streams (Eutrophication)	Montane Cordillera - Okanagan Basin, BC	0.019	0.21
IPS - Total Nitrogen (TN) & Total Phosphorus (TP) for Medium Rivers (500-5000 km^2 watershed) (Eutrophication)	Montane Cordillera	0.016	0.50
			nitrate (mg NO_3/L)
IPS - Nitrate in Freshwater (Toxicity)		Short-Term	218
		Long-Term	44

Sediments

The information presented in this section was summarized from a peer-reviewed NAESI Synthesis report prepared by Culp *et al*. (2008) entitled "*Total Suspended Sediment, Turbidity and Deposited Sediment Standards to Prevent Excessive Sediment Effects in Canadian Streams*"

Issue

Agricultural activities such as ploughing, tilling and harvesting can cause soil exposure and compaction resulting in higher rates of soil erosion from cultivated fields. Direct livestock access to watercourses can cause riparian and streambank erosion. Taken together, these practices increase the suspended and depositional sediment load of agricultural environments to aquatic ecosystems. Suspended sediments can be acutely lethal to fish at high concentrations. Sublethal responses may consist of reduced growth, respiratory impairment and behavioural effects. Changes in suspended sediments and turbidity also have direct and indirect effects on benthic flora and fauna and, at higher levels, contribute to impaired ecosystem function. Excessive sediment deposition impacts stream ecosystems directly, by scouring and smothering organisms, and indirectly, by reducing habitat quantity, complexity and connectivity.

Objectives

- To establish physical and biological IPS for total suspended sediments (TSS), turbidity and deposited sediments that confer good ecological condition and protect against excessive sediment effects in Canadian streams in agricultural landscapes.
- To develop and test a methodology for estimation of APS for sediments in streams using two targeted watersheds as demonstration sites.

Approach to Standards Development

IPS for total suspended sediments (TSS) and turbidity:

IPS were developed for large areas, usually a single physiogeographic region (i.e., ecoregion) of a province. IPS were developed using an iterative approach that combined calculation of provisional total suspended sediments (TSS) and turbidity standards using empirical methods with validation of these empirically-derived standards on the basis of benthic macroinvertebrate abundance and diversity. Two sources of data were used to develop IPS for TSS and turbidity: long-term monitoring data (physical parameters only) from numerous jurisdictional sources, and contemporary data (physical and biological) collected from seven study areas that comprised the national NAESI Water Theme field sampling program. Provisional TSS and turbidity standards were calculated as the average of the values produced using five different international approaches:

- the Y-intercept method
- the USEPA percentile approach
- the Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council percentile approach
- the Canadian Council of Ministers of the Environment percentile approach
- regression-tree analysis method

Several metrics of ecological quality, including measures of benthic macroinvertebrate diversity (EPT richness, total richness) and abundance (EPT relative abundance) were determined from the field sampling program and employed to examine the extent to which the provisional TSS and turbidity standards were good predictors of desirable ecosystem condition.

IPS for deposited sediments:

Deposited sediment standards were developed from field data collected in small streams within the potato production regions of NB and PEI. A number of possible geomorphic criteria were evaluated to assess the strength of their relationship with watershed land cover, and the five best performing criteria were selected for calculation of deposited sediment IPS. Two methods were employed to calculate IPS values: the Y-intercept method and the USEPA percentile method. As for the IPS for TSS and turbidity, empirically derived IPS were validated using macroinvertebrate metrics (EPT relative abundance and the modified family biotic index) to ensure that the empirically derived IPS were consistent with desirable ecosystem condition.

APS to protect against excessive sedimentation:

APS for TSS and turbidity were developed through non-point source water quality modeling for a targeted watershed in each of NB and Ontario. Different BMP implementation scenarios for soil/sediment management (e.g., diversion terraces, crop rotation and tillage practices for ON; biodiversity conservation scenarios and variable buffer widths for NB) were modeled using SWAT. The APS was determined as the lowest achievable TSS concentration or turbidity measurement for the particular watershed under an optimal BMP implementation scenario. A full account of the modeling approach is available in Benoy *et al.* (2008) and Culp *et al.* (2008).

Recommended Standards

The recommended IPS and APS for suspended and deposited sediment standards for the Okanagan region are presented in Table 3. Note that these standards are provisional until released in a NAESI Synthesis report by Culp *et al*. (2008) entitled "*Total Suspended Sediment, Turbidity and Deposited Sediment Standards to Prevent Excessive Sediment Effects in Canadian Streams*"

Table 3: Recommended sediment standards for the Okanagan region. Note: the standards are provisional until released in NAESI Synthesis report by Culp *et al*. (2008) entitled "*Total Suspended Sediment, Turbidity and Deposited Sediment Standards to Prevent Excessive Sediment Effects in Canadian Streams.*" NE = not evaluated

Type of Standard	Recommended Standard						
	TSS (mg/L)	Turbidity (NTU)	Deposited Sediments				
			Surface Sediment % fines <2 mm	Surface sediment % fines <6.35 mm	Surface sediment median particle size (d_{50})	% fines <2 mm From Sediment cores	Relative Bed stability
IPS – Total Suspended Sediments (TSS) and Turbidity and Deposited Sediments in Freshwater Streams	6.0	1.8	NE	NE	NE	NE	NE
APS - Total Suspended Sediments (TSS) in Freshwater Streams	NE						

Instream Flow Needs

The information presented in this section was summarized from a peer-reviewed NAESI Synthesis report prepared by Baird *et al*. (2008) entitled "*Establishing Standards and Assessment Criteria for Instream Flow Needs in Agricultural Watersheds of Canada*"

Issue

Instream flow needs (IFN) have traditionally been defined in terms of minimum flows required to protect and sustain aquatic resources in streams. However, it has become increasingly apparent that arbitrarily-defined minimum flows alone are inadequate, and that key elements of the hydrograph, such as annual flood flows, are important in the maintenance of riverine ecosystems. Quantitative analysis of critical components of flow regimes, including magnitude, timing, frequency, duration and rate of change of flows, can be used to determine both a stream's natural flow regime and deviations from this regime as a result of water diversion, storage and abstraction for irrigation or other uses. Since aquatic communities have evolved in response to natural flow regimes, where these regimes are disrupted, the biotic composition, structure and function of aquatic ecosystems may also be disrupted. As a result, indices of benthic macroinvertebrate community health are recommended for use alongside hydrologic indicators in the determination of an ecological instream flow need (IFN) standard.

Objectives

- To develop a methodology to undertake an initial assessment of the degree of streamflow alteration (i.e., the extent of the deviation from natural flow regime) in small agricultural watersheds.
- To develop a flow-specific bioassessment method (the Canadian Ecological Flow Index – CEFI) using standard Canadian biomonitoring data to diagnose flow habitat degradation, while controlling for the influence of other stressors.
- To propose a prototype ecological instream flow needs standard.

Approach to Standards Development:

An approach to deriving ecological instream flow targets was proposed using British Columbia watershed eco-hydrological information. Assessment of hydrologic alteration is determined via the Indicators of Hydrological Alteration (IHA; Richter et al., 1996) approach proposed by The Nature Conservancy. IHA statistics are used in conjunction with Range of Variability Approach (RVA; Richter *et al*., 1997) to establish initial hydrologic targets based on percentile ranges of the natural flow regime. We consider that the IHA and associated RVA have great potential for the initial phase of instream flow needs assessment and the approach is focused on protection of the whole ecosystem, and thus the protection goal is appropriate for the current purposes of the NAESI program. This is supported by Braggs *et al*. (2005) who based on an exhaustive review concluded that the IHA/RVA methodology appeared to be the most promising basis for the assessment of hydrological risk in the context of the European Union Water Framework Directive implementation.

The approach developed for NAESI encompasses two levels of assessment. A Level 1 Assessment entails a number of key steps: 1) Identification of study streams for classification; 2) Ascertaining if the streams are gauged (e.g., 20+ years of hydrometric monitoring); if not construct a hydrological model to simulate flows for existing system; 3), Are flows without hydrological alterations (i.e. naturalized flows) available?; if not, construct a hydrological model to simulate flows for naturalized (reference) system; 4) Quantify deviation of existing hydrological regime from reference (naturalized) regime using IHA/RVA software; if system outside accepted boundaries, go to 5) Calculate CEFI Index to test hypothesis of hydrological alteration; if within accepted boundaries, then assessment complete. The Canadian Ecological Flow Index (CEFI) is calculated as the weighted-average velocity sensitivity of all benthic macroinvertebrate families in a single biomonitoring sample, as:

$$\text{CEFI} = \frac{\Sigma\, a_i s_i}{\Sigma a_i}$$

where a_i is the macroinvertebrate abundance of "*i*"th taxon in the sample and s_i is the optimum (velocity preference) of the "*i*"th taxon. If there is evidence of impaired ecological status, as indicated by CEFI, then we recommend invoking a Level 2 Assessment, which would be determined by study-specific, stakeholder-defined protection goals (e.g., fish habitat / ecosystem protection) and would entail detailed, reach-specific eco-hydrological studies and modelling (e.g., PHABSIM).

<u>Recommended Standards</u>

As discussed above, the objective was not to produce a single standard, but to recommend a methodology for deriving and testing requirements for an initial ecological instream flow needs. Table 4 presents ecologically relevant hydrological parameters used as IHAs. A Level 1 Assessment involves ascertaining via the RVA if IHA variables fall outside the natural variability of the system and if so, determining if there is evidence of ecological status impairment as indicated by CEFI. Note that the steps outlined above remain to be tested. We are continuing our field research at key agricultural watersheds in the Okanagan region to attempt to validate the Level 1 Assessment approach. The prototype standard approach is provisional until released in a NAESI Synthesis report by Baird *et al*. (2008) entitled "*Establishing Standards and Assessment Criteria for Instream Flow Needs in Agricultural Watersheds of Canada*".

Table 4: Thirty-three ecologically relevant hydrological parameters calculated in the Indicators of Hydrologic Alteration (IHA) software program for each water year (after Richter *et al*., 1997).

IHA Flow Statistics
• Magnitude of monthly mean flows
• Annual 1-, 3-, 7-, 30- and 90-day mean minimum and maximum flows
• Number of days with zero flow
• Baseflow index
• Julian date of annual 1-day minimum and maximum flows
• Frequency and duration of low and high flow pulses
• Rate of hydrograph rise and fall, and number of flow reversals

Approach to Applying the Nutrients, Sediments, and ifn Standards

The nutrient and sediments IPS are intended as threshold levels that define 'how clean is clean' in working agricultural landscapes. They can be used as benchmarks in evaluating the environmental performance of the agriculture sector over time. Nutrient and Sediment APS values can be compared against IPS values to assess priorities for BMP implementation and research. While the IFN proposed approach offers significant promise in terms of general guidelines for deriving flow management criteria in small agricultural watersheds in Canada, it is not yet at a stage where robust science-based standards can be finalized and applied.

Limitations and Gaps in the Science

Further research is required in several areas to improve standards development, for example to determine or validate targets equating to good ecological condition for biological indicators, and to evaluate whether standards set for upstream waters are protective of downstream rivers, lakes and coastal waters. Further monitoring of ambient nutrient concentrations and biological responses to nutrients (along with relevant confounding physical factors) is required to develop standards for those areas where data are few or lacking, and to validate the broader applicability of standards developed for specific provincial regions.

The state of knowledge concerning the relationship between physical and biological endpoints related to sediments is still evolving, and requires further research to refine existing standards. Further development of efforts linking catchment topography, land use and hydrological response to in-channel sediment transport, deposition and biological condition is also required, with a focus on approaches that integrate modeling with field assessments. Monitoring of TSS, turbidity and deposited sediments has not been a priority in Canadian watersheds, despite the documented importance of excessive sedimentation as a major environmental stressor. This paucity of sediment data, particularly for smaller watersheds where agriculture can have major environmental impacts, was a limiting factor in the development of sediment IPS and APS values for many regions across Canada.

A number of factors limit the immediate utility of the IFN proposed approach. First, the significant natural variability in the climatic and hydrological regimes of small agricultural streams makes it challenging to produce a broadly applicable approach to establishing flow-based standards. Second, the paucity of long time series (20+ years) of observed hydrometric data for small watersheds in Canada constrains the ability to characterize natural flow regimes, a necessary first step in being able to quantify acceptable perturbations to those regimes. Finally, while there are excellent tools available for the derivation of hydrological indicators of flow alteration, much uncertainty still remains regarding the causal linkages between an altered flow regime and the ecological condition of a stream or river. In part this is owing to the challenge of isolating flow-related changes from other sources of stress (e.g. temperature, water quality changes).

Future Considerations

In future, standards development should consider interactions with other stressors and the combined effect of these multiple stressors on aquatic food webs. This is particularly relevant for agricultural streams where multiple stressors (nutrients, suspended sediments, pesticides, flow alterations) are often present. Additional effort to collect nutrients, sediments, biological and hydrological data in priority agricultural watersheds would expand the capacity to establish standards, and would improve confidence in existing standards for specific watersheds and ecozones.

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Assessing One Side of the Water Budget: How Can Groundwater Recharge Be Predicted Across the Okanagan Basin?

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Abstract

Determining the role of groundwater in meeting future water supply needs will rely on understanding spatial distribution and rates of groundwater recharge. Accurate recharge estimates are critical for effective groundwater management; however, recharge is difficult to quantify, especially over large, mountainous regions. For the Okanagan Basin, different approaches for predicting groundwater recharge are required that consider the wide range in data availability between valley bottom and headwater areas, large changes in elevation, and complex groundwater conditions. This paper presents findings from an assessment of recharge at the BX Creek watershed, and an investigation of broad-scale groundwater recharge mapping for the entire Okanagan valley bottom. For the entire BX Creek watershed, groundwater recharge was determined from a combination of flow models (MIKE-SHE and MODFLOW) and simple water budget calculations. Groundwater recharge was found to vary from 0 to 20 mm/yr at lower elevations, and from 20 to 50 mm/yr at higher elevations. Modelling of the complete watershed-scale flow system illustrated that 57% of the groundwater recharge to the valley bottom aquifers is from upland source water that flow through a relatively narrow alluvial fan, which extends to the valley bottom. The remaining recharge is nearly equally divided between groundwater flow through the less permeable mountain block (20%) and direct to the valley bottom (22%). Results of the BX Creek study were compared with regional-scale estimates of groundwater recharge for the entire Okanagan Basin valley bottom, which were made with the widely-used HELP model. Using identical data sources, estimates from the HELP model match the spatial distribution for the BX Creek area, but predict higher rates of groundwater recharge in this semi-arid area. These results suggest that the HELP model systematically over-predicted groundwater recharge, and that additional refinement would be necessary to provide accurate results for the entire Okanagan Basin. This paper illustrates the challenge of predicting groundwater recharge in semi-arid, mountainous regions, which is a major component of basin-wide water-budget analyses.

Introduction

Background

Groundwater recharge is the cornerstone of many water resources investigations. Estimating accurate rates of spatially distributed recharge is critical for: balancing water budgets (de Vries and Simmers 2002); assessing migration of contaminants in the subsurface (McMahon et al. 2006); determining the effects of land use/land cover change (Scanlon et al. 2007); and,

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forecasting the influence of climate change (Jyrkama and Sykes 2007; Scibek and Allen 2006). Estimates of groundwater recharge are meant to quantify the amount of water from the atmosphere that migrates to the groundwater regime. The recharge process results from a complex transfer of energy and moisture at the land surface, and relates climate, vegetation, characteristics of the soil, and depth to the water table. Various techniques have been investigated to quantify recharge fluxes (Scanlon et al. 2002b), including: direct physical measurements (e.g., lysimeters, fluctuations observed at the water table, soil moisture profiles); use of naturally occurring and applied tracers (e.g., heat, isotopic, solute); and mathematical models of varying complexity. Selection of an appropriate technique depends on the spatial and temporal scale of interest, the quality and quantity of available data, the investment of resources to acquire new data, and the range of acceptable error.

Valley bottom aquifers in mountainous terrain are often principal groundwater reservoirs, and recharge typically occurs from one or more of three mechanisms: (i) seepage from mountain streams and rivers; (ii) groundwater flow from the adjacent mountain block (mountain block recharge); and, (iii) direct (or diffuse) recharge to the valley bottom. A single mechanism may not characterize any given region, and the relative contribution of each method will depend on climatic and geologic conditions. To quantify direct recharge across broad regions,one often relies on models. A simple water budget for a basin can provide a first-order approximation of different components of the hydrologic cycle, including groundwater recharge. However, as variations in land cover and soil data are introduced, the complexity of the model typically increases to accommodate the spatially variable input parameters. For water limited regions, infiltrating water may be drawn up by vegetation (through evapotranspiration) or stored in the unsaturated zone under diminished potential for vertical drainage due to low relative permeability associated with dry soils. These transient processes also add complexity when quantifying direct recharge.

The objective of this paper is to present estimates of spatially distributed recharge for a portion of the semi-arid Okanagan Basin, British Columbia (BC). Two different methods are presented that generally follow the GIS-based approach described by Jyrkama et al. (2002), which would be required for determining recharge across large basins. In each method, diffuse recharge to valley bottom aquifers in the Vernon, BC area were compared, using common physiographic and climatic data. The results of direct recharge estimates to the valley bottom were also compared with estimates of lateral recharge from an adjacent upland area, determined from a watershed-scale groundwater flow model. The results of this study provide an illustrative example of the linkage between upland water sources and aquifers, and the challenge of predicting recharge in semi-arid regions.

Study Area

The BX Creek watershed (130 km^2) is located toward the north end of Okanagan Basin, near the City of Vernon, BC (Figure 1). The headwaters of BX Creek are located at Silverstar Mountain, which drains to Swan Lake, and which in turn discharges to Okanagan Lake. Bedrock is generally exposed at elevations greater than 500 m, and is comprised of argillaceous limestone, slate, and meta-siltstone and sandstone, and volcanics (Fulton 1975). The Swan Lake Valley has been filled with unconsolidated sediments from various fluvial, glaciolacustrine, and alluvial processes, forming stratified clays and silts, and un-stratified sands and gravel deposits (Nasmith 1962). The Basin is characterized by a semi-arid continental climate, with an increase in atmospheric moisture from valley bottom to upland areas (Cohen et al. 2006). Average annual precipitation for Vernon is 410 mm and the average monthly air temperature varies from -4.2°C to 19.7°C (Canadian Climate Normals 1971 to 2000; Environment Canada 2006a). The Okanagan Basin has snowmelt-dominated upland catchments and dry valley bottoms. Seasonal surface runoff and peak streamflow occurs in May, and low-flow occurs late in the summer months. Upland bedrock areas are fractured, and the specific hydraulic relationship between surface runoff from headwater catchments and groundwater recharge has yet to be determined (Voeckler, in progress). Mid-elevation, benchland areas coincide with the mountain-to-valley transition, where stream seepage losses recharge groundwater.

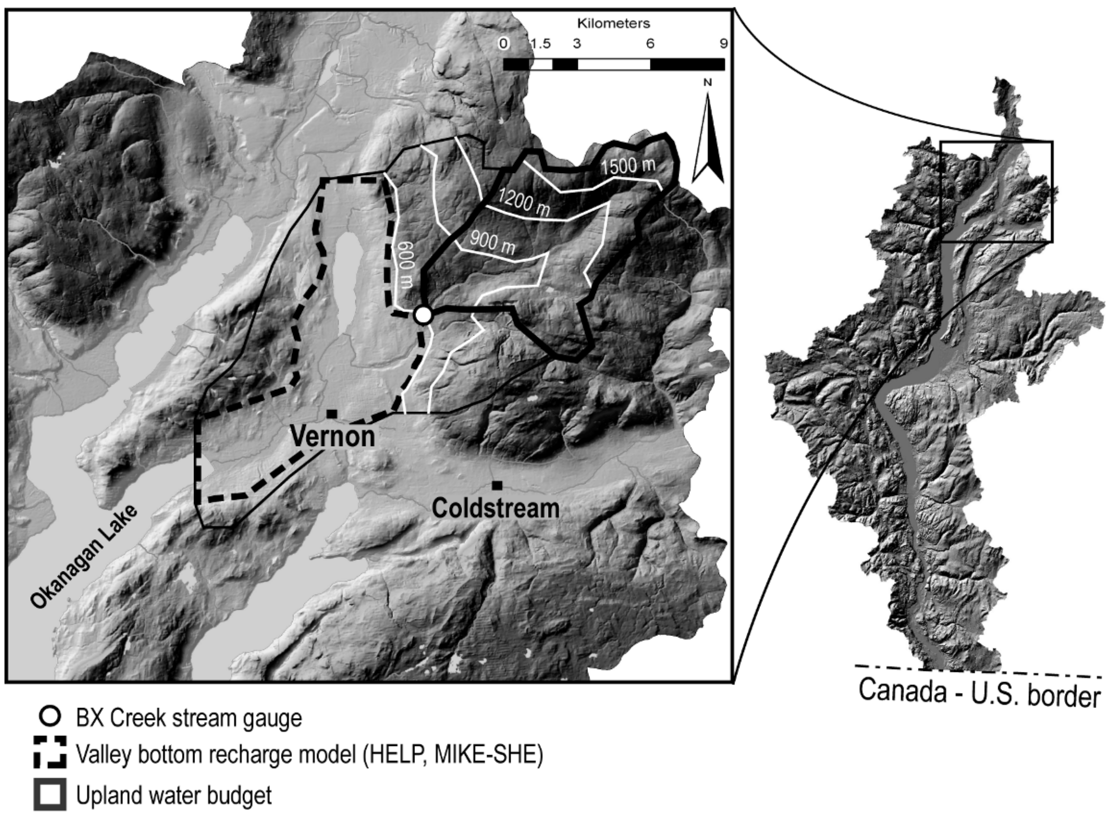

Figure 1: Location of BX Creek watershed (thin black line), valley bottom recharge model (dashed black line), and upland water budget area (thick black line). Elevation bands used for upland water budget shown as white lines and text.

Methods

Diffuse recharge for the valley bottom area near Vernon, BC was modelled with the HELP code (Hydrologic Evaluation of Landfill Performance; Schroeder et al. 1994) and with MIKE-SHE (Abbott et al. 1986). Geologic, soil, and climatic data were sufficient to support development of recharge simulations using continuous data for the 1961 to 1990 period (30 years). Similar data were sparse for the upland areas, so recharge was estimated from a more simplified water budget approach (upland water budget area shown in Figure 1). In addition to comparing results of the

HELP and MIKE-SHE approaches for the valley bottom, recharge estimates for the entire BX Creek watershed were tested in a groundwater flow model (Smerdon et al. in review), and the resulting distribution of hydraulic heads and baseflow to BX Creek were compared to available data.

HELP Modelling

The HELP code solves a series of water balance equations for a layered column of soil. The code requires a weather series, soil properties, and soil column data as input, and accounts for the effects of surface storage, runoff, evapotranspiration, snowmelt, infiltration, vegetation growth, soil moisture storage, lateral subsurface drainage, and unsaturated vertical drainage. For recharge simulations, the base of the column is set equal to the depth of the water table, and leakage simulated through the bottom of the soil column is considered representative of direct recharge to the groundwater system. Diffuse recharge was simulated in the Okanagan utilising six, spatially variable inputs: climate, soil type, vadose zone type, depth to water table, leaf area index (LAI), and evaporative zone depth. The inputs were grouped in ArcGIS to form unique HELP columns, and a HELP model was run for each column. The recharge results were then applied to all areas containing that particular combination of variables, thus yielding a map of recharge.

Daily precipitation, temperature, and solar radiation were processed by Agriculture and Agri-Food Canada (AAFC) to ensure a continuous period of record (described in Liggett 2008). Growing season start and end days were determined by identifying days for which the mean daily temperature was above (or below) 10°C and 5°C for five consecutive days. The median start and end dates were entered into the HELP model. Soil properties and related hydraulic parameters (hydraulic conductivity, porosity, wilting point, and field capacity) were determined from 1:20,000 digital soils maps and assigned to each soil horizon based on soil texture properties within HELP. The depth to water table was interpolated from water well data from the BC WELLS database (BC Ministry of Environment 2006) that were completed in valley fill sediments. Leaf Area Index (LAI) is the ratio of upper leaf surface area to the surface area of the land upon which the vegetation grows, and is used in HELP to calculate actual evapotranspiration (AET). LAI was estimated from 30 m resolution Landsat imagery (Fernandes et al. 2003). The range of LAI values throughout the valley was from 0 to 8; however, 87% of the area had an LAI of < 2. According to the code documentation, HELP is insensitive to LAI values above 5. Therefore, LAI was split into two groups from 0 to 1, and 2 to 8, and assigned mid-LAI values of 0.5 and 3.5, respectively. Evaporative zone depth (EZD) is the depth to which water can be removed from the soil column by evaporation or transpiration. This depth is dependent on both the soil texture and the vegetation (Shah et al. 2007) and must be explicitly specified within HELP as it controls the depth to which upward water loss can occur. Each of the different land cover types in the Okanagan were grouped into four categories and assigned representative evaporative zone depths (described in Liggett 2008).

The spatially varying input parameters (e.g., soil, vadose zone, etc.) were defined for 50 m x 50 m cells and combined in ArcGIS. For each column, a 30 year simulation, plus a 60 or 150 year model spin-up was completed. These spin-up times were used to allow for an adequate initialization of soil moisture, storage, and recharge and were created by repeating the 1961 to 1990 data series three to five times. Tabular results of monthly totals, annual totals, average monthly, and average annual recharge and evapotranspiration values were created for the 1961 to 1990 timeframe. The average monthly and average annual tables were imported into ArcGIS and linked to the location of each unique HELP column to produce spatially-distributed maps of average monthly and average annual recharge conditions.

MIKE-SHE Modelling

MIKE-SHE has the capability to describe the main physical processes of the hydrologic cycle, and in this study the overland flow, evapotranspiration, and unsaturated flow modules were used. The rationale was to allow redistribution of water to each of these segments of the hydrologic cycle and predict diffuse groundwater recharge, similar to the HELP modelling described above. Overland flow was routed in downslope directions from cell-to-cell on the model grid (by diffusive wave approximation and finite-difference method), and had the potential to evaporate, infiltrate, and transpire, based on spatially distributed land cover and soil properties. Ground surface topography was derived from 25 m horizontal resolution digital elevation data (GeoBase 2007) that was smoothed using a Spline algorithm, to the 100 m x 100 m model grid. In semi-arid regions, a limited amount overland flow can be expected, and the entire study area was assumed to have uniform hydraulic characteristics. Manning’s n was assumed to be 0.3 for the entire landscape (Woolhiser 1975), and detention storage was set to 10 mm.

Actual evapotranspiration (AET) was modelled by the Kristensen and Jensen (1975) method, and required time-series climate data, including an estimate of potential evapotranspiration (PET), LAI and root zone depth. The precipitation and temperature data described for HELP modelling were input to MIKE-SHE with a degree-day-factor of 2 mm/d/°C and threshold melt temperature of 0°C to approximate snowmelt. PET was calculated by the Thornthwaite (1948) method from average monthly air temperature. LAI values were assumed to increase linearly throughout the growing season to the maximum values. Rooting zone depths were assumed to be 500 mm for areas of little vegetation, 1000 mm for recreational and some residential areas, and 2000 mm for agricultural and rangeland areas.

Soil moisture conditions (for use in the evapotranspiration module) and infiltration are modelled by Richards’ equation for a static water table condition in MIKE-SHE. The physical characteristics of the unsaturated zone, including relationships for capillary pressure, saturation, and relative permeability were developed from a combination of digital soils maps for the north Okanagan (Walmsley and Maynard 1987), and surficial geology maps (Nasmith 1962). Textural descriptions for each soil horizon (to approximately 1.3 m depth) and descriptions of the surficial geology (below 1.3 m depth) were matched to the USDA system of soil classification, and assigned corresponding hydraulic parameters for each soil layer (Carsel and Parrish 1988). For computation of unsaturated flow, the lower boundary condition was a specified water table, interpolated from water well data from the BC WELLS database (BC Ministry of Environment 2006) that were completed in valley fill sediments. Initial conditions were required for unsaturated hydraulic head, saturation, and overland flow for each grid cell within the model domain. These conditions were established by allowing an 11 year initialization period prior to the simulated time frame (i.e., 1950 to 1961). For this spin-up period, mean values of precipitation, air temperature, and potential evaporation were assumed and initial conditions were generated. Model time-steps were adaptive (dependent on changes in saturation, pressure head and ponded surface water), and limited to a maximum of one day. Water balance data were output every 30 days, and assumed to be representative of each 30 day period. Interception, bare soil evaporation, and transpiration were summed for estimates of actual evapotranspiration, and the flux between the unsaturated zone and specified water table boundary condition was assumed to represent groundwater recharge.

Upland Water Budget

For elevations above 500 m, soil survey, groundwater, and climatic data were sparse, and recharge estimation using the HELP or MIKE-SHE codes was not possible. Continuous stream discharge measurements were available from a gauging station on BX Creek maintained by the Water Survey of Canada (gauge 08NM020; Environment Canada 2006b), which is located at the margin of the valley bottom (Figure 1). To estimate the magnitude of groundwater recharge for the upland area, a seasonal water budget was developed for 4 month periods, from 1961 to 1990, for the 52 km^2 topographic catchment area for the streamflow gauge on BX Creek. The water budget area was subdivided into elevation bands, and water budget components were defined for each band, interpolating between known values for the valley bottom (i.e., lowest band) and Silverstar Mountain (i.e., highest band). Snow survey data from Silverstar Mountain (site 2F10, 1840 masl) were reported from January to June (BC Ministry of Environment 2007). These data include snowpack height and snow water equivalent (SWE), and are assumed to represent the majority of precipitation to uplands areas (Cohen et al. 2004). For the lowest elevation band (Figure 1), daily precipitation was summed at a monthly interval, and AET results from the MIKE-SHE recharge model were used for the water budget. Since insufficient climate data for estimating evapotranspiration in the upland areas were available, actual evapotranspiration rates were assumed to follow average rates measured and modelled (2002 to 2005) for the Upper Penticton Creek watershed (unpublished data from D. Spittlehouse, BC Ministry of Forests and Range). Total groundwater extraction from the alluvial aquifer in the lowest portion of the upland water budget area was approximately 130,000 m^3/yr (Golder Associates 2006), which equates to less than 1 mm/yr for the entire water budget area. The water budget accounted for known inputs and outputs: $\pm r = P - AET - SW_{out} - GW_{pump}$, where P is precipitation, AET is actual evapotranspiration, SW_{out} is surface water discharge, and GW_{pump} is groundwater extracted from the alluvial aquifer in the vicinity of the stream gauge on BX Creek (Figure 1). The residual (r) represents the sum of errors and an estimate of groundwater recharge.

Watershed-Scale Flow Model

To combine the valley bottom and upland area recharge estimates, a simplified three-dimensional, groundwater flow model was developed for the entire watershed area in MODFLOW. The model area extended from the north end of Okanagan Lake to the peak of Silverstar Mountain (Figure 1), covering an elevation range of 350 to 1850 metres above sea level (masl). Steady-state flow was simulated for a conceptualized representation of hydrostratigraphic units that was developed from a combination of borehole log data (BC Ministry of Environment 2006), distribution of surficial geologic deposits (Nasmith 1962), and aquifers delineated according to the BC Aquifer Classification System (Berardinucci and Ronneseth 2002). Additional details of groundwater model development are provided in (Smerdon et al. in review). Steady-state heads were compared with the BC WELLS database, and groundwater discharge to the upland section of BX Creek (implemented as a drain boundary condition) was compared with average yearly low-flow determined from the Water Survey of Canada stream gauge.

Results

Valley Bottom AET and Direct Recharge

AET is a dominant hydrological process in semi-arid regions, and percolation to the water table and net groundwater recharge occurs once the demands of vegetation have been met. In each of the recharge models for the valley bottom (HELP and MIKE-SHE), AET was calculated internally as part of recharge simulation (Figure 2). Thus, one indication of the accuracy of recharge estimate is comparison of simulated AET with measured rates. AET results were compared to values measured (Figure 3) by the AAFC for an alfalfa crop study (1969 to 1973) in the Vernon area (Stevenson and Munn 1978) and calculated AAFC data from daily climate measurements (Neilsen Personal Communication). For the summer months (May to September) of 1969 to 1973, AAFC data suggest mean monthly AET varying from 60 to 120 mm (Figure 3). The mean monthly AET calculated by the HELP model for the same timeframe was at least 50% lower for May, August, and June. Results for June and July were also under predicted by the HELP model. The AET calculated by MIKE-SHE for the same 5 year period was 1% lower than measured in May, 9% higher than measured in June, 3% higher in July, 8% higher in August, and 28% higher in September.

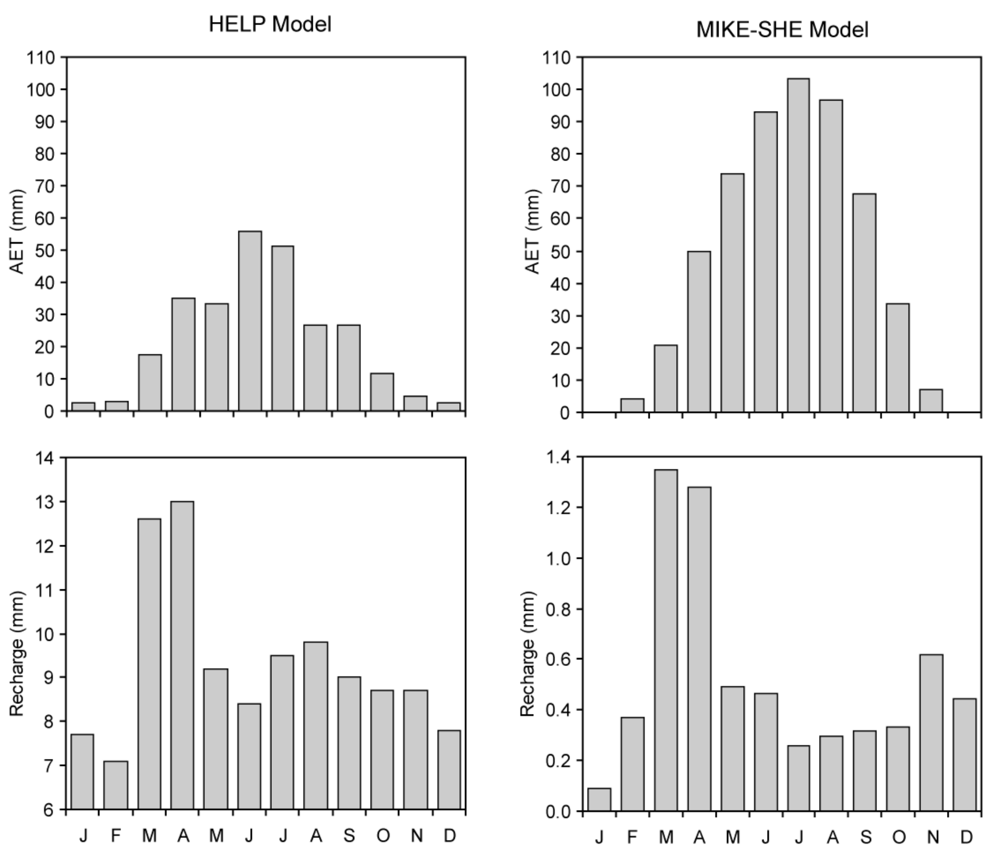

Figure 2: Mean monthly actual evapotranspiration (AET) and groundwater recharge predicted by the HELP and MIKE-SHE models. Note similarity of AET axes and difference in recharge axes.

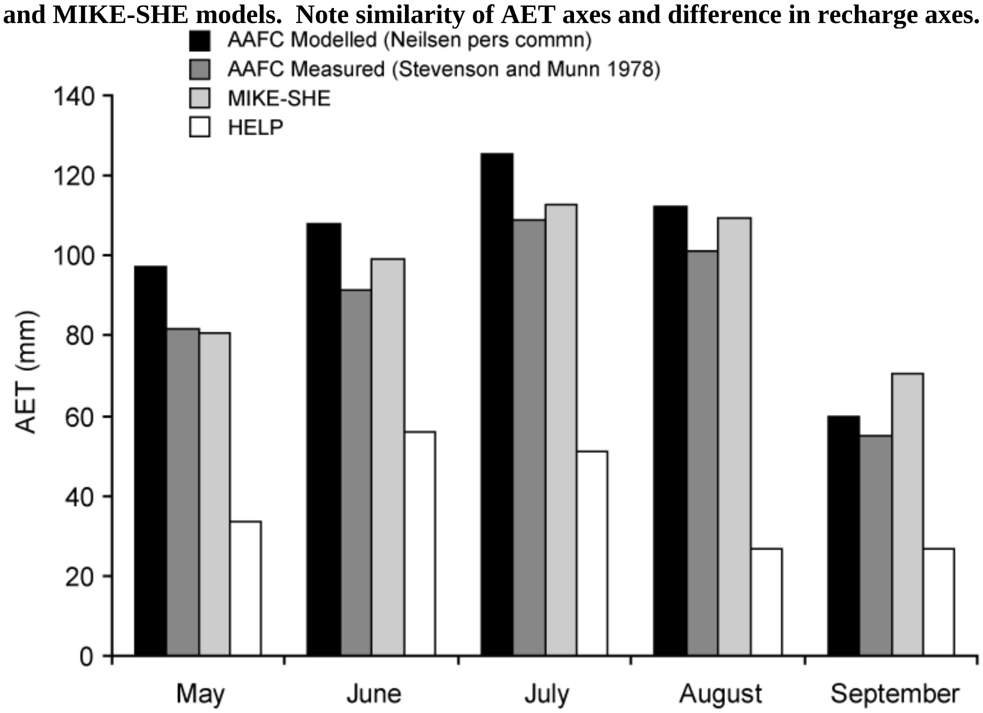

Figure 3: Comparison of AET estimates for the Vernon area.

For the 1961 to 1990 period, mean annual recharge across the entire valley bottom area was predicted to be 6 ± 8 mm by the MIKE-SHE model and 109 ± 40 mm by the HELP model. These averages correspond to 1.3% and 24% of the average annual precipitation for the MIKE-SHE and HELP models, respectively. Although there was a difference in the absolute value of recharge between the MIKE-SHE and the HELP models, a comparison of the monthly distribution of recharge in the Vernon area suggests that the timing of recharge throughout the year is similar (Figure 2). Peak groundwater recharge rates occur in March and April, and decline throughout the summer months as LAI and simulated AET increase. The spatial distribution illustrates that the widest variability of recharge occurs across the valley floor (Figure 4), which is predominately composed of silty loam soils over alluvial sediments that have a shallow rooting zone. For valley margins, where the soil texture is coarse and root zone depth is deeper, groundwater recharge was predicted to be consistent for each month (Figure 4).

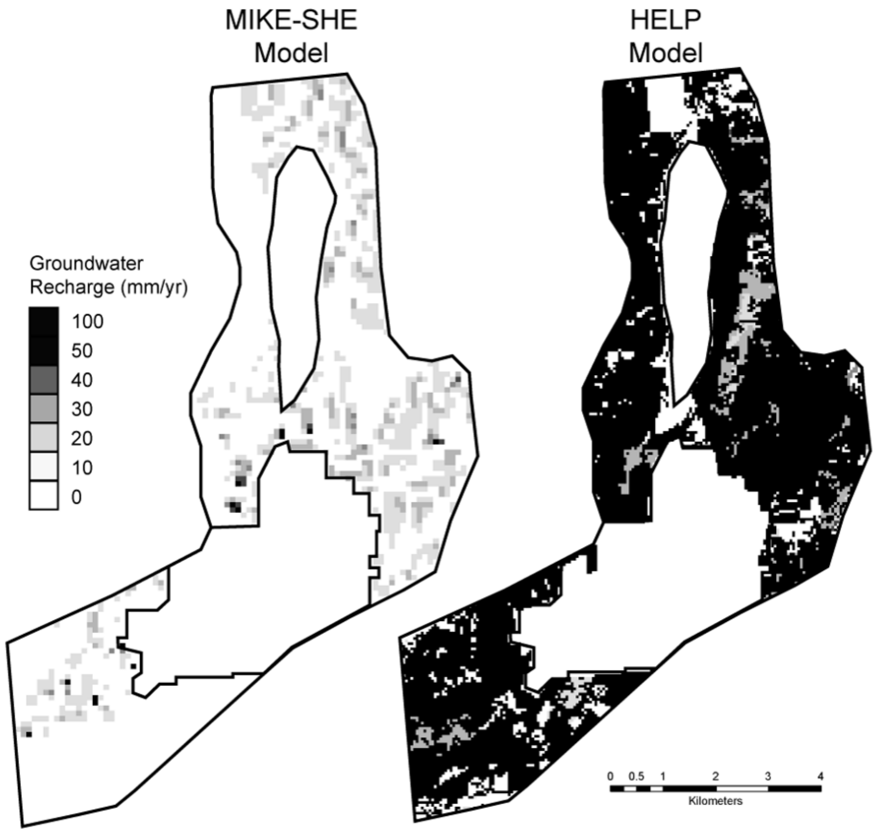

Figure 4: Mean annual groundwater recharge predicted by HELP and MIKE-SHE models.

Upland Recharge

The mean upland water budget residual for winter, spring, and summer seasons was +40, +130, and -135 mm, respectively, where positive values indicate water surplus conditions and negative values indicate water deficit. The standard deviation (61 mm) and absolute range (+/- approximately 125 mm) were highest for the spring season, indicating a sensitivity of water budget to annually variable snow accumulation. Annual water budget residual values varied from -117 to +156 mm/yr, with an overall average of 35 mm/yr for the 1961 to 1990 period. These residual values include the sum of errors and components not considered in the simple water budget calculation, which in this case would be inclusive of groundwater recharge. While a robust error analysis was not completed, the overall average value of 35 mm/yr represents a suitable first-order approximation for broad-scale recharge rate for the upland areas. Thus, 35 mm/yr was assumed to represent broad-scale upland area recharge, and was further sub-divided into four zones based on the elevation bands, for inclusion in the watershed-scale flow model. Values increased from 20 to 50 mm/yr with increasing elevation (Figure 5).

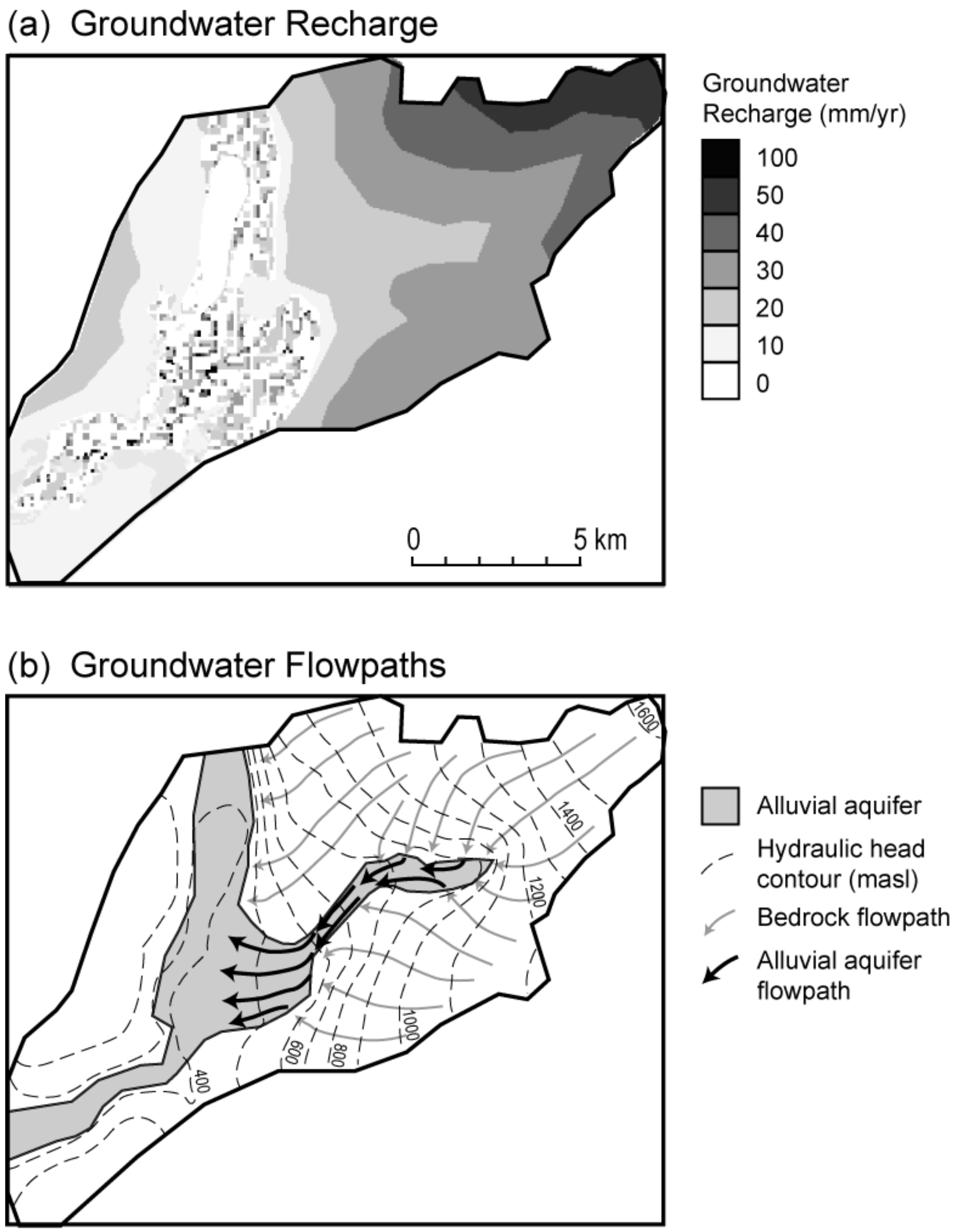

Figure 5: Distribution of annual groundwater recharge for BX Creek watershed and contours of simulated hydraulic head (100 m interval) from the watershed-scale flow model.

Watershed-Scale Groundwater Flow

The intent of the watershed scale flow model was to combine the most realistic values of direct recharge for the valley bottom and uplands areas, with realistic hydraulic properties for the subsurface. The groundwater flow model was run under steady-state conditions and compared with known hydraulic head data from the BC WELLS Database (Ministry of Environment 2006). Simulated hydraulic heads appeared to follow topography (Figure 5) and compared moderately well to the water well data (normalized root mean square error was 3.6%). For the 1961 to 1990 period, the average low flow condition to BX Creek was approximately 2590 m^3/day, and simulated groundwater discharge for the upland creeks was 2332 m^3/day (90% of average low flow). These results indicate that the groundwater flow model adequately represents the watershed scale groundwater flow regime, and is useful for the determination of water budget components.

Groundwater flow to the valley bottom from the uplands occurred along the eastern boundary of the Swan Lake Valley, and either traveled through (a) the alluvial aquifer (3127 m^3/day, 74% of the subsurface flux), and (b) the adjacent bedrock deposits (1101 m^3/day, 26% of the subsurface flux). In addition to these subsurface pathways, direct groundwater recharge was found to be an average of 6 mm/yr for the valley bottom (from MIKE-SHE results; 1211 m^3/day). Therefore, recharge to the valley bottom aquifer is from a combination of subsurface groundwater flux from upland areas (Figure 5) and direct recharge to the valley bottom (Figure 4). The majority of water appears to flow through the alluvial fan, which would be derived from bedrock groundwater in the headwater of BX Creek (i.e., captured from the uppermost portion of the watershed), and seepage loss from streamflow occurring in the vicinity of the stream gauge.

Discussion

HELP vs. MIKE-SHE for Predicting Recharge

Estimating groundwater recharge in semi-arid regions can be challenging due to the complexity of hydrological processes occurring in the rooting zone, which depend on balances of energy and moisture. Once infiltration passes the rooting zone, groundwater recharge is a transient process, and deeper percolation is governed by distribution of soil moisture gradients, gravity drainage, and capillarity. In this study, mean annual direct (diffuse) recharge was estimated from two different models, and lateral recharge (from upland sources) from a watershed-scale flow model. The 1D water balance approach of the HELP model is less computationally intensive than numerical models of infiltration based on Richards' equation (e.g., MIKE-SHE), and is especially useful for climate change studies, where different forecast scenarios could be readily implemented (e.g., Scibek and Allen 2006). However, the process of infiltration and deep percolation modelled in HELP does not account for transient soil moisture retention and upward migration of moisture by capillarity. Furthermore, the HELP model also appeared to under predict AET in this study area, which is consistent with findings from other studies of recharge in semi-arid regions (Scanlon et al. 2002a).

For the years 1967 to 1971, mean flux at the water table was actually found to be negative in the MIKE-SHE simulation, indicating an upward migration of water from the water table into the soil column. Upward flux of moisture from water table depths of up to 4 m are not uncommon in sub-humid or semi-arid environments (Smerdon et al. 2008), and will be important when developing basin-wide water budgets. For the Vernon area, these non-recharge conditions were caused by lower than average precipitation from 1965 to 1970 (less than 400 mm for each year), and illustrate the impact of drought on groundwater resources for the region. These findings illustrate some of the challenges associated with modelling recharge in semi-arid regions, and especially highlight the importance of explicitly considering unsaturated zone processes in recharge models (Keese et al. 2005) for inclusion in basin-wide water balances (Hunt et al.

2008). Furthermore, the discrepancy between different methods of modelling recharge should be investigated, to better define an adequate approach for the Okanagan Basin.

Diffuse vs. Lateral Recharge to Valley Bottom Aquifers

With the aid of a watershed-scale flow model, the relative contribution of water sources were quantified for the Swan Lake Valley, considering all three of the recharge mechanisms (i.e., stream seepage, bedrock groundwater flow, and direct recharge). The majority of recharge (57%) to valley bottom aquifers occurs due to the presence of an alluvial fan and narrow aquifer that extends up the BX Creek valley. This landscape feature acts as a large-scale preferential pathway to transmit groundwater (and seeping surface from BX Creek) to lower areas in the watershed. The remainder of recharge occurs nearly equally from lateral flow through the bedrock (20%) and directly to the valley bottom area (22%). The presence of the narrow alluvial aquifer and BX Creek valley across the benchland area is a unique hydrolgeologic deposit that forms a subsurface capture zone for upland groundwater (Winter et al. 2008). Results from steady state flow models are typically considered non-unique, and equivalent results could be replicated with different recharge and K values (Jyrkama and Sykes 2007). However, groundwater recharge rates were calculated a-priori to the flow model, the hydraulic heads and groundwater discharge flux rate compared well with measurements, and the K values are appropriate for the conceptual flow model.

Highland plateaus, mountain peaks, and inter-basin valleys develop over millions of years, with a tectonic history (possibly including glaciations) that have produced complex deposits of sediments and rock formations, which form aquifers and aquitards. Quantifying the magnitude of groundwater flow through mountain blocks and predicting recharge relies on hydrogeologic data that are generally sparse in mountainous terrain. However, understanding the linkage between mountain water sources and aquifers, and predicting recharge, is required to manage groundwater resources. At the transition between mountainous uplands and valley lowlands, stream and river discharge often decreases, and groundwater recharge increases (Covino and McGlynn 2007). The findings of this study indicate that the majority of recharge to valley bottom aquifers can be expected to originate from adjacent areas (i.e., lateral recharge). Whether this will occur from stream seepage (i.e., losing rivers at the upland to lowland transition) or from flow through bedrock, will depend on characteristics of the mountainous watershed. Thus, the question of how much lateral recharge will occur is yet unresolved. This study suggests that the challenge of estimating lateral groundwater flow could be greater than estimating recharge directly to the valley bottom.

Conclusions

Estimating groundwater recharge rates in mountainous terrain is challenging due to limited data to support common recharge modelling methods. In this study, the HELP and MIKE-SHE models utilized the same data for the valley bottom area, and predicted significantly different results. It appears as though HELP under predicted AET, which resulted in an over prediction of recharge, which was most significant in the summer months. The Richards' equation based approach of MIKE-SHE resulted in AET and recharge results that appeared reasonable, yet required more extensive parameterization for the soil columns. This more robust technique of modelling unsaturated flow (and AET) appeared to better represent the recharge process. However, for the Vernon area, the majority of recharge occurred laterally from groundwater (and surface water) in close connection with BX Creek and the narrow alluvial aquifer. Therefore, although careful consideration must be taken when choosing a method for direct (diffuse) recharge, more consideration must be taken when conceptualizing and quantifying the input from upland water sources. Thus, from the perspective of water resource management, and developing a comprehensive water budget, the key to assessing groundwater recharge for the Okanagan Basin will be defining upland-to-lowland characteristics for common watershed types (Neilson-Welch, in progress). Through a comprehensive understanding of hydrogeologic processes in targeted, instrumented watersheds, indices could be developed for broad-scale applicability.

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Source Protection and the Future of Safe, Clean, Reliable Tap Water in the Okanagan Valley

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* The views expressed in this document are those of the authors and not necessarily of Interior Health. Any errors are the sole responsibility of the authors'.

Abstract

Safe, clean, and reliable tap water is essential for the prosperity and health of all communities in the Okanagan Valley. A multiple barrier approach is the best means of addressing the numerous challenges to supplying safe drinking water in this fast growing, water limited region of British Columbia. A multiple barrier approach recognizes and applies efforts at all points where risks to drinking water and public health can be reduced. Source protection is a core element of the multiple barrier approach. As is the case for most regions in British Columbia, the needs of Okanagan communities make exclusion of human activity and dedication of entire watersheds for the sole purpose of providing drinking water typically unfeasible. Thus, successful source protection for most hinges on integrated watershed management to control potential threats to drinking water and public health. The ultimate vision is that everyone (including water suppliers, industry, land use agencies, and the public) has the information and opportunity they need to be empowered stakeholders in drinking water management. Collaborative efforts of water suppliers, government, and other watershed stakeholders have resulted in improvements. However, without source-to-tap water system assessments to characterize health risks and support a comprehensive approach to drinking water management, efforts to protect drinking water sources in the Okanagan will undoubtedly fall short.

Introduction

Located in the southern interior of British Columbia (Figure 1), the Okanagan Valley is home to over 325,000 people (BC Statistics, 2008), and with its lakes, ski hills, and warm climate serves as a world-class, year-round tourist destination. It is also one of the driest watersheds in Canada (Stats Can, 2003). As such, water has traditionally been a most valuable resource for health, nature, agriculture, economy, and recreation. But even in the Okanagan drinking water is sometimes taken for granted; when turning on the tap we expect safe, pleasant tasting water. Tap water delivers public health, fire protection, economic development; it is an essential element to overall quality of life. When you consider the critical needs tap water addresses, it has an incredible value; some might consider it a bargain!

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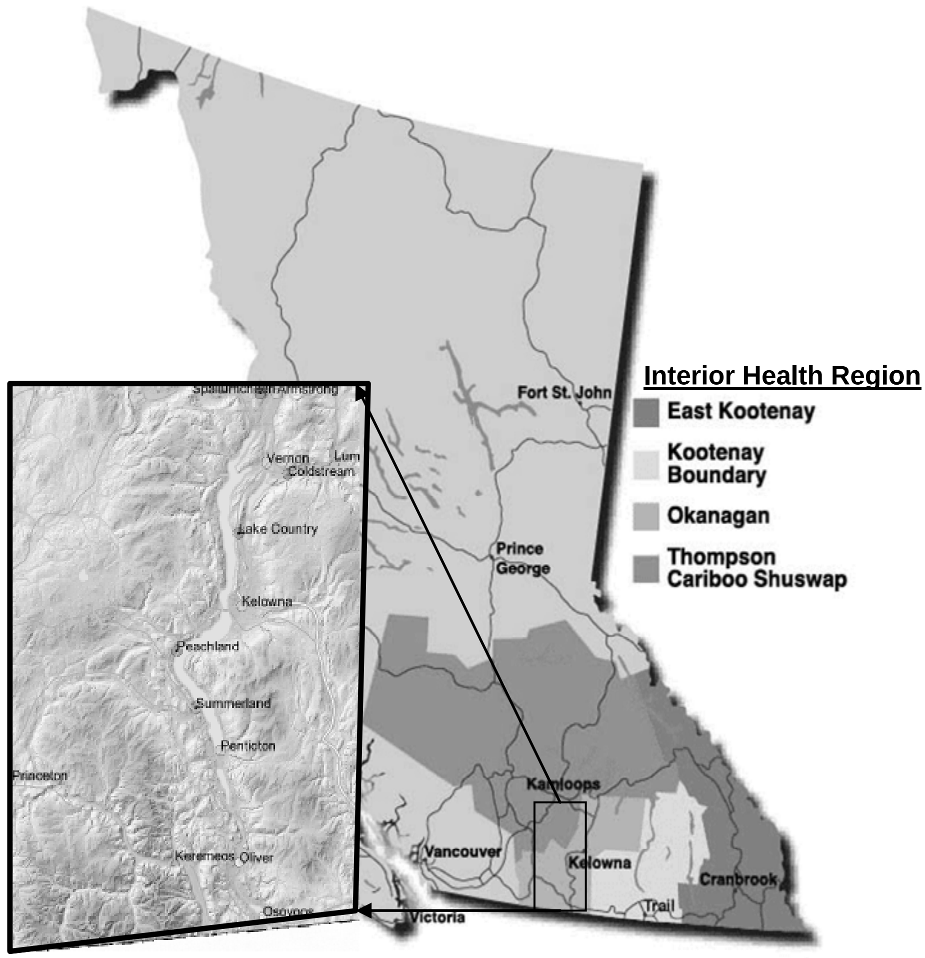

Figure 1: Okanagan and Interior Health Region.

To have an adequate supply of safe water for everyday drinking, cooking, and all other domestic uses, it is essential to ensure it is properly protected. The link between water supply and disease, particularly from microbial pathogens, is well recognized (CCME, 2004; NHMRC/NRMMC, 2004). At greatest risk are the immunocompromised, young children and the elderly (BC-PHO, 2001). The first responsibility of all water suppliers must be the provision of continual access to clean, safe and reliable tap water.

This paper explores the role of source protection in a multiple-barrier approach to drinking water protection. Supported by observations of source protection efforts in other regions of British Columbia and North America, key elements for defining and overcoming obstacles to source protection in the Okanagan Valley are identified.

Multiple-Barrier Approach to Protecting Drinking Water in the Okanagan

No single barrier can be 100% successful 100% of the time against all potential hazards. A recognized universal standard for drinking water protection, the multiple-barrier approach is an effective way to reduce the risk of illness from drinking water contamination to acceptable levels (Figure 2) (NHMRC/NRMMC, 2004; CCME, 2004). Multiple barriers compensate for short term reductions in performance of any individual barrier, thus providing a greater assurance that the water will be safe to drink over the long term (CCME, 2004; Hrudey & Hrudey, 2004). The components of a multiple barrier approach differ slightly between jurisdictions, but always include the following key elements:

- Source selection and protection (high-quality, protected water source)
- Appropriate water treatment (as determined by source characteristics and risks)
- Water distribution system protection (secure with appropriate monitoring)
- Water quality monitoring (including timely, appropriate response to adverse results)
- Financing and governance (engaged, supportive management and regulatory oversight)

These elements must be managed in an integrated manner and be supported by vigilant, qualified operators (Hrudey, 2003).

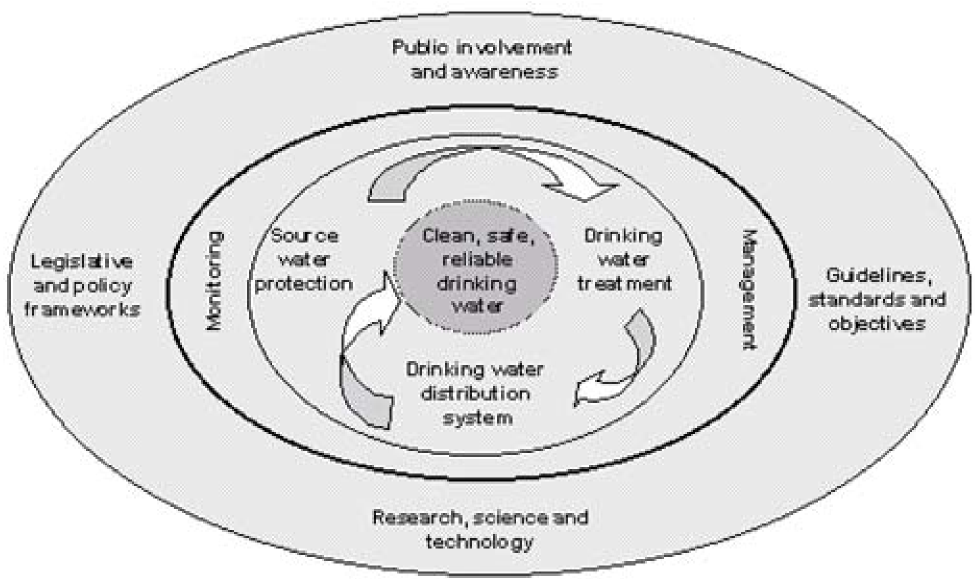

Figure from:
Federal-Provincial-Territorial Committee on Environmental and Occupational Health
Canadian Council of Ministers of the Environment
From Source to Tap – May 2002

Figure 2: Multiple Barrier Approach to protect drinking water.

Several factors hinder water suppliers' pursuit of providing the elements of a multiple-barrier system in the Okanagan, including:

- Multi-use watersheds and a multi-agency regulatory environment;
- Residential development based on systems originally built to support irrigation;
- Emerging threats (e.g. protozoan parasites *Cryptosporidium* and *Giardia*);
- Climate change (e.g. changing seasonal and extreme weather patterns);
- Competition with home treatment and bottled water industries; and
- Multiple water supply systems with differing governance structures

When considering how to move forward with improving drinking water safety, it is important to recognize that in terms of the ultimate goal (i.e. protecting public health) not all barriers are of equal importance. In their 2002 report on safe drinking water, the Network of Environmental Risk Assessment and Management (NERAM) made the following observations and recommendations for enhancing robustness of drinking water systems in Canada:

- Health risk is a direct function of raw water quality; as such source characterization and protection should be the basis of providing safe drinking water;
- Source protection can not be relied upon to provide significant improvements over the short-term nor absolute protection; as such, initial focus should be on upgrading treatment, monitoring, and emergency response;
- Robustness of water sources, treatment operations, institutional, and human elements of water systems all need to be evaluated when assessing water supply systems; and
- Distribution protection is important, but is typically of a lower importance and cannot counter the effects of inadequate treatment (Hrudey, 2003)

Since proclamation of the BC Drinking Water Protection Act and Regulation in 2003, in the Okanagan regulators have focused on critical improvements to treatment, operations, and monitoring (Interior Health, 2007). In consideration of the long-standing (circa 1986) Canadian water quality guideline that filtration is provided for all surface waters (Health Canada, 2004), upgrading treatment on systems providing only chlorine disinfection has been a top priority. However, many suppliers have made other significant improvements including:

- Recruitment, training, and retention of certified operators
- Improved online monitoring and biological/chemical sampling programs
- Updated emergency response plans that are reviewed annually

Having taken these initial crucial steps to protect public health, attention is shifting towards the complex, difficult tasks of assessing water systems and source protection planning.

Source Protection

Selection and protection of a high quality water source is the first step in a multiple barrier approach and a cornerstone of safe, clean, reliable tap water (CCME, 2004). There are limitations to what protection can be achieved through watershed management alone; even the most pristine watershed from which human activity is barred still harbours contaminants harmful to human health. But by avoiding or controlling potential hazards before they enter the drinking water system, not only are threats to public health reduced but treatment and operational costs minimized (CCME, 2004) helping to achieve the provincial goal of smart spending for smart infrastructure (BC Gov., 2008). In some cases intake location and source protection can make a difference to the level of treatment required (e.g. filtration vs. disinfection alone) (e.g. Metro Vancouver's Coquitlam Source). More commonly, however, the economic benefits of source protection and improved water quality are decreased operation and maintenance costs (e.g. Metro Vancouver's Capilano and Seymour Reservoir sources).

With human activity in a drinking water source comes an increased risk of introducing hazards to drinking water supplies. Although mitigation (e.g. engineering; operations) and natural properties of the watershed (e.g. dilution; filtration) may reduce risk, if a hazard exists the risk it poses can never be eliminated with 100% certainty. As such, the only means to completely avoid risks from human activity is to exclude it. However, even in the absence of human activity, threats to quantity (e.g. drought) and quality (e.g. wildlife; mineral deposits; erosion) of drinking water may still exist. Focused management of the watershed is required to achieve the highest quality source water possible. Examples of this gold standard include the Metro Vancouver and Greater Victoria water supplies. The three watersheds supplying Metro Vancouver comprise a total area of over 580 km^2 to which public access is restricted and all activities are managed in the interest of protecting the one billion litres of water delivered daily (Metro Vancouver, 2008). Greater Victoria's Sooke Reservoir watershed is strictly controlled, including specific wildfire, wildlife, and security programs, for the purpose of providing safe water to over 300,000 residents (CRD, 2008). In both examples intakes are located at higher elevations, thus decreasing reliance on treatment while increasing distribution costs.

Exclusion of human activity from water supplies as a means of reducing risk to drinking water and public health seems intuitive. However, exclusion of human activity from water sources is not practiced for the majority of water supplies in North America. Communities and governments often allow forestry, agriculture, recreation, settlement, liquid waste disposal, among other activities, to occur in their drinking water supply areas. Whether a conscious decision or a product of ignorance, activities increasing risk of exposing the public to drinking water health hazards are permitted in the majority of watersheds in North America.

At first glance, it is easy to conclude that since drinking water is such a high priority all activities potentially impacting drinking water should be banned. However, the exclusion of all activities from a watershed is often not in the best interests of the community or public health. When considering the factors that determine the overall health of a community, physical environment is a key, but typically not the only (or even most critical), factor. The Public Health Agency of Canada currently recognizes a number of key determinants for public health (Figure 3), with physical environment (including access to safe, clean drinking water) listed as number six (PHAC, 2008). As such, when deciding on what activities should be tolerated in a watershed, the best interests of the community necessitates consideration of not only threats to drinking water but also the impact the proposed activity will have on economic and social well being. As stated by the British Columbia Provincial Health Officer, "*From a public health perspective it is often not necessary, nor in some instances even desirable, to ban all activities from watersheds providing drinking water in order to adequately protect public health. Instead, it is more important to understand the risks activities may pose and take steps to ensure the risks are adequately addressed within the multiple barriers*" (BC-PHO, 2001).

1. Income and Social Status
2. Social Support Networks
3. Education
4. Employment/Working Conditions
5. Social Environments
6. Physical Environments
7. Personal Health Practices and Coping Skills
8. Healthy Child Development
9. Biology and Genetic Endowment
10. Health Services
11. Gender
12. Culture

Adapted from www.phac-aspc.gc.ca (PHAC, 2008)

Figure 3: Public Health Agency of Canada – Determinants of Health.

So what is a reasonable level of protection to expect for drinking water sources? Each watershed and community is unique and, as such, it is difficult to establish a standard benchmark. However, from observation of communities with and without dedicated watersheds, the following three factors appear significant:

1. **Population Served –** shear number of people served is related to the value of drinking water production relative to other land-uses. As community size increases, the relative importance of activities in any specific watershed to the overall economic and social wellbeing of the community will tend to decrease.
2. **Available Water Sources –** of seemingly equal importance is availability of a suitable water source. Despite having large populations served by individual water systems, many urban centers in North America (e.g. New York City; Edmonton; Calgary; Toronto) do not have dedicated water supplies. Economic and political costs of obtaining and managing a dedicated watershed that may be located 100s or even 1,000s of kilometres away outweigh potential benefits. Conversely, there are a number of small communities in British Columbia (e.g. Revelstoke; Nelson) that enjoy highly protected sources due in part to the proximity of high yield, relatively undeveloped watersheds.
3. **Governance –** the way water supply systems and land use are managed and regulated impacts the level of protection achieved. For example, both Metro Vancouver and Victoria are served by a single, publicly-owned water supplier that has the financial and political capacity to acquire and manage a large watershed. New York City's aggressive source protection campaign is in large part a response to pressure from their regulator (the US Environmental Protection Agency) (NYC-DEP, 2008). In New Hampshire, legislation is available to bar activities that may cause adverse impacts to water quality in drinking water supply areas (NH-DES, 2008).

Given the common reality of integrated-use watersheds, best practice for protecting drinking water sources is typically the provision of transparent, evidence-based management of watersheds to ensure the appropriate allocation of resources (e.g. increased operation costs; land reserves to provide natural treatment processes) (O'Connor, 2002; Hrudey, 2003; CCME, 2004). Integrated watershed management (and the related ecosystem-based or place-based management approaches) strives to comprehensively address physical and biological issues to achieve locally-established goals and objectives. These local goals and objectives are determined based on watershed characteristics, public needs, and regulatory/resource management considerations (Hartig, 1995). This approach requires a thorough understanding of the water systems and watersheds involved. Without this understanding, the ability to characterize risks, identify options (e.g. limiting land-use vs. relocating intakes vs. increasing reliance on treatment) and assess costs and benefits is severely limited.

The primary focus of protecting drinking water sources in an integrated watershed management approach is typically to ensure water receives treatment through the natural environment to achieve the best quality possible before entering the water supply system. This approach is consistent with current provincial direction to utilize natural processes for water treatment as much and whenever possible (BC Gov., 2008) and is typically achieved through:

1. Maintaining natural function of the watershed through good land-use practices (e.g. riparian area and stream corridor protection; rainfall runoff management),
2. Location and design of intakes (e.g. utilizing natural barriers), and
3. Appropriate monitoring and enforcement of activities in identified sensitive areas (e.g. source protection zones).

Source Protection in the Okanagan

Rapid population growth, climate change, and increased expectations for public health protection are all factors pushing water to the forefront in the Okanagan Valley (OBWB, 2008). The bulk of the population in the Okanagan receive their domestic water from one of 28 large (greater than 300 connection) water systems, most of which draw water from the large valley lakes and/or one of the 26 upland community watersheds. Unfortunately, although a few benefit from relatively under-developed watersheds (e.g. City of Armstrong's Fortune Creek source), at this time none of the communities in the Okanagan enjoy the gold standard of a watershed dedicated exclusively for the production of drinking water. It is beyond the scope of this paper to assess why each individual system and/or community has not achieved this standard. However, a cursory assessment suggests that the three factors identified in the previous section play a role in the current state of source protection in the Okanagan. For example:

- **Population Served –** Kelowna, the largest population centre with over 100,000 permanent residents, is served by five different water systems with distinct sources. As a result, the relative importance of each of the water sources is diluted over the entire population. Greater Vernon Services water system (with plans for Duteau Creek to be primary water supply to over 50,000 (GVS, 2006)), and the City of Penticton (which uses Penticton Creek as a source for over 38,000 (City of Penticton, 2007)) have the next greatest potential political/economic influence.
- **Available Water –**with its relatively under-developed upland watersheds (Turner *et al*., 2006), water sources would not seem an insurmountable barrier to achieving optimal source protection. However, development patterns, including a historical focus on irrigation for some areas, has contributed to the use of valley bottom sources. Coordinated water system planning, focused management of upland sources (e.g. reservoir construction), and demand

side management could make dedicated upland watersheds a realistic alternative in some cases.

- **Governance –**Patrick *et al*. (2008) provided a detailed review of the regulatory structure supporting source protection in the Okanagan. Key findings included:
  1. Direct water supplier engagement in watershed management brought about measurable, sustained improvements in drinking water source protection, and
  2. A lack of co-ordination and engagement at the provincial agency level posed a significant obstacle to source protection.

  The conditions observed by Patrick *et al.* are likely in part due to a poor link between water system management and land use governance in the Okanagan. Even in cases where local governments are the water suppliers, consideration of drinking water in land use approvals has often been inconsistent or ineffective. For example, Greater Vernon Services has been active in the Duteau Creek watershed for many years working collaboratively with other stakeholders (e.g. forestry companies, range users) to better protect their source. However, they have experienced difficulty in achieving a high level of protection due in part to a perceived lack of support from provincial agencies responsible for regulating land-use and drinking water (GVS, 2008).

Forestry (as demonstrated by the numerous mills throughout the valley) and agriculture (producing 25% of total crop by value in BC (Turner *et al.* 2006)) have historically provided the economic foundations for Okanagan communities. More recently settlement (population projected to exceed 425,000 within 30 years (BC Stats, 2008)) and tourism (~25,000 tourism jobs linked to tourism in region (Okanagan Partnership, 2004)) have increased in importance. As is the case with most other areas of BC (BC Gov., 2008), the importance of these sectors makes integrated use of watersheds a preferred scenario despite the potential threats to drinking water and public health.

Integrated watershed management to control risks to drinking water needs efficient, effective collaboration at all levels to be successful. Cooperation and planning between provincial (e.g. Southern Interior Regional Drinking Water Team) and regional (e.g. Okanagan Sustainable Water Strategy) agencies along with focused planning for priority areas/issues (e.g. Shuswap Lake Integrated Planning Process (FBC, 2008); East Kootenay Integrated Lake Management Partnership) serve to break down the historical barriers to source protection identified by Patrick *et al.*. However, real protection of drinking water resources on the ground requires engagement and commitment of those who live and work in the watersheds. To ensure continuity and a focus for drinking water at a local level, water suppliers (and by extension the customers they serve) must be engaged, empowered advocates for drinking water in their watersheds.

Comprehensive, transparent, evidence-based assessments (Figure 4) characterize the hazards and events that can compromise drinking water quality while identifying and evaluating options for addressing risk to health. This information also serves to empower water suppliers in the management of their watersheds. Defensible evidence of health risks provides a basis for fair, evidence-based application of legislation to protect drinking water and public health. It is also a necessary component for area specific governance models (e.g. Water Management Plans under the Water Act; Drinking Water Protection Plans under the Drinking Water Protection Act) in cases where existing legislation proves inadequate.

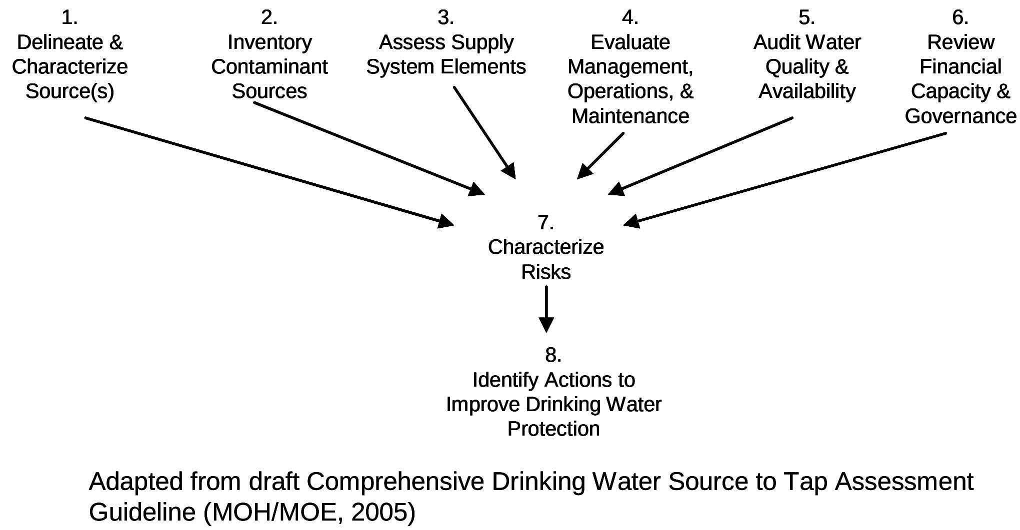

Figure 4: Drinking water risk assessment process.

The shift of regulatory focus towards drinking water source protection in the Okanagan is still in the relatively early stages. To date the attention to, and validation of, concerns regarding risks to community water sources is resulting in improved range-use (e.g. installation of off-stream watering; upgrading of fencing in sensitive areas), industrial practices (e.g. direct collaboration with water suppliers), and recreational practices (e.g. off-road vehicle trail management planning). However, the lack of comprehensive water system assessments remains a common obstruction for source protection efforts.

Without a firm understanding of all components of the water system (including water source, treatment, financial capacity, and governance), identification and assessment of all options to improve and protect source water quality can not be done. Taking the time to conduct comprehensive assessments and planning can frustrate those who yearn for immediate improvements to drinking water source protection, but responsible drinking water management requires consideration of all water system elements. The future of clean, safe, reliable tap water in the Okanagan depends on it.

Conclusion

Source selection and protection is the first step of the multiple-barrier approach to safe drinking water and a cornerstone for the future of safe, clean, reliable tap water in the Okanagan Valley. To achieve this goal, integrated watershed management to reduce risks to drinking water sources is required. Once critical inadequacies in treatment, monitoring, and emergency response are addressed, water suppliers need to provide source-to-tap assessments of their systems to support comprehensive water system planning. Defensible evidence regarding specific health risks posed will facilitate effective source protection planning and allow water suppliers to be empowered stakeholders in management of their water supplies. Although excluded watersheds managed solely for the purpose of providing drinking water may not be achievable for all, a collaborative, integrated-watershed management approach is a goal worth striving for.

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Water Sustainability under Climate Change and Increasing Demand: a One-Water Approach at the Watershed Scale

Adam Wei

Abstract

Water will become Canada's foremost ecological crisis early in this century (Schindler, 2001). A watershed based approach for water management is repeatedly suggested to address water sustainability issues. However, full implementation of such an approach is seldom realized. Achieving a full understanding of total water resources (climate, surface water, shallow and deep groundwater etc.) and their interactions at a watershed scale is a major barrier. We have recently obtained NSERC strategic funding to take a one-water perspective to evaluate watershed sustainability under climate change and increasing socio-economic drivers of water demands (agriculture and population) in the Deep Creek watershed (306 km^2), located in the Okanagan Basin of the semi-arid southern interior of British Columbia. The suitable watershed size and significant water conflicts among water users make this watershed an ideal place for this interdisciplinary research. The purpose of this presentation is to describe our methodology and the research significance.

A combination of geo-chemistry and integrated watershed modelling (MIKE SHE or others) will be used to quantify the total water resource, surface water – groundwater connections and the watershed response to various water stressors. A Canadian Land Surface Scheme (CLASS) model will be used to improve estimation of spatially varied groundwater recharge for model calibration. In addition, future agriculture water demands will be projected using both environmental and economic drivers (changes in product prices, climate, water pricing policies, and water use regulations) rather than based on simpler trend projections. This study is novel in its quantitative integration of the physical and human dimensions of water use at a watershed scale, enabling adaptive management responses to climate change and increasing demand impacts.

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Water Markets and Good Watershed Governance: An Inherent Conflict?

John Janmaat

Abstract

From Alberta to Australia, watershed governance is incorporating greater degrees of individual responsibility, sometimes expanding the scope for trading water rights. While the British Columbia Water Act does not preclude the trading of water rights, the current distribution of those rights rules out this option for most water users. However, following the Australian example, Okanagan water purveyors can facilitate water trading among those they service, providing water users with greater flexibility in managing their water use. Among irrigators, most are very uncomfortable with the idea of selling water, and are uncertain about how it could be implemented. However, they also realize that there is a need for policy change, and support the use of incentives similar to those that a market for trading water rights would provide.

Introduction

I presented a paper at the 2005 conference “Water – Our Limiting Resource,” where I made the case for an extensive revision of the BC Water Act that would expand the scope for water trading. The audience was polite enough not to throw me in the lake. This paper is a bit less radical, arguing that the pieces are already in place to implement an Australian style water market in BC. Further, such a market could do more to both enable the main water users – irrigators – to earn the most from their water and protect water for specific uses like agriculture. In so far as these are our goals, increasing the role of water markets is not only consistent with good watershed governance, it would improve that governance.

Ethical and environmental goals are often thought to be at odds with economic efficiency, and sometimes this is even true. Protecting ethical and environmental goals in the face of an economic system that does not directly promote them is like buying insurance. While insurance does protect us from undesirable outcomes when they occur, we have to pay for it whether they do or not. The best insurance policy is that policy which gives us the protection we want, at the lowest cost. Likewise, the best policy, the best way to manage water resources, is that policy which achieves our ethical and environmental goals at the lowest possible cost. For policy, this cost is often as foregone opportunities which generate less value for the community.

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There are a variety of ways to achieve our ethical and environmental goals. At the Socialist extreme, government could tightly regulate all activities. However, while this may protect the environment and ensure those most vulnerable are protected, it typically does so at tremendous economic cost, and conflicts with other social values such as freedom and autonomy. At the Libertarian extreme, government abandons all pretext of acting to protect ethical and environmental goals, leaving it to the voluntary action of concerned citizens. A properly constructed and managed water market, similar to that in place in Australia, occupies neither extreme. A water market fosters autonomy and creativity, enabling water users to find the best uses for our scarce water. An appropriate distribution of the tradable water rights and regulation governing their transfer will better promote our ethical and environmental goals. We await but a trial to demonstrate the viability and practicality of such reforms here in the Okanagan.

Governance

To examine whether or not a water market is consistent with good watershed governance, a definition of governance is required. From Wikipedia:

> Governance relates to decisions that define expectations, grant power, or verify performance. It consists either of a separate process or of a specific part of management or leadership processes. Sometimes people set up a government to administer these processes and systems.
> (http://en.wikipedia.org/wiki/Governance)

We are herein interested in the governance of water resources in the Okanagan Basin, and in particular good governance of those water resources. Is the current distribution of rights and authority with respect to water resources in the Okanagan that the best way to achieve our collective goals? This issue is examined at length in the Commonwealth of Australia Productivity Commission (2003) research paper "Water Rights Arrangements in Australia and Overseas," which informs much of what is discussed below. Further background can be found in Shaw (2006); and Kemper et al (2007) analyse the evolution of watershed governance in a number of river basins around the world.

In British Columbia water is the property of the province and individual entities (persons, businesses, communities, etc.) can be granted a usufructuary right – a right to use the water and keep the profits earned – through the granting of a water licence. From the Water Act:

> **2** (1) The property in and the right to the use and flow of all the water at any time in a stream in British Columbia are for all purposes vested in the government, except only in so far as private rights have been established under licences issued or approvals given under this or a former Act (British Columbia, 2008).

This type of water right is typical for western North America, with the comparable clause from the Alberta Water Act being:

> (2) The property in and the right to the diversion and use of all water in the Province is vested in Her Majesty in right of Alberta except as provided for in the regulations (Alberta, 2008).

There are very few ways that water can be used that does not have impacts on persons other than the user. Interceptions and diversions impact downstream users, return flows likewise impact those located where returns occur, both can affect ecosystem services, and pollution can impact all users forced to accept polluted water. The complexity of these interactions, the difficulty in managing them, and the fact that water is essential suggest that ownership of this resource should not leave the public realm. Maintaining water ownership in the public realm is therefore consistent with good governance.

The question is then whether or not the management of these usufructuary rights is consistent with good governance. Water licences are very specific. They provide the holder of the licence with the right to use a specific quantity of water for a specific activity at a particular location. If a licence holder does not make use of the water prescribed in the licence for a period of three years, the licence can be cancelled. Water licences also provide a priority ranking, such that if there is a shortage, those with the lowest priority must go without first. These aspects of water rights can conflict with equity goals and maximizing value to the community.

Since the amount of water available differs every season, a method of dealing with these fluctuations is necessary. Prior appropriation, "first in time, first in right," manages these risks by putting the burden on those with the most junior rights. As a result, it is much safer for those with senior rights to make investments that rely on a secure supply of water, and consequently they also reap the greater profits that these investments can return. If changes in technology or market conditions favour activities that are better suited to the junior water users, it may be beneficial to exchange or otherwise transfer senior water rights. Prior appropriation may also conflict with certain ethical objectives, if we believe that the consequences of a natural water shortage should be shared by all water users. While water licence holders may choose to share the risk more equally, there is no legally binding reason for them to do so, and no guarantee that they will. This contrasts with the Australian system, where proportional appropriation rights prevail, entitling each water user a share of the total water available, in proportion to the rights held.

The fact that a water licence can be lost for lack of use creates a 'use it or lose it' problem, which can result in water being used for activities that generate little value, beyond ensuring that the owner does not lose the right. Since water is scarce, it does seem reasonable that licenced water must be used. However, it is also wasteful to use water for activities that generate little value. This is particularly true if the community would benefit by not abstracting the water at all. Facilitating the movement of water from low value uses to high value uses, including leaving it for the environment, would improve the state of water governance.

Water licences are also appurtenant to land, and designated for particular activities. The former means that it may not be simple to transfer a water licence to a different parcel of land, particularly if the transfer is temporary. The latter means that it is not simple to use water for something other than that for which the licence was issued. Tying the water right to a parcel of land seems reasonable in an arid region, where the land has little value without water. If the water right could be seized against the land owner's objections, without compensation, then this protection makes sense. However, our legal system is mature enough that this is unlikely to be an issue. Restricting water licences to specific uses is also problematic, as it prevents water from being directed towards its most valuable use. Put these two aspects together and we can lock in pattern of water use that is likely far from the one that makes the best use of the water. Add to this the 'use it or lose it' provision, and the problem may be even worse.

What partially justifies these provisions is third party effects. Water used at one location almost certainly has impacts at other locations. Moving a water licence may impact people other than those directly involved in the transfer. Likewise, particular classes of water use – particularly irrigation – may generate benefits beyond the profits captured by the rights holder. Good watershed governance must account for these third party effects. Preventing transfers and changes in use is one solution, although it is likely not efficient. Providing for those affected to demand compensation or otherwise ensure that their adverse effects are accounted for, while still allowing transfers to occur, would be superior.

Transferring Water Rights

While the transfer of water rights is not common, it does not violate the water act in BC or Alberta. The province of Alberta has recognized the potential benefits of water rights transfers, and is actively encouraging them. The 'Water for Life' strategy states that "Alberta must preserve the "first-in-time, first-in-right" principle for granting and administering water allocations, but water allocations will be transferable to ensure societal demands and needs can be met" (p6, Government of Alberta, 2003). Changing prior appropriation would harm senior water users and benefit junior users, inviting a political battle best avoided. However, transferability does not threaten any licence holder, and thus could be pursued. To facilitate water licence transfers, Alberta Environment has set up a "Licence Viewer" website "… for the convenience of individuals researching the potential of arranging a water allocation transfer, or for other purposes." (Alberta Waterportal, 2008). From the Alberta Water Act:

> 82(1) Subject to this section and sections 34, 81 and 83, on application, the Director may
>
> (a) approve the transfer of an allocation of water under a licence and, subject to subsections (6) and (7)(b), issue a new licence for the transferred allocation of water subject to any terms and conditions that the Director considers appropriate, including specifying in the licence the land or undertaking to which the licence is appurtenant, or
>
> (b) refuse to approve the transfer of an allocation (Alberta, 2008).

In practice, all water licences in Alberta do remain appurtenant to land. However, the transfer process is one of transferring that licence from one parcel of land to another, by application of the transferor and transferee to the director for the area where the transfer is to occur. It is implemented by modifying or cancelling the old licence and issuing a new one. Concerns about exporting water out of Alberta or between major water basins are addressed by ruling out such transfers.

While Alberta has taken the lead within Canada in publicly supporting the development of a water market, it is somewhat surprising that there is relatively little difference in the substance of the Alberta and British Columbia water act, with regards to the transfer of appurtenant water rights between parcels of land. In particular, the British Columbia Water Act (Part 2) states:

> **19** (1) On the application of the holder of a licence, approval or permit and on compliance by the holder and by the proposed transferee with the comptroller's or the regional water manager's directions as to giving notice, the comptroller or the regional water manager, on the terms he or she considers proper, may
>
> (a) transfer all or part of the rights and obligations granted and imposed under the licence, approval or permit from the holder to the proposed transferee, and
>
> (b) issue a new licence, approval or permit to the transferee or transferor, or both, and determine the appurtenancy of the licence, approval or permit.
>
> (2) Subject to section 11 of the *Water Protection Act*, the comptroller or regional water manager must not exercise his or her discretion under subsection (1) of this section to determine an appurtenancy that is not in British Columbia.
>
> (3) Despite subsection (1), if satisfied that no person's rights will be injuriously affected, the comptroller or the regional water manager may dispense with providing directions as to giving notice under subsection (1) (British Columbia, 2008).

Under the current act governing water in British Columbia, water rights can be bought and sold. For a transfer of appurtenancy to occur, the controller must be satisfied that persons who might be 'injuriously' affected have a chance to respond. The transfer must also not confer the appurtenancy to land that is outside of British Columbia. Within these provisos, the approval of a transfer seems to be largely at the discretion of the relevant manager. The largest difference with the Alberta Water Act is that it contains sixty paragraphs and sub-paragraphs outlining the application for transfer process, the conditions that must be satisfied if the application is to be considered, and how the transfer is to be implemented. In Alberta, if those seeking to trade their water rights satisfy the conditions set out in the Act, there is likely limited reason that the director could provide to refuse the transfer. By contrast, as the British Columbia legislation is currently worded, there seems to be less certainty that a requested transfer will be approved.

Structure of the Market

The advantage of a market for water is that it provides individual water users greater flexibility in the management of their business. An effective market will have a large number of potential buyers and sellers, none of which owns a disproportionate share of the market. With data from the BC Ministry of Environment (2008) Figure 1, Panel (a) shows the entities that hold the largest total volume of water licence in the Okanagan. No single licence holder has over ten percent of the water that has been licenced in the Okanagan. All but one of these entities supply water to other users, that one being a numbered company registered in Ontario (but associated with Vincor International in Oliver). However, this overview hides the fact that the Okanagan is composed of many different watersheds, and there may be limited opportunities to move water between them. Panel (b) of the same figure shows the share of the total licenced water volume for the twenty most important water sources on which licences are issued. While a number of these sources can be considered part of the same watershed, it is important to examine how the water licences are distributed on these sources. For these twenty most important sources, only three, the Similkameen River, Okanagan River and Okanagan Lake, do not have at least half of the licences owned by one entity. On a number of sources, there is only one licence holder. These include Inkaneep Creek (Osoyoos Indian Band, 22,626 Mm^3), Hydraulic Creek (South East Kelowna Irrigation District, 13,531 Mm^3), KLO Creek (South East Kelowna Irrigation District, 12,334 Mm^3), Robinson Creek (Regional District of Okanagan-Similkameen, 7,419 Mm^3) and Hardy Creek (South East Kelowna Irrigation District, 7,400 Mm^3). On the Similkameen itself, 47.64 % of the licenced volume belongs to the Similkameen Improvement District. Except for Osoyoos Lake, the largest licence holder on the remaining largest water source is a water distributor. The exception, Osoyoos Lake, has 59.33% of the licenced water volume held by the associate of Vincor International. Although these figures overstate the issue somewhat, it is clear that in most of the watersheds in the Okanagan, there are a small number of entities that hold the bulk of the licenced volume of water. Such a concentration is generally seen as incompatible with an efficient, competitive market.

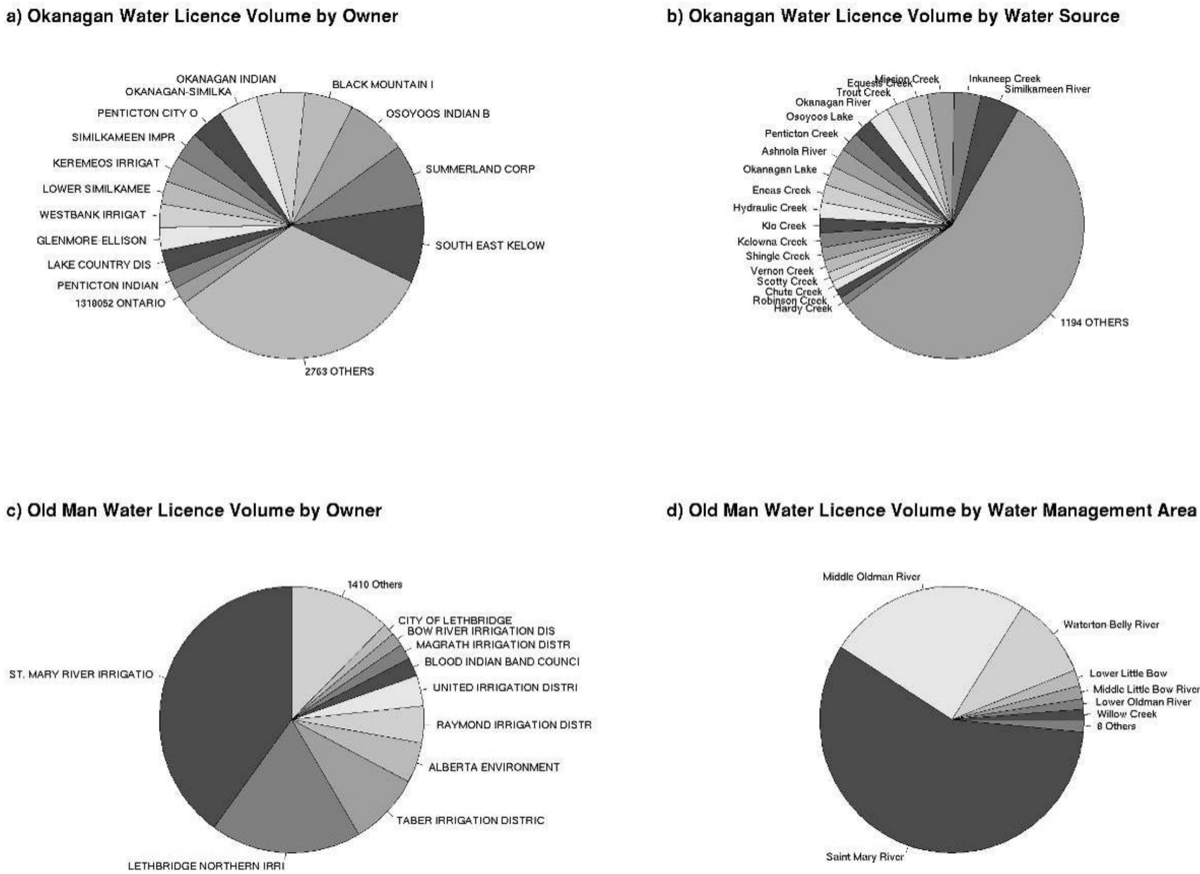

Figure 1: Okanagan watershed and Old Man River watershed licenced water volume, by major water licence holders and by major water sources.

It is interesting to consider the similar data for Alberta (Alberta Waterportal, 2008), in particular the Old Man River watershed. This part of Alberta has the greatest diversity of irrigated crops, and likely the greatest potential to gain from flexible water rights. Figure 1, Panel (c) shows the largest licence holders in the Old Man watershed, those who individually account for at least one percent of the total licenced volume. Within the Old Man watershed, concentration of water rights ownership appears to be even higher than in the Okanagan. While the BC government only reports the source on which a licence is granted, the Alberta data is organized by larger Water Management Areas (WMAs), which are sub-watersheds with multiple sources. Panel (d) shows the relative size of these WMAs. As for the Okanagan, on any one WMA, the ownership of licences is more concentrated than for the watershed as a whole. Again, these results suggest that the conditions for a competitive market are missing, making it questionable whether water trading can generate much of an increase in the economic benefits realized in the watershed, and practically provide individual water users with greater flexibility in their management decisions. Rather, for both British Columbia and Alberta, it appears that water rights trading is likely to be an instrument whereby large entities are able to rebalance their water holdings amongst themselves, with little scope for the small licence holder to be active in the market. Donna McColl (personal communication, August 12, 2008), a Senior Water Administrator with Alberta Environment indicated that there have only been 14 transfers of water licences between owners in Alberta since trading has been possible. To date, the reforms in Alberta have not resulted in a very active market for water rights.

The distribution of water rights in Australia is qualitatively little different. Bulk water licences are held by water purveyors (variously Irrigation Trusts, Irrigation Cooperatives, Water Companies, etc.) similar to arrangements in British Columbia and Alberta. However, water markets are active in Australia, and individual water users participate in these markets, using it to manage their water needs and shield themselves from drought risk. The large difference is that in Australia, the water purveyors essentially operate the water delivery infrastructure while water users themselves own a tradable water entitlement. Unlike water rights in British Columbia, these entitlements are for a share of the available water. Periodically throughout the season, the new water available in the system is determined, and the quantity corresponding to each entitlement calculated. This provides the individual water user with an amount of water 'in the bank' which they can draw down and use, or sell to another water user. Banked water can be carried forward between years. The water purveyor acts as the bank manager, recording each water user's balance and adjustments to that balance, from net inflows and water trades, as well as managing the delivery of water through the canal and pipe network. Figure 2 illustrates the role of water purveyors in the Australian context.

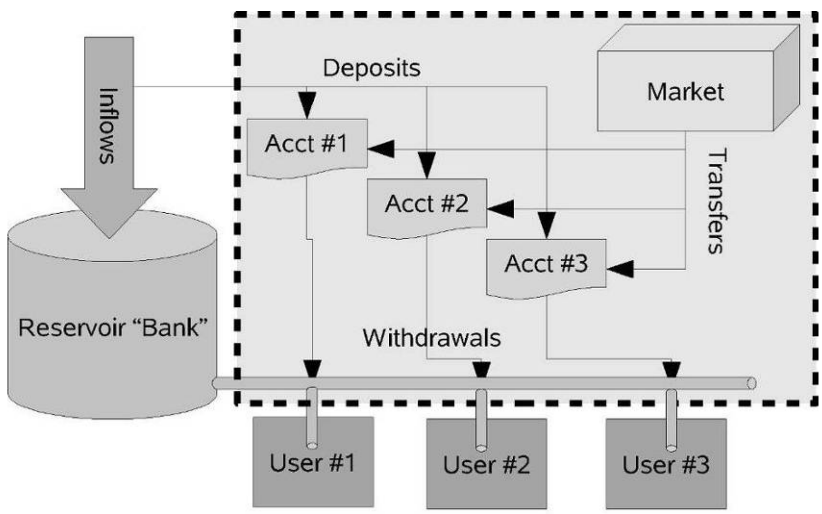

Figure 2: Schematic representation of the role water purveyors play in Australia.

Water purveyors in the Okanagan (irrigation districts, improvement districts, etc.) play a similar role to Australian water purveyors. They hold water licences, determine annual allotments for their customers based on available water, deliver the water and maintain the infrastructure needed to enable the delivery, monitor water use, and ensure that their customers operate within the established rules. The difference lies largely in the relationship between the water users and the water they use. In Australia, the water right belongs to the final user, and the purveyor acts much like an agent of the water user, managing the delivery of the water. This role is somewhat like a banker, who is responsible for safeguarding the monies deposited, but does not own those deposits. Okanagan water purveyors are more like water use managers than delivery service providers. In their role as managers, purveyors have determined a set of acceptable practices. When violations become a problem, the rules are tightened up. Okanagan water purveyor rules generally limit the flexibility that their customers have with respect to using their allotment. In particular, water users are not permitted to trade their allotments with each other, and generally are not permitted to move their allotment between different parcels that they own. Further, any water savings that occur provides the purveyor with more water to sell, in particular to sell to new land developments. In Australia, water savings give the water users more water to sell.

As a usufructuary right, there is some logic in the Australian approach that is absent in the Okanagan. Water purveyors do not use the water, their clients do. Being the ones that ultimately use the water, it is these clients who exercise the usufructuary right. However, in western Canada they are limited in how they can use that right, and thereby in realizing the full value that their right could provide. If the greatest value is to be generated from the water that the purveyors manage, the water users themselves should be given as much freedom as possible in how the water is used. The appropriate role for the purveyor should be to maximize the flexibility that the water users they supply have in the use of their water, provided that those uses satisfy the water act and other provincial legislation, and that other water users are not adversely affected. Given that Okanagan water rights are to a large degree concentrated with water purveyors, the greatest scope for water trading in the Okanagan is among those served by water purveyors – the Australian model.

The Okanagan water purveyors (and those elsewhere in British Columbia and Canada where the doctrine of prior appropriation applies) are in a unique position to facilitate water trading. The popular perspective on dealing with drought is that all should share in the cost of accommodating the water shortage, which is inconsistent with the exercise of prior appropriation water rights. Exactly what constitute the right way to share that burden may take some time and effort to negotiate (e.g development of the Trout Creek management plan). At present, most water purveyors spread the risk equally among those they serve, through the allotment system. This type of risk sharing can continue if a purveyor adopts an Australian style water market.

Maintaining a supply of water for the agricultural community is a topic of current concern. At present, agricultural water ‘seeps’ out of agriculture when water conservation on the farm provides the purveyor with surplus capacity that can be used to service non-agricultural users. Tagging tradable water allocations to particular uses would ensure that farmers do not trade agricultural water out of agriculture. This approach does come at the cost of maximizing the flexibility water users have in deciding how to use their water, and for agriculture does not guarantee that the farm will be profitable. However, barring an alternative that makes farming as profitable as alternative land uses, restricting water trades can limit the amount of water rights leaving agriculture. A transparent process by which allotments are converted from one use to another, rather than the current seepage of conserved water, may help to both highlight the full nature of this issue, and provide a means of review and appeal to control it.

Attitudes

While both economic theory and practical experience elsewhere may emphasize the promise of water markets, water users must themselves recognize the benefits and be willing to accept such a change. An ongoing research project is examining the irrigation practices and attitudes of farmers to a range of water management issues, including tradable water rights. Figures 3 through 5 present the results for 24 attitude questions from this survey.

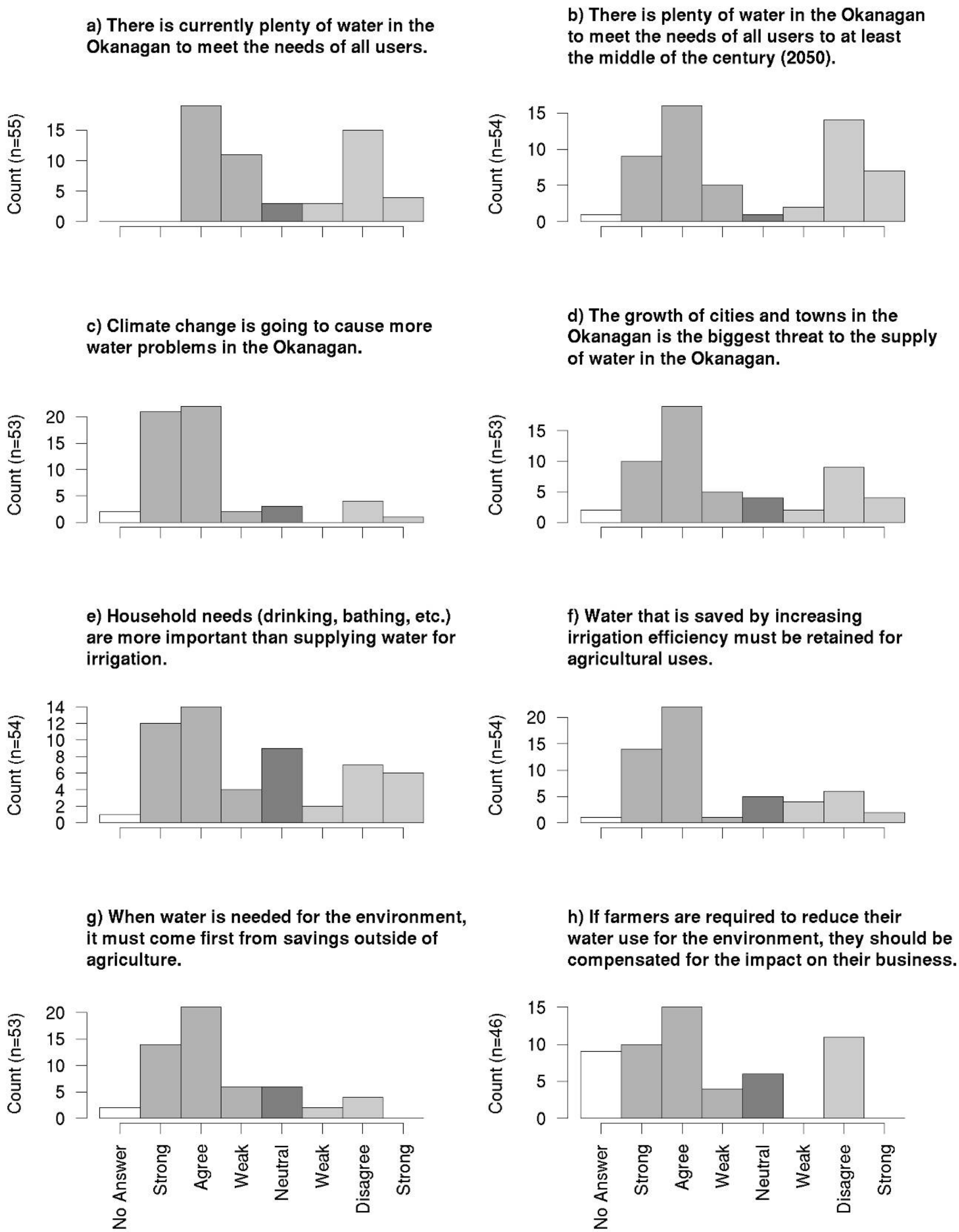

Figure 3: Okanagan irrigator responses to attitude survey questions.

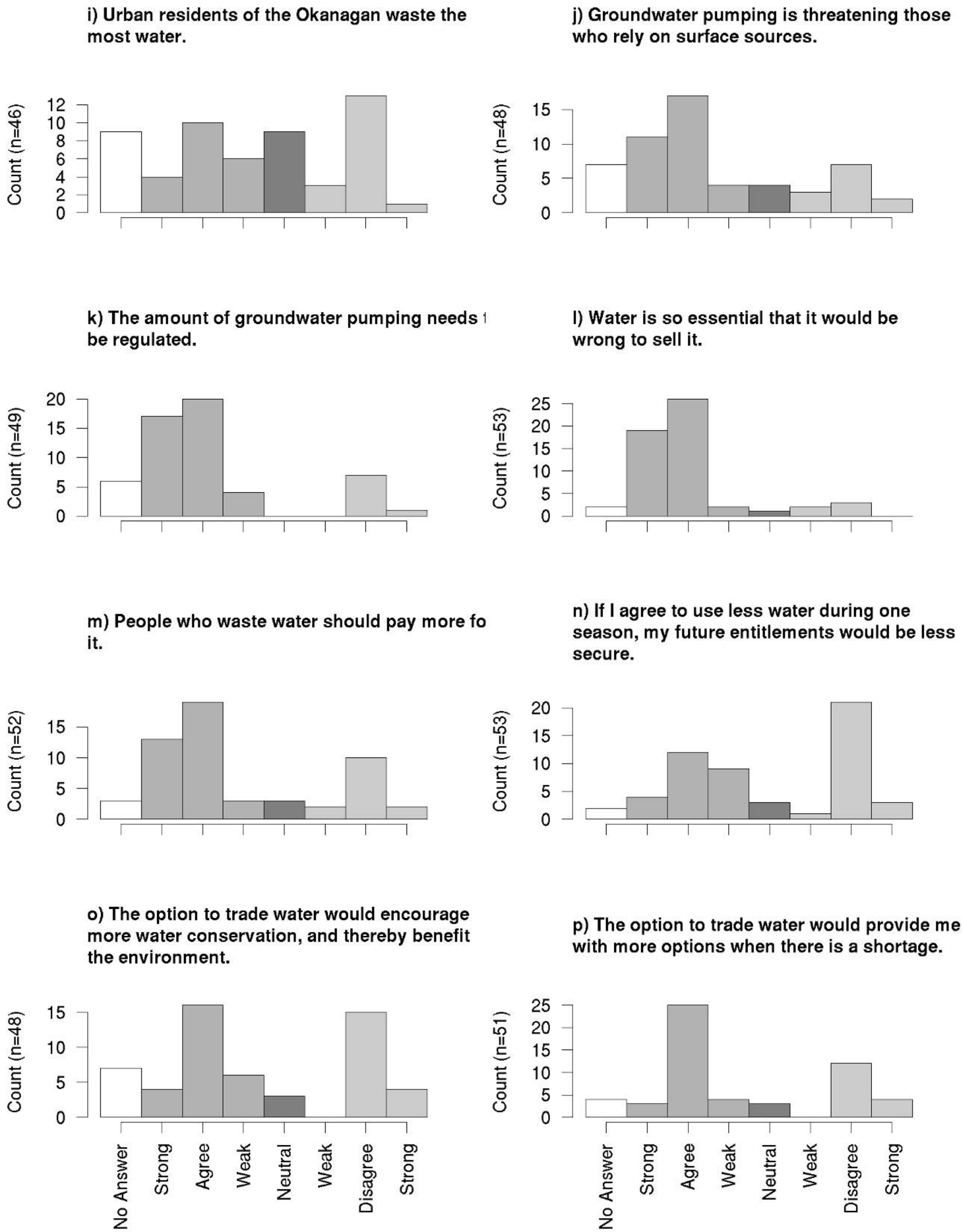

Figure 4: Okanagan irrigator responses to attitude survey questions (cont.).

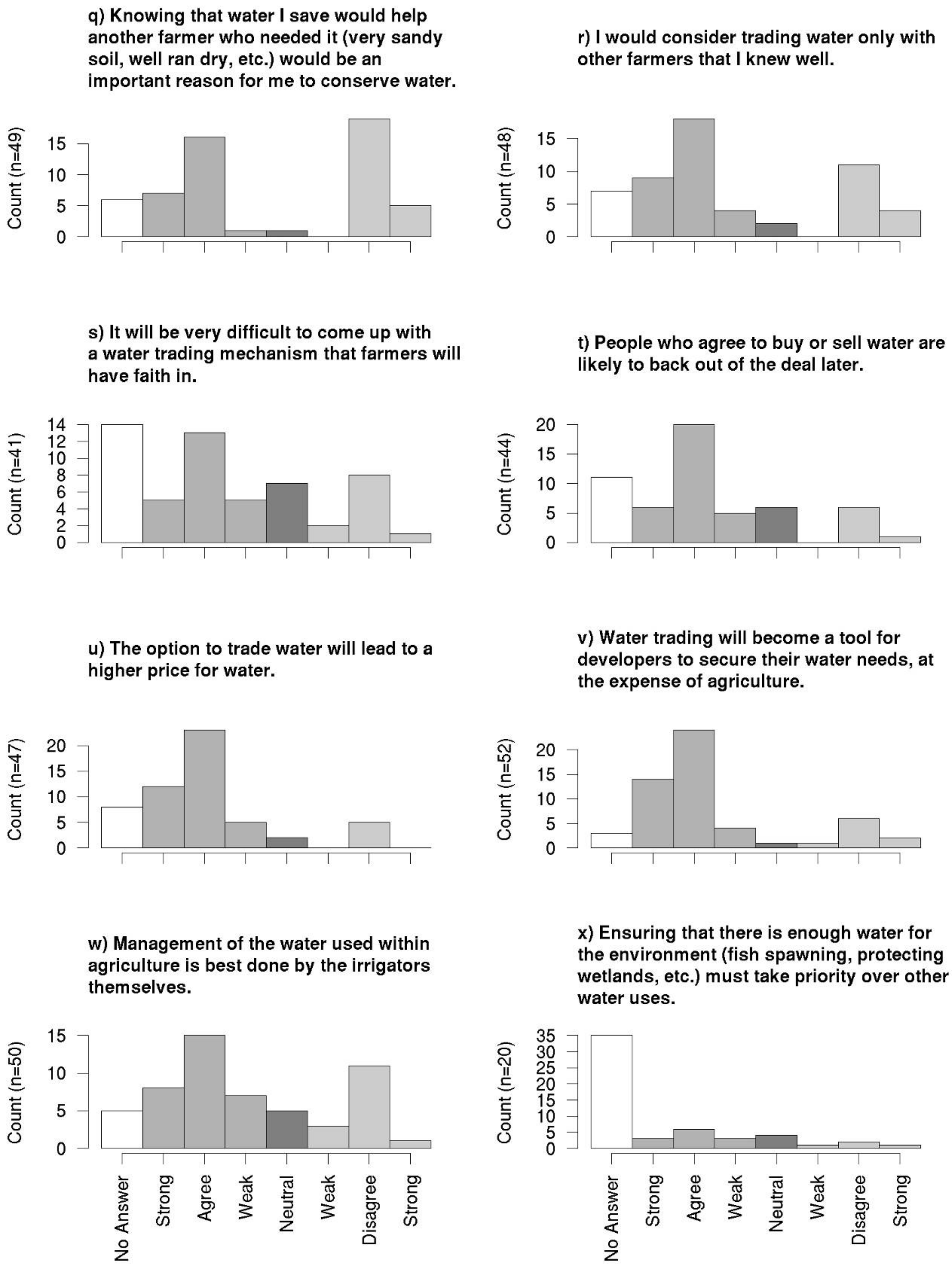

Figure 5: Okanagan irrigator responses to attitude survey questions (cont.).

Several themes emerge in these results. The respondents are about equally split on whether they believe that there is enough water at present, and enough forward to 2050, to meet the needs of all users (Panels a and b). However, there is broad agreement that climate change is going to cause more water problems (c). This suggests that irrigators may be open to policy reforms which will enhance adaptability to climate change.

While irrigators are more or less split on whether their urban cousins waste more water (i), and whether household needs deserve a higher priority than irrigation (e), many do see the growth of cities and towns as a large threat to the supply of water in the Okanagan (d). It follows that there is strong agreement that water saved through increasing irrigation efficiency should remain in agriculture (f). This concern carries through into a fear that if water could be traded, the market would become a tool whereby developers would be able to take water from agriculture (v). This fear may also be reflected in the tendency to believe that the management of water resources within agriculture is best left to the irrigators themselves (w). Thus, if irrigators are to support reforms that include a role for water trading, those reforms must ensure that water trading is not a vehicle to pull water away from agriculture.

On the environment, irrigators seem to agree that they should not bear the primary burden for protecting fish and aquatic habitats. There is broad agreement that water for the environment should first come from outside of agriculture (g). There is also a tendency to support compensation if an irrigator is required to reduce their water use for the environment (h). However, when asked if the environment should take priority over other water uses, many irrigators were unwilling to answer (x). With respect to groundwater in particular, there is strong agreement that groundwater pumping is harming surface water users and must be regulated (j and k). When it comes to the role of a water market, irrigators are more or less split on whether a water market would help the environment.

When it comes to a water market, attitudes are a bit contradictory. The idea of selling water is almost uniformly seen as wrong (l). However, several benefits of water trading are recognized. Respondents agree that people who waste water should pay more for it (n). They also see that the ability to trade water could provide them with more options during a drought (p). There is also a weak tendency to see it as beneficial for the environment (o). While these benefits are recognized, there is considerable concern about how a water market might be implemented (s). Some fear that their entitlements would not be secure if their water use was reduced (n). Others believe that irrigators who agreed to buy or sell water would not honour the arrangement (r and t). Finally, there is a strong perception that a water market will lead to a higher price for water (w). Thus, any reforms involving water trading need to ensure that entitlements are secure, that contracts will be honoured, and that water trading does not create financial difficulties for irrigators.

An Australian style water market within a purveyor's service area is compatible with the concerns expressed by the survey respondents. First, what is being termed a water market is a market in water use rights, not ownership of the water itself. By creating specific irrigation entitlements, which can only be traded with other irrigators, water can be secured for agriculture. Saved water will also remain in agriculture, so that the ability to trade water does not become a tool for developers to take water out of agriculture. Transfers out of agriculture would involve a cancellation of an existing agricultural licence and issuing of a new one, rather than the current seepage of conservation savings. Establishing an accounting system similar to that used in Australia will provide security for the water rights and ensure that exchanges are honoured, since the banker controls the tap. While the market will determine a price for water, the entitlements themselves will provide each irrigator with a guaranteed supply at the cost of delivery. The market will only be for buying or selling water relative to this entitlement. Thus, the price for water will not be a price that each user must pay for each unit of water they receive. The fact that water will bear a price means that those who waste it are paying for it, as they could sell it and earn something. Finally, if there is an environmental need for water, those seeking water for the environment can purchase water, thereby compensating those who do without at a fair market price. Thus, provided that water users can become comfortable with the idea that trading water entitlements is not the same thing as trading water, an Australian style water market operating within the service areas of water purveyors could bring greater flexibility to water management in the Okanagan, and elsewhere in Canada where water purveyors operate.

Conclusion

Governance is the name given to how we distribute power and arrange the management of society. Watershed governance is about how we distribute power and arrange management within a watershed. Watershed governance is good if that governance is consistent with society's broader goals. Presently, the system of water rights is consistent with some of society's goals, particularly that of retaining water in the public realm. However, it is not consistent either with maximizing the value generated through the exercise of the usufructuary rights we do grant over water, nor with the ethical view that the burden of water shortages should be shared by all. While wholesale reform of water rights in British Columbia is a long term project, there is scope for innovation within the current structure if Okanagan water purveyors are willing to implement an Australian style system of water entitlements within their service area.

Australian water rights are proportional appropriation, rather than prior appropriation. However, this difference is not relevant at the level of a purveyor's service area, as the purveyors already determine a water allocation with equal priority for all. To enable trading, purveyors will need to guarantee water volumes as water availability becomes know. They will then need to set up an accounting system to track transfers of these guaranteed volumes between individual water users, and to ensure that deliveries are consistent with the bank balance. Such reforms will introduce greater flexibility into the management of individual water users, enabling them to find new ways to realize the full value of this precious resource.

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Cumulative Effects of Economic Growth on Watershed Ecosystems in the Okanagan Valley

Barry Wilson

Abstract

The Okanagan Valley is experiencing tremendous economic growth and this trend is expected to continue. This growth will bring about a suite of cumulative effects - changes to environmental, social and economic values caused by activities in combination with other past, present, and reasonably foreseeable human activities. Water is a common thread across all components of the triple bottom line and the need for strategic level cumulative effects assessments including watershed impacts is increasing rapidly with pressures from mountain pine beetle damage, new transportation infrastructure, urban growth, foreshore development, ALR withdrawals and climate change to name a few.

Simulation models can be used to help quantify the effects of human activity in concert with natural disturbance events. These models help planners and decision makers to understand the consequences (both opportunities and risks) of defined land use scenarios, appreciate those variables (environmental, economic, social) that "drive" watershed performance and the consequences of various land use trajectories. When effectively used, these tools provide the opportunity to explore strategies that lead to maximizing favorable outcomes and minimizing unfavorable footprint effects. Anthropogenic disturbances simulated include tourism and recreation, agriculture, forestry, energy, transportation, surface and subsurface water use, human populations and settlements. Natural systems simulated include fire, insect outbreaks, climate change, flooding, avalanches and succession.

This paper provides an overview of these tools, examples of how they have been used in other jurisdictions and how they can be used in the Okanagan.

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A Comparison of Stormwater Runoff Reduction by Green Roofs Between Kelowna and Vancouver

Daniel Roehr, Yuewei Kong, and Jon Laurenz

Abstract

This research focuses on the contribution of green roofs towards reducing stormwater runoff in the cities of Kelowna and Vancouver. As these areas have disparate climatic conditions, they are ideal for analysing and comparing the effects of green roofs on stormwater runoff. The Curve Number Method (Technical Release-55) and Crop Coefficient Method are used to quantify the existing stormwater runoff and the potential runoff reduction of green roofs using local climatic data, such as rainfall, snowfall, evaporation and temperature. Two selected sites are analysed, including both commercial and residential buildings in Kelowna and downtown Vancouver, and are compared to show the particular effects of stormwater management in different climatic zones. This research also includes previous studies conducted, among others, in Berlin, Germany; Ottawa, Toronto and Vancouver, Canada; Chicago, Portland and Seattle, USA. The findings and calculated results are then used to develop the most effective green roof systems for Kelowna and Vancouver.

Due to the high rainfall and moderate evapotranspiration rates in Vancouver, extensive green roofs could reduce rooftop runoff by 29% if growing with drought tolerant plants like sedum, and by 49% with moderate water-use plants like sea pink (*Armaria maritime*). If 30% of the existing rooftop areas on the case study areas are greened, the total runoff could be reduced by 4%.

Because of the low rainfall and high evapotranspiration rates in Kelowna, extensive green roofs grown with sedum could achieve zero rooftop runoff by planting only 44% of the existing roof areas. The total runoff could be reduced by 24% if 30% of the existing rooftop areas on the case study areas are greened, and by 36% when planting 44% of the existing roof areas.

Keywords: stormwater runoff, green roofs, green streets, evapotranspiration

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Introduction

In many cities around the world, population growth and urban development have resulted in increased impervious surfaces in cities, thereby increasing stormwater runoff from urban areas. Stormwater management is currently one of the major tasks for cities towards achieving environmental sustainability.

Studies from the United States indicate that the world's population will reach a landmark in 2008: for the first time in history the urban population will equal the rural population and subsequently the majority of the world's population will be urban (Department of Economic and Social Affairs, 2008). According to the 2006 Census of Canada, the population percentage change in British Columbia (2001-2006) was 5.3% (BC Stats, 2007a). Compared with British Columbia's average, Kelowna and Vancouver are experiencing rapid population growth. The 2006 Census of Canada shows that the population percentage changes (2001-2006) are 10.8% in Kelowna, and 16.7% in Vancouver Centre (BC Stats, 2007a; 2007b).

Due to population growth and urban development, open space and undisturbed lands have yielded to encroachment from buildings and roads, resulting in increased impervious surface areas within cities, such as buildings, streets, sidewalks, and parking lots. This increased impervious area results in greater quantities and velocities of stormwater runoff, because these impervious areas no longer permit water infiltration into the soil; and smooth, compacted surfaces accelerate the velocity of surface flows. An example below shows that impervious surfaces would generate five times more runoff than from pervious landscaped surfaces during a 25.4cm (1-inch) rainfall event. The example uses the Curve Number (CN) method from the Technical Release-55 (TR-55) by the Natural Resources Conservation Service (NRCS), to calculate the stormwater runoff during a 24-hour rainfall event (Cronshey et al, 1986). This method was used because in comparison to the United States, Canada does not have all the data available to use more sophisticated calculation methods. The results from the TR-55 method however, are accurate enough to evaluate and compare stormwater runoff on large scale test sites like those in Vancouver and Kelowna. For impervious surfaces like roofs, streets, sidewalks and parking lots, a CN of 98 was used. As recent research shows, compacted urban soil would have a low rate of water transmission (0-12.7mm/hr), and a CN of 84 was used for pervious surfaces (Pitt et al, 2002; Cronshey et al, 1986). The results in Table 1 show that 20.1cm of runoff would be generated from the impervious surfaces during a 25.4cm rainfall event, while only 3.9cm from be generated from pervious surfaces.

Table 1: Calculation example of stormwater runoff

	Impervious surfaces (i.e., buildings, streets, sidewalks, parking lots.	**Pervious surfaces (i.e., landscaped area)**
Curve Number (CN)	98	84[1]
S [potential maximum retention after runoff begins (in)] (1inch= 25.4cm): *S=1000/CN-10*	0.2	1.9
P [rainfall (in)] (1inch= 25.4cm)	25.4cm	25.4cm
Q [Runoff (in)] (1inch= 25.4cm): $Q=(P-0.2S)^2/(P+0.8S)$	20.1cm	3.9cm

[1] Assume that the soils have a very low rate of water transmission (0-0.05 in/hr), and the grass coverage is 50% to 75%.
Source: Cronshey et al, 1986

The increased impervious surfaces would not only increase runoff quantity, but also deteriorate runoff quality. The quality can be influenced by the concentration of contaminants and runoff volumes. Studies show that the concentration of heavy metals like Zn (zinc), Pb (lead), and Cu (copper), would be greatly influenced by impervious surface coverage. The concentration of Zn from high-density residential areas can be up to six times that of urban open areas (CH2M HILL, 2000). Traditional rooftops are also a source of heavy metals. A study in Austin, Texas, shows that metal roofing is also a source of cadmium and zinc, and asphalt shingles are a source of lead and possibly mercury (Van Metre and Mahler, 2003).

Green roofs can provide a partial solution to these problems by reducing the velocity of rooftop runoff with vegetation and soil, storing rainwater in the growing medium and transferring it back into the air via evapotranspiration. Studies from Sweden show that extensive green roofs planted with sedum could significantly reduce runoff amounts- especially peak flow runoff (Bengtsson, 2005). According to current research in the British Columbia Institute of Technology (BCIT) in Vancouver, a green roof with 150mm of growing medium could reduce annual runoff volumes by 26%; with 13% in the wet season and 94% in the dry season (Connelly, 2006).

However, the runoff reduction of green roofs could be influenced by local climatic conditions. In order to discover how climatic conditions influence the effects of green roof on stormwater runoff, this research selects Kelowna and Vancouver with distinctly different conditions, and applies local climatic data to quantify the potential runoff reduction of green roofs in these areas. Results from this research could further be used to investigate green roof design strategies for stormwater runoff in Kelowna and Vancouver.

Methodology

Stormwater runoff is influenced by the total rainfall amount, the intensity and duration of a rainfall event, and the total area of impervious surfaces. This research selects a 20ha case study area in the city centres of Kelowna and downtown Vancouver, and then measures the green and gray surface areas on each site. It also obtains local daily climatic data such as rainfall, temperature, and evapotranspiration, uses the Curve Number method (Technical Release-55) to calculate existing runoff, and uses the Crop Coefficient method to calculate the runoff reduction potential of green roofs.

Case Study Areas: Kelowna, BC

The selected site in Kelowna, BC (Figure 1) has a total area of 20 ha. It is contained by the following four streets: Cawston Ave, Richter St, Bernard Ave and Ellis St. It includes commercial buildings and residential buildings such as single family houses and multi-story apartments. After measuring the total areas of all cover-types on the site such as streets, roofs, sidewalks, parking lots, and pervious landscaped areas, the total green space accounts for 18% of the total site area.

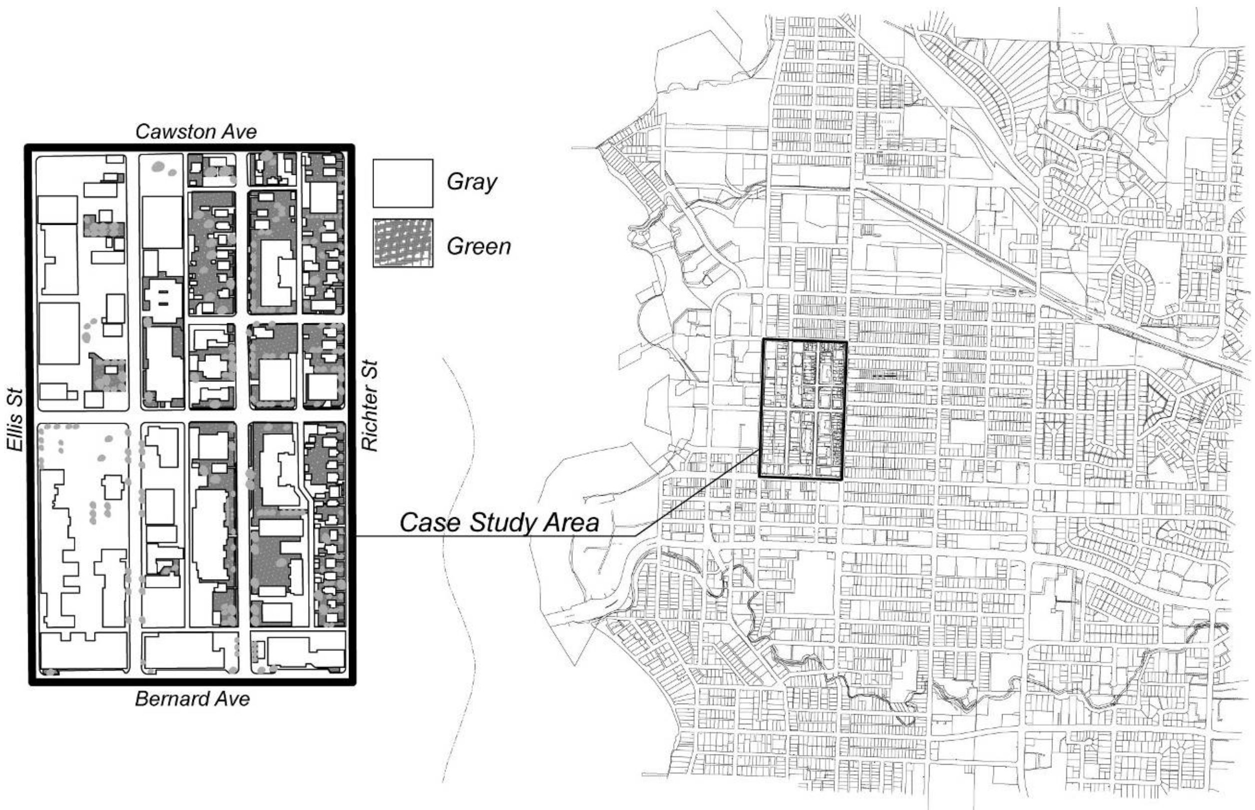

Figure 1: Case Study Area in Kelowna, BC.

Case Study Areas: Downtown Vancouver, BC

Figure 2 below is the selected site in the city core of downtown Vancouver, BC, with a total area of 20 ha. It is contained by the following four streets: Melville St, Thurlow St, Barclay St, and Jervis St. It combines the Downtown District neighbourhood and the West End neighbourhood, including commercial and residential high-rise buildings and low-storey townhouses. The measuring results of green and gray surfaces show that the total green space on the site only accounts for 12% of the total site area. (Roehr and Laurenz, 2008a)

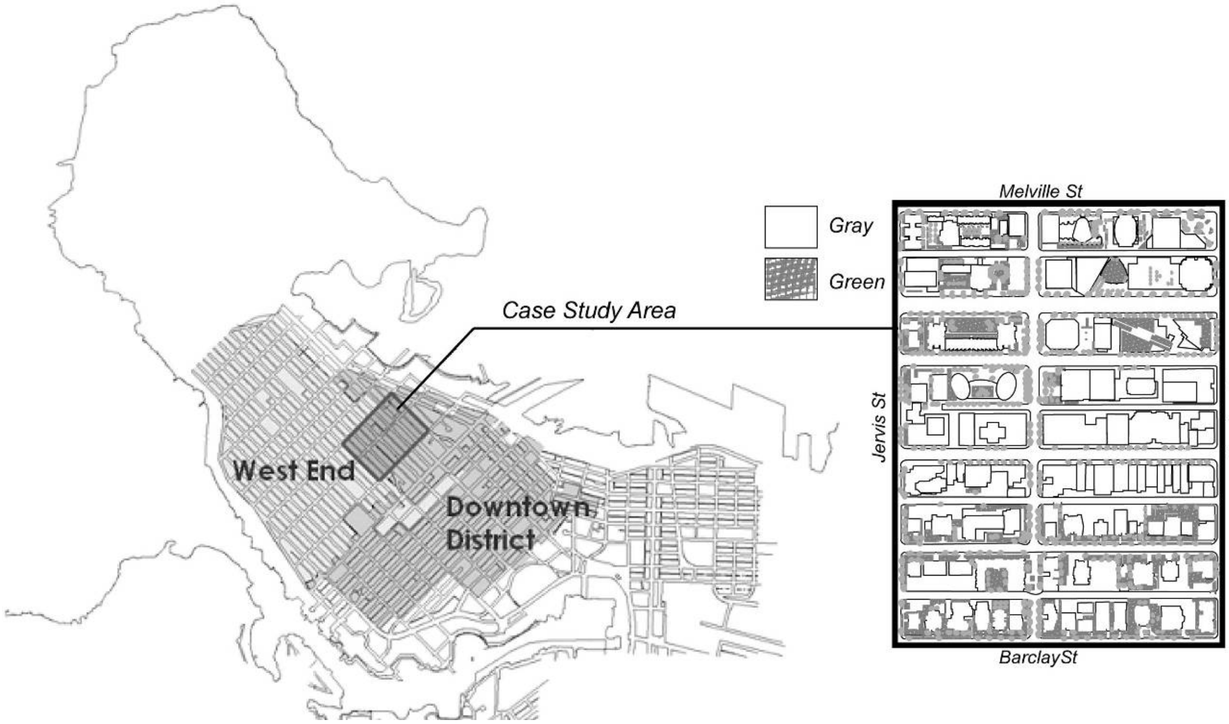

Figure 2: Case Study Area in downtown Vancouver, BC. (Roehr and Laurenz, 2008a)

Curve Number Method

This research uses the Curve Number method to calculate the existing runoff. It assumes a CN of 98 for impervious surfaces like roofs, streets, sidewalks and parking lots, and a CN of 84 for pervious landscaped areas with compacted urban soil. Using the daily rainfall data of an average moist year, the runoff rate generated from each rainfall event would be calculated by the following formulas:

$Q = (P-0.2S)^2/(P+0.8S)$
$S = 1000/CN-10$

Where
Q: runoff (in)
S: potential maximum retention after runoff begins
CN: curve number
(1inch= 25.4cm)

Crop Coefficient Method

This research uses the Crop Coefficient method to calculate the potential runoff reduction of green roofs. When rainfall occurs, a portion of rainwater will be stored in the growing medium. After the growing medium reaches its field capacity, overflow rainwater will drain into the pipe and end up in the city's sewage system. Rainwater stored in the growing medium will gradually evapotranspirate into the air. For extensive green roofs with no maintenance or irrigation systems, the runoff reduction would be equivalent to the evapotranspiration rate of the selected plants. The evapotranspiration rate of plants can be calculated using the following formulas: (California Department of Water Resources, 2000)

ETc = Kc X ETo

Where
ETc: evapotranspiration or water use of plants
ETo: reference ET for vegetation (mm)
Kc: crop coefficient

Calculated Results

Stormwater Runoff

In Kelowna, the annual precipitation amount during an average moist year is 370.8mm (Environment Canada, 1998). Using the CN method, the annual runoff rates are 133.5mm from impervious surfaces and 2.1mm from pervious landscaped area. As the total area on the selected site consists of 3.7ha of impervious surfaces and 16.3ha of pervious landscaped area, the total runoff rate on the site is 109.2mm (per annum).

In Vancouver, the annual precipitation amount during an average moist year is 1224.2mm (Environment Canada, 2006). Using the CN method, the annual runoff rates are 736.5mm for impervious surfaces and 99.4mm for pervious landscaped areas. The total area of the site consists of 17.7ha of impervious surfaces and 2.3ha of pervious surfaces. The total runoff rate generated by the Vancouver site is 687.1mm (per annum).

Runoff Reduction

This research uses an average Kc of 0.3 for sedum, a plant commonly used on extensive green roofs, to calculate the potential runoff reduction of such roofs (City Of Riverside Planning Department, 1994).

Due to high temperature and evapotranspiration rates in Kelowna during the summer period, the annual evapotranspiration rate of an extensive green roof growing with sedum would be 301.6mm, which means that 301.6mm of rainwater could be reduced via evapotranspiration. With a low annual rainfall of 370.8mm in Kelowna, the annual runoff rate is only 133.5mm. As a result, rainwater alone is insufficient for the water requirements of sedum. Greening the total rooftop area with sedum would require an extra irrigation rate of 168.1mm (301.6mm-133.5mm =168.1mm) during an average moist year. Without an irrigation system, the maximum greening percentage of rooftop areas would therefore be 44% (133.5mm/301.6mm=44%). Zero rooftop runoff could be achieved by greening 44% of the total rooftop area with sedum.

Because of the mild climate in Vancouver, the annual evapotranspiration rate of extensive green roofs in Vancouver would be 215.1mm. Due to the high precipitation rate (1224.4mm per annum) in Vancouver, a runoff rate of 736.5mm would be generated from impervious roof tops. Greening the total rooftop areas would reduce rooftop runoff by 29% (215.1mm/736.5mm=29%). Plants with a higher Kc value could also be used in Vancouver, in order to achieve a higher runoff reduction rate of green roofs. For example, using sea pink (*Armaria maritime*) with a Kc of 0.5 could achieve a higher runoff reduction of 49% (29%X0.5/0.3=49%) (City Of Riverside Planning Department, 1994).

Design Strategy

The calculated results of this research show that climatic conditions have direct influence on the design strategies for green roofs. This research is based on previous studies conducted on the downtown Vancouver case study area, and attempts to investigate a new design strategy for Kelowna.

In order to quantify the amount of environmental improvement by green roofs and other green interventions like green façades and green streets, previous research applied the Seattle Green Factor to analyze the Vancouver case study area (Department of Planning and Development, 2007). To achieve the value of 0.3 suggested by Seattle Green Factor, two scenarios have been analyzed for the Vancouver sites. The first scenario consists of greening 30% of the existing roof areas, 30% of the existing sidewalks, and 15% of the existing façade areas. By doing so, 4% of the stormwater runoff could be reduced by applying extensive green roofs grown with sedum (Roehr and Laurenz, 2008a). Because of the high precipitation rate (1224.4mm) in Vancouver, the selected site could green a higher portion of existing roof areas. The second scenario greens 60% of the existing roof areas, and 10% of the existing façade areas (Roehr and Laurenz, 2008b). In this case, 8% of the total runoff could be reduced by extensive green roofs.

However, according to the calculated results in Kelowna, the high evapotranspiration rate and low rainfall amounts do not support a greening percentage of existing roof areas higher than 44% without an extra irrigation system. To achieve the value of 0.3 suggested by the Seattle Green Factor would require applying permeable paving, growing trees and designing rain gardens (Department of Planning and Development, 2007). Greening 30% of the existing roof areas could reduce stormwater runoff by 24%. If greening 44% of the existing roof areas, zero rooftop runoff could be achieved. The total runoff could be reduced by 36%.

This research also analyzes the performance of green roofs during the warmest summer months (June to September) in Kelowna and Vancouver, by comparing the evapotranspiration rates with the existing runoff rates of traditional rooftops. The final runoff rate is assumed as the existing rooftop runoff rate minus the evapotranspiration rate.

According to the calculated results, the accumulated evapotranspiration rates in Vancouver from June to September area are 123mm by sedum and 205.1mm by sea pink (*Armaria maritime*). The runoff rates generated from traditional roofs are 67.5mm. If 30% of the rooftop areas in Vancouver are greened, the evapotranspiration rate would be 36.9mm (123mmX30%=36.9mm), and the final runoff rate would be 30.6mm (67.5mm-36.9mm=30.6mm). If 30% of the rooftop areas are planted with sea pink (*Armaria maritime*) with an average Kc of 0.5, the evapotranspiration rate would be 61.5mm. The final runoff rate would be reduced to 6mm (67.5mm-61.5mm=6mm).

The calculated results show that the accumulated evapotranspiration rate of sedum from June to September is 188.2mm in Kelowna, and the runoff rate generated from traditional roofs is 35.4mm. If 30% of the rooftop areas is planted, the evapotranspiration rate would be 56.5mm (188.2 mmX30%=56.5mm), thus no runoff would be generated from the roofs (35.4mm-56.5mm=-21.1mm).

Conclusions

Results of this research show that climatic conditions can influence the effects of green roofs on stormwater runoff significantly. In Vancouver, runoff generated from existing rooftops is 736.5mm. Extensive green roofs growing with drought tolerant plants like sedum could reduce rooftop runoff by 29%. Due to sufficient rainfall amounts in Vancouver, moderate water use plants like sea pink (*Armaria maritime*) could increase rooftop runoff reduction to 49%. If 30% of the existing rooftop areas are greened with extensive green roofs, 4% of the total runoff could be reduced.

In Kelowna, due to high average temperatures and low rainfall, runoff generated from existing rooftops is only 133.5mm. An appropriate percentage of extensive green roofs planted with sedum is recommended to be no higher than 44%, at which point zero runoff can be achieved. Greening 44% of the total rooftop area with extensive green roofs could reduce total runoff by 36%.

Discussion

Green roof design is one method to reduce stormwater runoff in cities. However, reducing stormwater runoff is only one benefit contributed by green roofs. Local climatic conditions and the properties of plants and the selected growing medium could further influence the performance of green roofs and the effects on stormwater runoff. To develop the best design strategies for green roofs, local climatic conditions should be considered.

There are also limitations in the Curve Number method. As the equation does not contain an expression for time and, therefore, does not account for rainfall duration or intensity. Furthermore, the CN calculation is less accurate for small rainfall events (Cronshey et al, 1986). On-site testing and measuring are recommended to obtain more accurate data.

Due to high rainfall amounts in Vancouver, green roofs would be efficient and significant towards reducing stormwater runoff. As studies conducted in Vancouver show, green roofs could reduce energy demand of buildings and lower CO2 emissions (Roehr and Laurenz, 2008a; 2008b). Considering the low rainfall and high evapotranspiration rates in Kelowna, it would be more efficient and effective to apply green roofs to contribute to other benefits such as reducing energy demand, CO_2 emissions, urban heat island effects, and improving urban biodiversity.

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Using the Forest and Range Evaluation Program (FREP) Water Quality Protocol to assist in the management of Community Watersheds

David Maloney and Brian Carson

Abstract

Water purveyors want to determine the effects of forestry operations on water quality. Should negative impacts be confirmed, watershed managers want to be able to prioritize actions that will economically mitigate those impacts. The Water Quality Effectiveness Evaluation procedure described here evaluates the fine sediment generating potential of common disturbed forestry sites within watersheds (slope failures, road stream crossings, windblown riparian zones etc.) Forest Licensees on the coast and in the interior have adopted this FREP Water Quality Evaluation methodology as a integral part of their environmental monitoring program. The method is relatively simple, takes a technician around 20 minutes to evaluate one site, and provides a clear inventory of forestry induced sediment sources in a watershed and how they might be better managed.

Preliminary provincial data from 540 watershed sites collected in 14 forests districts in 2007 found that 71% of the sites had a low or very low potential to generate fine sediment, 22 % had a moderate potential and 6 % had a high potential to generate fine sediment. Opportunities for reducing fine sediment generation centered around paying more attention to planning road alignments near streams, increasing culvert density and improving placement during design and enhancing maintenance operations while road is actively used. This presentation introduces the FREP Water Quality evaluation methodology and provides examples of how it can improve management of B.C.'s community watersheds.

Introduction

Water purveyors, in the implementation of Tap to Source Assessments, increasingly wish to determine the effects of forestry and range operations on water quality. Should negative impacts be confirmed, the Ministry of Forests and Range may wish to alter policies related to forest management and watershed managers may wish to prioritize actions that will mitigate those impacts. The Forest and Range Evaluation Program, (FREP) through the Water Quality Protocol described here, evaluates the fine sediment generating potential of common disturbed forestry sites within watersheds (slope failures, road stream crossings, windblown riparian zones etc). The fine sediment so generated is responsible for increasing raw water turbidity above

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normal background levels. Sites are rated from very low to very high fine sediment generating potential. These ratings form the basis for comparing potential problem areas and prioritizing what, if any, management options need be considered. If livestock are present, range impacts on water quality are also evaluated at the same time. The sites selected by the procedure to address forestry impacts generally reflect conditions of range sites with the highest risk for generating fecal contamination. A number of Forest Licensees within the Okanagan Basin are actively experimenting with the procedure presented here, as a part of their environmental monitoring program.

The Water Quality Protocol is not meant to be a rigorous research tool to direct stream sedimentation research. However, it does provide defendable, order of magnitude estimates of potential fine sediment delivery to streams from disturbed sites. Such estimates are appropriate for making informed management decisions about sediment management during location, construction, maintenance and deactivation of roads and cutblocks in community watersheds.

Summary of steps used to conduct the water quality protocol

1. Identify area(s) to be evaluated.
These could be community watersheds, road networks under permit to Licensee, newly constructed road segments, high profile work sites, etc.

2. Identify site(s) to be evaluated within chosen area.
These sites would include bridge and culvert crossings, roads running parallel to and within 20 m of streams and riparian leave strips- any site where artificial and natural drainage might meet.

3. Define the "mini- catchment" associated with the disturbed surfaces of the site.
The evaluator determines the boundary of the disturbed area draining the site.

4. Identify the components associated with the site.
These could be road surfaces, ditches, cutbanks, fill slopes, failures, root wads, etc.

5. Characterize the individual components of the site within the "mini-catchment".
The evaluator determines the surface area of components and then assigns a relative erosivity to each, using tables provided in the protocol.

6. Estimate the connectivity between the components and the stream.
The area upslope of the storm drainage outfall and distance over forest floor between ditch outlet and stream are considered using tables provided in the protocol.

7. Calculate the fine sediment contribution from the site.
Connectivity (Values between 0 and 1) x **Portion of fine sediment** (Values between 0 and 1) x **Volume of sediment generated** (Usually values between 0 and 20 m^3)

8. Assign site to a Sediment Generating Class
Very Low *(0-0.2* m^3*)* ***Low*** *(0.2-1* m^3*)* ***Moderate*** *(1-5* m^3*)* ***High*** *(5-20* m^3*)* ***Very High*** *(>20* m^3)

9. Consider options for improved management to reduce sediment loading.
Consideration might be given to location, design, management, maintenance and /or deactivation of road or cutblock.

10. If range conditions suggest livestock is compromising water quality, the site information is forwarded to the Range Branch.

Small bridge on branch road in OK Falls area **Same site with components identified**

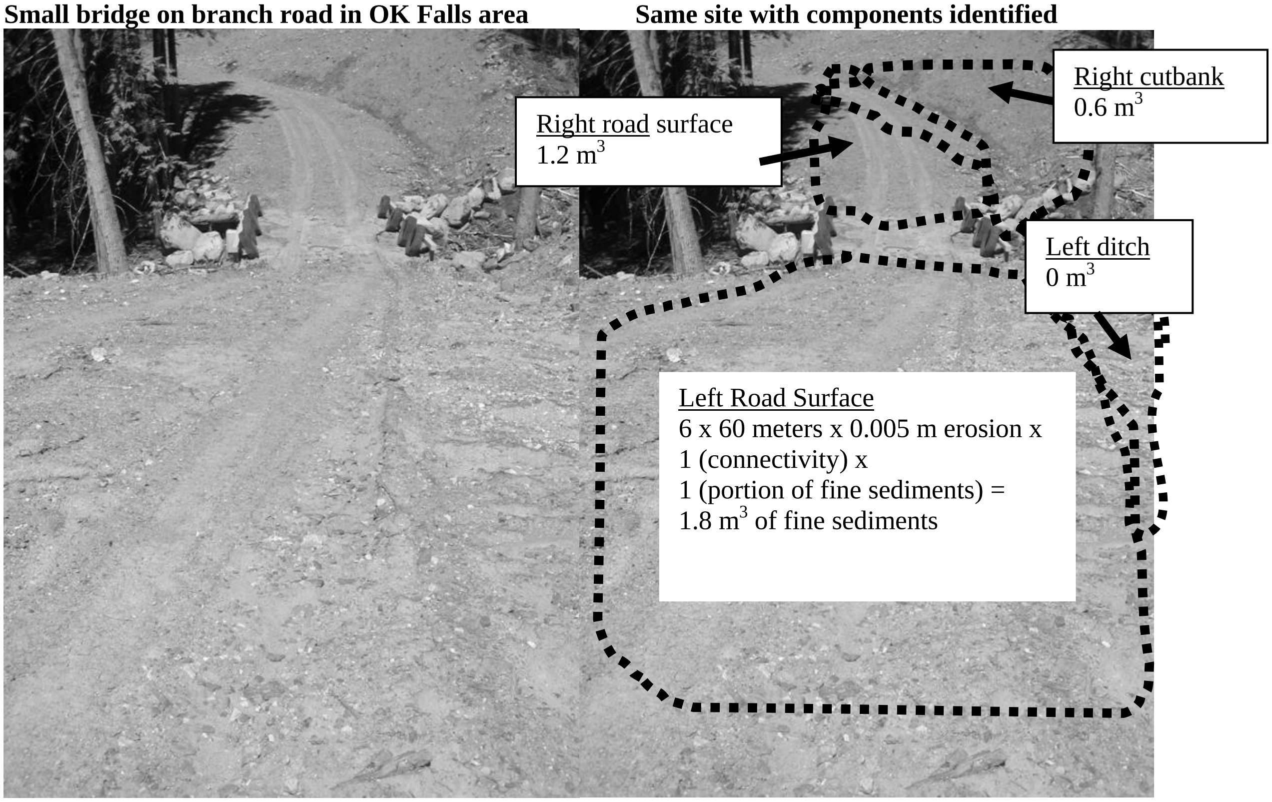

Figure 1: Example of a typical site evaluated by the Water Quality Protocol.

The outcome of this evaluation determined the potential fine sediment generation from site = 3.6 m^3. This translates into a Moderate Sediment Generation Potential. Mitigation is recommended.

To reduce the sediment generation potential, the licensee might consider one or more of the following options.

1. Using better road surfacing materials.
2. Installing strategically placed ditch blocks and culverts.
3. Crowning of road.
4. Removing berm from outside of road.

Any or all of these options would reduce sediment loading from this site to the creek. The evaluation technique provides the ability to estimate the improvement expected from each mitigation option. By comparing cost of mitigation technique with benefits, in terms of sediment reduction at any site, the manager can choose the most economical option. For instance, removal of a grader berm may reduce sedimentation by 30%, whereas installing two more culverts to intercept ditch water might accomplish the same, however, at a much greater cost.

Present Uses of the Water Quality Protocol

An evaluation tool of the Forest and Range Evaluation Program

The protocol has been initially developed to evaluate whether the Forest and Range Protection Act (FRPA) is providing a policy framework that is protecting our water resources. The procedure has been taught in a two day workshop to more than 70 stewardship staff of the Ministry of Forest and Range in 14 districts in B.C. It is relatively simple to learn, provides consistent results between different evaluators, requires around 20 minutes to evaluate one site and provides an inventory of forestry induced sediment sources and how they might be better managed. Preliminary provincial data from 540 watershed sites collected in 14 forests districts in 2007 found that 71% of the sites evaluated had a low or very low potential to generate fine sediment, 22 % had a moderate potential and 6 % had a high potential to generate fine sediment. While mass wasting was not commonly encountered, when it was, impact on water quality was high. Opportunities for reducing fine sediment generation centered around improving the planning and designing of road alignments near streams, increasing culvert density and enhancing maintenance operations while road is actively used. Fifty of the 540 watershed sites in the province required an evaluation of range effects on water quality, of which the results from 10 sites indicated that livestock had negatively impacted water quality. Some of these impacted sites were located in the Okanagan Basin.

A self administered management tool for licensees and water purveyors.

A number of managers of community watersheds on the coast and in the Okanagan are using the Water Quality Effectiveness Procedure to gauge their environmental performance. Foresters, road supervisors, builders and maintenance crew have found the procedure of value in dealing with road sediment issues. Licensees are working in conjunction with water purveyors in deployment of the procedure. Most watershed managers are committing to a stepwise reduction of fine sediment generation from their road networks. The expected sediment reduction can be easily calculated from any proposed mitigation option. By combining expected sediment reduction with estimates of costs to implement specific recommendations, a simple cost benefit analysis can be conducted.

Regulatory environmental audit undertaken by Forest Practices Board

The Forest Practices Board is using the procedure to conduct audits of licensee's chart areas to determine their compliance with provincial standards outlined by FRPA.

For further information regarding this water quality evaluation procedure see:
http://www.for.gov.bc.ca/hfp/frep/site_files/indicators/Indicators-WaterQuality-Protocol-2008.pdf

Landscape and Irrigation Standards for Water Efficiency

Neal Klassen

Abstract

The City of Kelowna is located in British Columbia's southern interior, an area noted for its long summers and semi-arid climate. Watering requirements for landscape irrigation creates a summer demand as high as 7:1 over winter. Conservation efforts begun in 1996 have focused almost entirely on assisting residents to reduce landscape irrigation.

Early work revealed three clear challenges for reducing outdoor irrigation: 1) the poor soil in the area is not conducive to moisture retention; 2) a proliferation of poorly designed and maintained automatic irrigation systems contribute to water waste; and 3) many landscaping choices are not suitable for the area.

Conservation efforts to address these challenges at existing homes have been successful. In 1998, total utility water production for the year was 15.3 million Cubic Meters. In 2007, total water production was 15.6 million Cubic Meters, an increase of around 2% - despite a 25% increase in population over the same period.

In 2007, Kelowna adopted a Water Sustainability Action Plan that calls for a 15% reduction in water use over and above those reductions already achieved. To meet this target, conservation efforts had to go beyond remediating the challenges present at existing homes, to preventing those issues from occurring in the first place.

This paper examines the process by which Kelowna developed landscape and irrigation standards for water efficiency in all new development. Based on similar development bylaws in California and Nevada, these may be the first of their kind in Canada. The standards ensure that all new developments include: 1) adequate soil; and 2) irrigation systems and landscape plans that meet pre-set standards for water efficiency.

The City of Kelowna has had a bylaw requiring low-flow shower and toilets since the early 1990s. This ensures that water efficiency is "built in" to each home. The new landscape and irrigation standards ensure that water efficiency is now also "built out."

This presentation will be of interest to those concerned with reducing peak flows created by residential irrigation.

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Introduction

The City of Kelowna is located in British Columbia's southern interior, an area noted for its long summers and semi-arid climate. Watering requirements for landscape irrigation creates summer demand as high as 6:1 over winter (Figure 1). This paper examines the process by which Kelowna determined that landscape and irrigation standards were necessary to reduce peak demand created by residential irrigation.

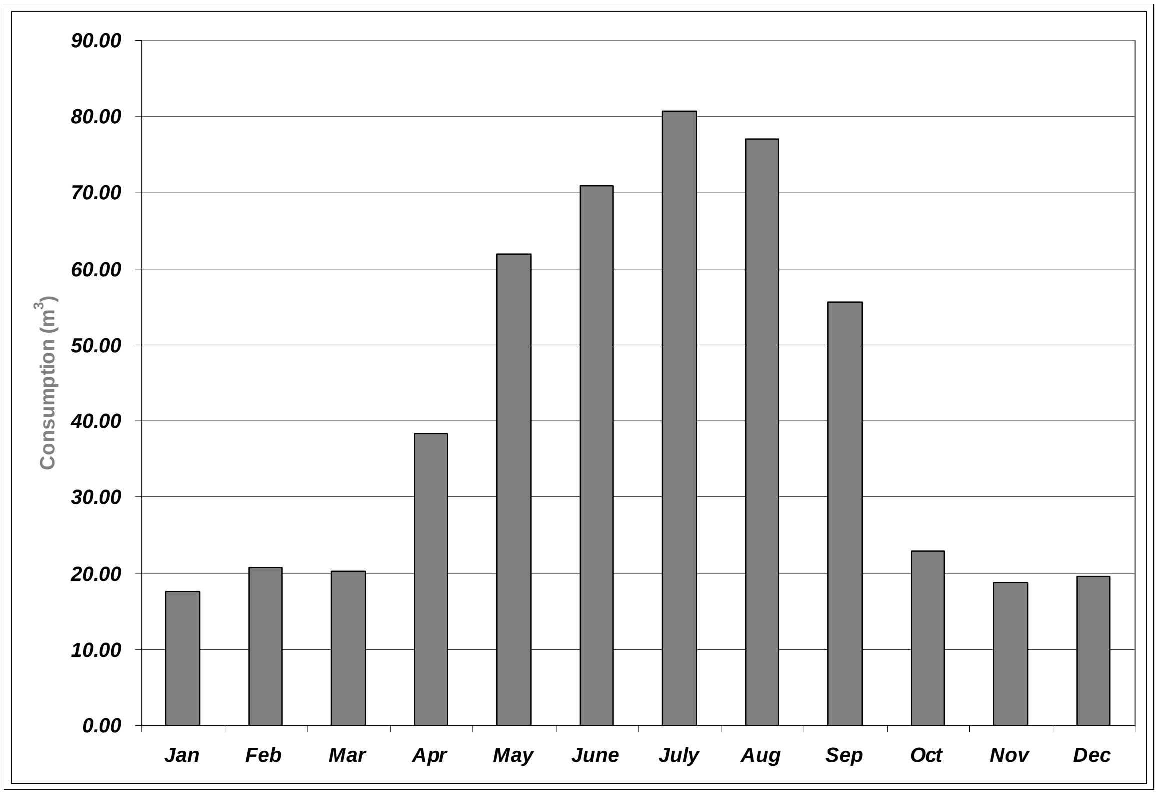

Figure 1: Residential average monthly consumption - City of Kelowna 2007.

The City of Kelowna Water Utility implemented universal water metering in 1998 and by 2001 reduced overall water use by 20% (City of Kelowna, 2007). A 2001 study suggested that if residential water users could reduce their consumption by an additional 16% in the month of July, the City could defer or eliminate $16 million worth of infrastructure expansions (City of Kelowna, 2007).

Conservation efforts begun in 1996 focused almost entirely on assisting residents to reduce landscape irrigation. Analysis of water meter data revealed that certain residential areas of the city used substantially more water for landscape irrigation than others (Figure 2). For example, in 2007, homes in the highest consumption area averaged 157 Cubic Metres in July, while homes in the lowest consumption area averaged 44 Cubic Metres in the same month (Figure 3).

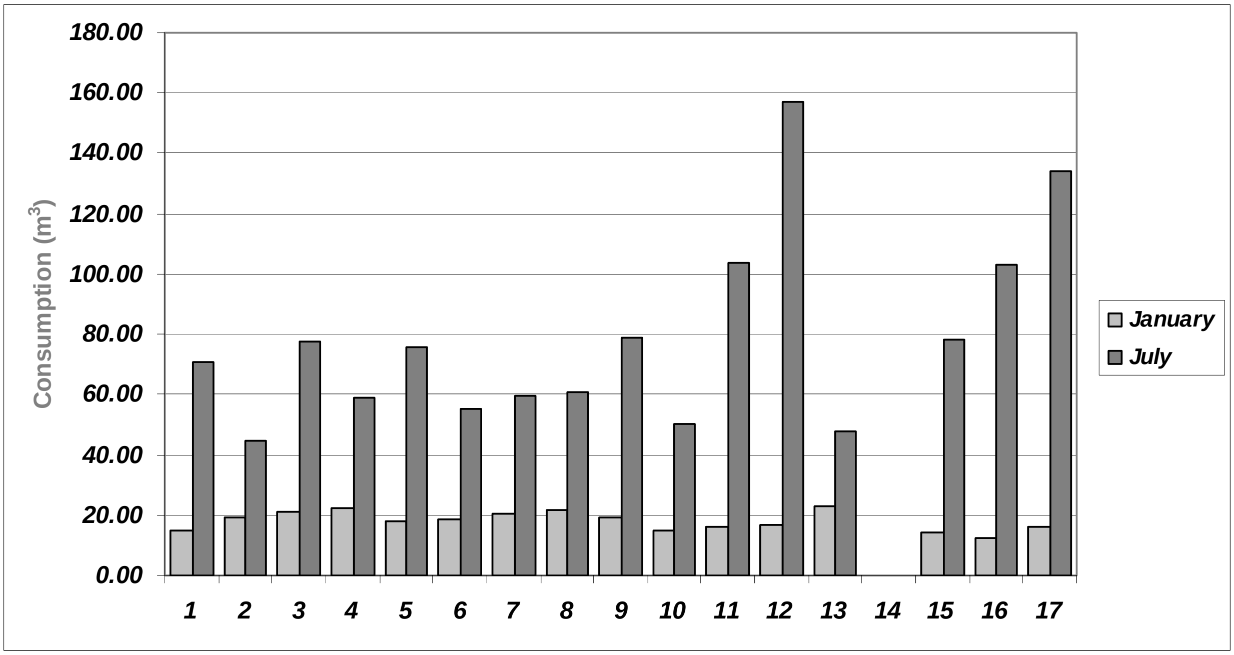

Figure 2: Average residential consumption by area: January and July comparison - City of Kelowna 2007.

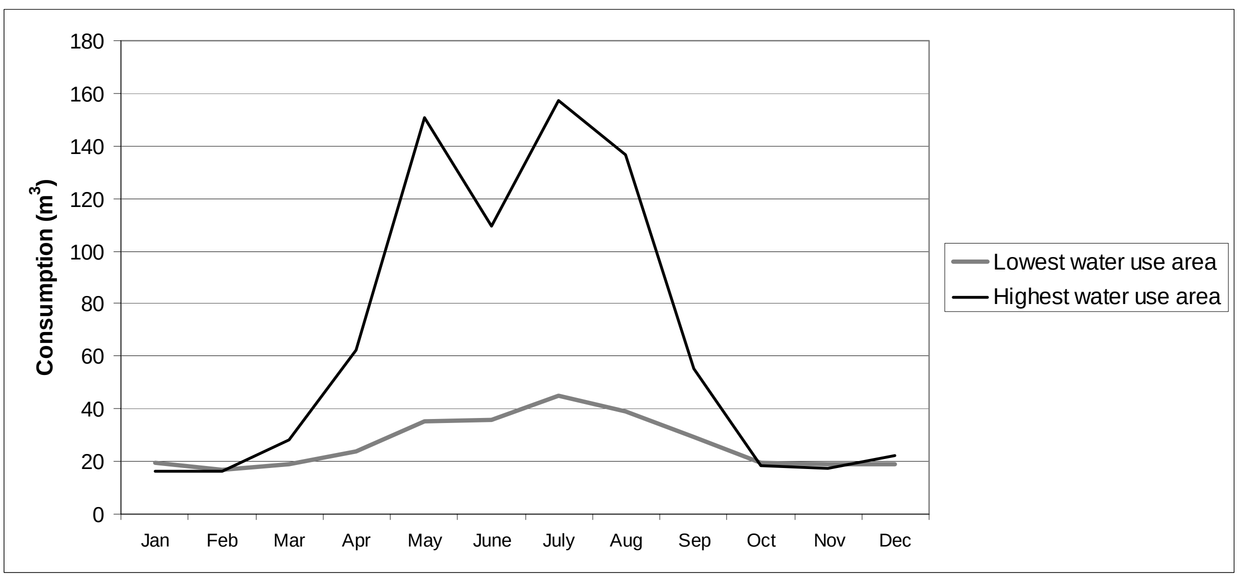

Figure 3: 2007 comparison of highest and lowest water use areas (average monthly residential water consumption) – City of Kelowna.

The areas where high consumption occurs have a few common elements. First, they tend to be the newer, more affluent neighbourhoods, where homeowners may be less likely to reduce water use as a means to save money. Second, they tend to be located in the hillside developments on the outskirts of the city, rather than on the flat land of downtown and surrounding area.

While lot sizes are not necessarily larger in all the high consumption areas, early work by the city's *Water Smart* water conservation program revealed three clear challenges in these areas that are not as prevalent in lower consumption areas: 1) the poor soil in hillside developments is not conducive to water retention; 2) a proliferation of poorly installed and maintained automatic irrigation systems contribute to water waste; and 3) the extensive and expensive landscaping choices utilize high water using plants not native to the area (City of Kelowna, 2008).

In response to these challenges, a number of cost-shared and free services were made available through the *Water Smart* program. These include a soil amendment program, landscape and irrigation system audits, and Xeriscaping workshops.

Good soil saves water

The soil in Kelowna's hillside developments is glacial till, a mixture of rock, gravel and boulders within a matrix of a fine powdery material. There is very little organic material to promote healthy root development and water retention. As a result, homeowners in these areas need to water more often to maintain their landscapes than homeowners in the lower consumption areas, where the soil tends to be a mixture of sand and organics (City of Kelowna, 2008).

In 2001, *Water Smart* initiated a soil amendment program targeted specifically to the high consumption areas in the hillside developments. Fifteen of the highest water users had their lawns top-dressed with approximately 3cm of fine compost. These homeowners were able to reduce their water consumption by an average 35%, with no noticeable difference in the quality of their lawn (Klassen, 2002).

Since then, the soil amendment program has expanded to include as many as 300 homes per year, and it has provided sufficient evidence that good soil can reduce water use in the high consumption areas. It also sparked the idea that new homes should have good soil installed during the construction stage.

Efficient irrigation reduces waste

With a few exceptions, almost every home in the high consumption areas has an automatic irrigation system. In theory, these systems should provide the maximum in water efficiency; in practice, often the opposite occurs. In 2002, *Water Smart* began offering free residential irrigation system audits and noted that poorly installed and improperly maintained irrigation systems contributed significantly to water waste.

System deficiencies include irrigation zones with a mix of sun/shade, fixed/rotor sprinkler heads, and high/low water using plants. In addition many sprinkler heads are not properly spaced, broken, or blocked by plant material. Compounding these problems are homeowners who do not know how to maintain their system or even how to set their irrigation timer.

Water Smart staff conducts about 100 residential irrigation system audits per year, suggesting improvements that reduce irrigation requirements by an average 15-25% (Figure 4). After conducting more than 500 irrigation system audits since 2002, *Water Smart* was convinced that much of the water waste could be eliminated if the systems were simply designed and installed properly in the first place.

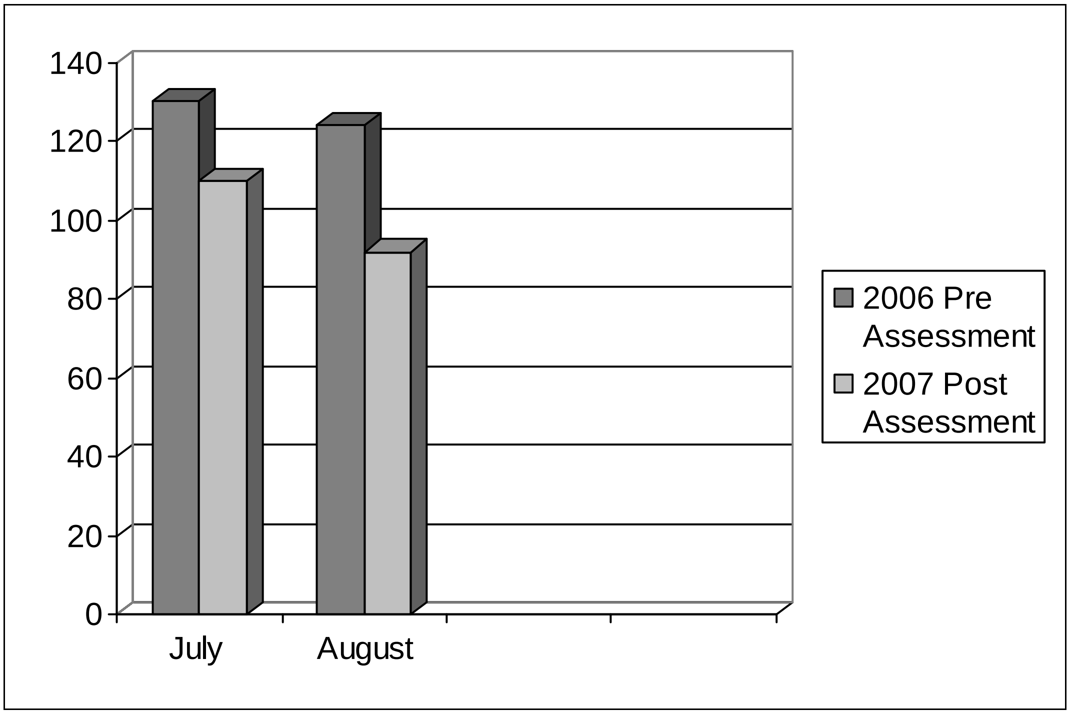

Figure 4: Average water consumption of 50 homes: pre- and post-irrigation system assessment measured in cubic metres.

Xeriscaping can reduce the need to water

The third challenge present in Kelowna's high consumption areas is the choice of landscaping. These areas are noted for extensive, manicured turf along with ornamental gardens and cedar hedges which require daily watering during dry spells. In affluent areas there is also social pressure to maintain the "perfect lawn," which has been described as an obsession for upwardly mobile people (Steinberg, 2007).

Xeriscape is a set of seven landscaping principles (which include proper soil and efficient irrigation) that can drastically reduce or even eliminate the need for irrigation once the garden is established. Xeriscaping includes the use of plants that are native to the area, which have adapted to local conditions and often require no supplemental water (City of Denver, 2008).

While *Water Smart* has promoted Xeriscaping through a series of workshops, the idea has been slow to catch on. There is local evidence that converting from a traditional landscape to Xeriscape does save water. One homeowner in Kelowna who converted to Xeriscape after the Okanagan Mountain Fire destroyed his original landscaping has seen his summer water use reduced by 34% (Figure 5).

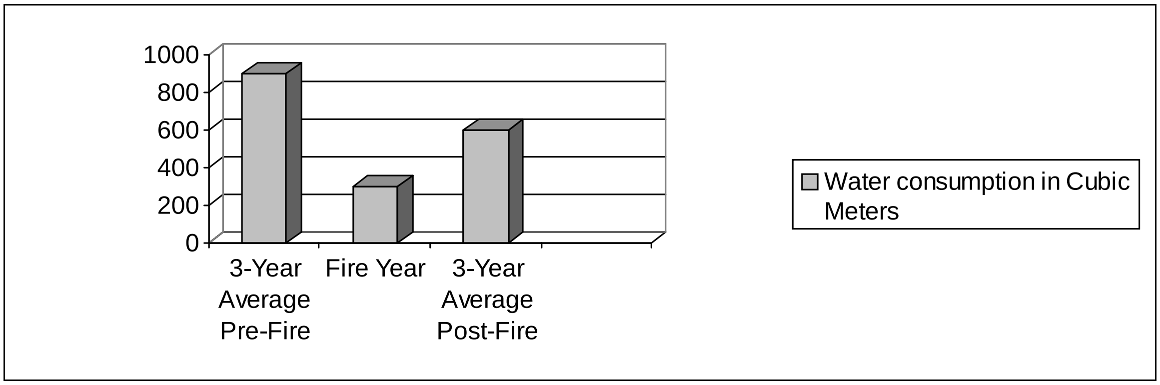

Figure 5: Pre- and post-fire average summer water consumption, 4877 Parkridge Place

Water sustainability action plan

In 2006 the utility pumped just 2% more water than in 1998, despite a 25% growth in population over the same period. However, analysis of water meter data revealed that conservation efforts, although successful, had hit a plateau. It was at this point that the utility developed a Water Sustainability Action Plan calling for a 15% decrease in overall water use, over and above the reductions already made, by the year 2012 (City of Kelowna, 2007).

The plan, adopted by City Council in early 2006, is made of the following actions:

1. Demand Side Management Programs
2. Continued Customer Education
3. Link Water Conservation to Development Approvals
4. Ensure Effective Full Cost Pricing
5. Reduce Water System Leakage
6. Ensure Use of Efficient Fixtures
7. Explore and Develop Water Reuse

While *Water Smart* programs to improve soil and irrigation systems and promote Xeriscaping were effective, it became apparent that for every existing home that benefited from these services, a new home was built that re-created the same challenges. Action Item number three, Link Water Conservation to Development Approvals, was designed to address these issues through landscape and irrigation standards for water efficiency.

Landscape and irrigation standards for water efficiency

Throughout 2006 the water utility hosted workshops with local developers, landscapers, irrigation companies, municipal staff, members of city council, and other stakeholders. The goal was to gauge industry reaction to the concept of adopting landscape and irrigation standards for all new development, and to discuss how the permitting/approval process would flow through City Hall.

On a general level, it was decided that the City will require permits for new irrigation and landscape installations, with designers required to meet a minimum standard of expertise, and to certify compliance with City standards. The standards will include:

1. Adequate soil to improve moisture retention and require less fertilizer and pesticides
2. Reduced turf and more drought tolerant plants.
3. Coordinated landscape and irrigation design to match irrigation type (hyrdrozones)
4. Proper irrigation design and installation to avoid water waste
5. More sophisticated time clock settings or weather-based controllers

The response from the industry was generally positive, although concerns were raised about the level of “red tape” required for the permit/approval process. Members of the irrigation industry expressed concern about the time requirements to obtain certification for staff, but they were assured that the standards would be phased in.

The initial goal was to phase in the new standards beginning in 2010, but members of City Council expressed interest in accelerating the process to begin in 2009.

In early 2008, a brochure was produced outlining the general concepts of the landscape and irrigation standards. These were distributed to both the industry and the public. The specific standards and requirements for landscapes and irrigation are still under development and are expected to be complete by 2008, for the phased in approach beginning in 2009.

The question at this point is how prescriptive the standards need to be. One school of thought is that requirements for soil depth, plants, and irrigation systems should be described in specific detail. Specific and prescriptive landscape and irrigation standards are common in the southwest United States, such as those adopted by the City of Perris in California (City of Perris, 2008).

Prescriptive standards would ensure that the requirements are being met, however the process could become complex because staff would be required to check permits, grant approvals, conduct site inspections and enforce the standards.

The other school of thought is that the standards should be more suggestive, and that certified irrigation and landscape designers will follow their industry’s best practices to ensure their work is water efficient. While this would simplify the permitting process, there’s no guarantee that the standards would be followed in the field

The final standards will likely fall somewhere between prescriptive and suggestive. Spot checks will be carried out to ensure the standards are being followed. If it is found that the industry is not following the standards, or have found ways to get around complying, then the standards will likely be tightened up and become more prescriptive in the future.

Low-flow plumbing fixtures can ensure that water efficiency is built in to new construction. Kelowna’s landscape and irrigation standards should ensure that water efficiency will also be “built out.”

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Delegating Water Governance: Issues and Challenges in the BC Context

Linda Nowlan and Oliver Brandes

Abstract

The UBC Program on Water Governance published a report on evolving approaches to water governance in Canada, focusing on BC, commissioned by the BC Water Governance Project, a partnership of the Fraser Basin Council, BC Ministry of Environment, Fraser Salmon and Watershed Program, Georgia Basin Living Rivers Program and Fisheries and Oceans Canada in 2007. The paper is intended to provide useful information and tools for government and other stakeholders participating in the ongoing dialogue on water governance in the province of British Columbia. It presents an independent, academic analysis of select water governance issues, focusing on 'delegated' (also known as 'devolved' or 'shared' or 'distributed') water governance.

The analysis is predicated upon a recognition that water governance has undergone dramatic changes in Canada over the past decade, characterized by three key trends: the introduction of new watershed-based delegated governance management models in a number of Canadian provinces; legislative and policy reform setting higher standards for drinking water supply in a number of Canadian jurisdictions; and greater citizen involvement in environmental policy-making and environmental management. These trends have occurred for several reasons: a shift in the view of the role and mandate of governments; new legal requirements (particularly with respect to First Nations, and also mandated by a new generation of environmental laws); awareness of the expertise available outside of government, particularly in the context of decreased government resources; new approaches to citizen participation; increased emphasis on integrated management of environmental issues and watershed based management; and concern over the implications of climate change for both water resources and supply.

With this context, the paper examines the advantages and disadvantages of delegated water governance, and discusses the questions:

- What are the barriers to delegating water governance?
- Do the potential advantages of delegating water governance to lower scales outweigh the disadvantages?
- Which issues/aspects of decisions about water should be delegated, and which should not?

The report *Delegating Water Governance: Issues and Challenges in the BC Context* is available at: http://www.watergovernance.ca/Institute2/PDF/FBCwatergovernancefinal2.pdf.

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An Optimist's View of Human Disturbance Regimes and the Future of Aquatic Ecosystems and Fisheries Resources in the Okanagan Valley

K.D. Hyatt, D. Paul Rankin, D.J. McQueen, V. Jensen, C. Alexander, M.M. Stockwell, P. Askey, and H. Wright

Abstract

Aquatic ecosystems in the Okanagan Basin have been subjected to "disturbance regimes" that are increasingly influenced by activities associated with global and local human population growth which shows no sign of abating. Disturbance regimes induced by global and local effects of human population growth and development increasingly threaten the integrity of "services" provided by aquatic ecosystems. Southern interior temperatures have warmed by approximately 1.5°C over the past 50 years and recent year hydrographs have been characterized by lower average snow-pack and an extended period of late summer drought reflecting impacts of global climate change on local aquatic ecosystems. Virtually all portions of valley-bottom, aquatic ecosystems in the Okanagan exist on a continuum from moderately disturbed (e.g., pelagic zone of Okanagan lake) to severely degraded (e.g., riparian zone and channel of Okanagan River). This circumstance is attributable to decades of physical alterations to near-shore, riparian and wetland habitats; water regulation, changes to nutrient loading rates, and exposure to multiple waves of invasion by exotic species. Taken together, these changes have profoundly influenced cold-water fish populations and their associated fisheries over the past century. Most undesirable changes to aquatic ecosystems and the fish populations they support in the Okanagan are attributable to human impacts. Thus, management of the latter through directed interventions to conserve, protect and restore aquatic ecosystem elements is required if they are to retain some semblance of their historic character (e.g., healthy populations of anadromous and resident coldwater fish supporting sustainable use by human populations).

Development of an ecosystem based management (EBM) framework has been proposed as the key to maintenance of healthy aquatic ecosystems and the reversal of both fisheries declines and increasing risks of native species extinctions. Although development and maintenance of a truly effective EBM framework is constrained by physical, biological, social, economic and political realities, several recent initiatives provide encouraging signs that sufficient flexibility remains to adaptively manage combinations of these elements to achieve progress to this end in the Okanagan. Contributing factors to be discussed include: the recent emergence of improved collaboration among several levels of government, improved knowledge of cause and effect associations between human activities and aquatic ecosystem state, development of new resource management tools and the surprising resilience of some native fish species.

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The Okanagan Water Supply and Demand Project

Anna Warwick Sears

Abstract

Water availability has been a long-standing and contentious issue in the Okanagan, shaping land use and development patterns, and driving our economy. As we enter the 21st century, the Okanagan is experiencing one of the fastest population growth rates in Canada, and climate change projections indicate that the valley's already-arid environment will become more variable, with more frequent drought years. The goal of the Okanagan Basin Water Supply and Demand Project is to develop a water budget, using the best available science to estimate present and future water needs and availability, taking into account population expansion, climate change, land use change, preservation of the environment, and other factors. The last water evaluation of this magnitude was the Okanagan Basin Study in 1974. The project consists of a series of studies, reports and modeling efforts to describe water use and demand, surface water hydrology, groundwater, and climate scenarios for 81 separate nodes in the Basin. The results of this effort will have far-reaching impacts for water management, licensing and infrastructure planning and decision making. The project is being conducted as a joint partnership of eight different agencies representing four orders of government.

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Water Information Management in the Okanagan Basin: Progress and Lessons

Clint Alexander

Abstract

The previous Okanagan Basin conference on water (CWRA 2005) called for the creation of a single Okanagan Basin Information Network (OBIN) to link existing data sources and make information readily available for decision makers. The mandate of the OBIN included an initial user needs assessment, establishing data quality standards, identifying priority gaps and a long-term funding plan. This paper focuses on information management progress since the 2005 conference, emphasizing products that will be generated by the 2007-2009 Water Supply and Demand Project. The paper emphasizes the discipline required to select, present and disseminate the most suitable data for multiple audiences, in addition to other success factors. Important water management questions exist at different scales and levels of detail, a fact that is often underestimated or 'lost in the excitement'. Here, information management projects too often attempt to be all things for all people, collapsing under the weight of their overgrown expectations. Instead, a distributed approach to information system development with standards coordination designed to connect up with value added synthesis tools is advocated. A highly collaborative OBIN service with sustained funding and a dedicated champion capable of staying in tune with its primary audience will go a long way toward enhancing regional understanding of current issues and future trends, truly helping to catalyze better water management decisions.

"Where is the knowledge in all the information?
Where is the wisdom in all the knowledge?"
- T.S. Elliot

Introduction

The previous Okanagan Basin conference on water (CWRA 2005) called for the creation of a single Okanagan Basin Information Network (OBIN) to link existing data sources and make information readily available for decision makers. The mandate of the OBIN included an initial user needs assessment, establishing data quality standards, and identifying priority gaps and a long-term funding plan. The majority of 2005 conference plenary participants agreed that water information needed for *decision making* should be a higher priority, and the management and distribution of this information carefully coordinated. The idea for an OBIN is not new, town hall meetings held by the British Columbia Freshwater Institute (BCFI) led to a proposal to develop an OBIN to support better management of basin water information. Likewise, one of the

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conclusions reached by participants of the March 2004 "Running On Empty? Water and Our Common Future" workshop was the need to overcome the lack of research and monitoring information at the basin-wide scale. Indeed, long before these events, the 1974 Okanagan Basin Study (OBA 1974) recommended establishing a central clearinghouse for water related information and data.

The goals for an OBIN (and its thematic relatives) have varied somewhat over time, depending on the proponent. For example:

- Provide a single *portal* for researchers, planners and professionals *to discover data* ("a one-stop-shop internet portal for Okanagan environmental information")
- A *single repository* for data and studies related to water
- *Increase information exchange*, greatly enhancing regional awareness and understanding of current issues and future trends, thereby contributing to better decisions

The remainder of this paper summarizes the priorities and rationale for water information management in the Okanagan, emphasizing key attributes that generally drive the success or failure of any information management project, including an initiative like establishing an OBIN. A partial listing of Okanagan Basin water information tools is also given for readers interested in further researching this subject[1].

Priority Needs

Wise decisions require quality, reliable data at the necessary scale/resolution *and* people who are enthusiastically willing to work with this information. Inadequate data (missing, biased, unreliable, not available in a timely fashion, etc.) is often used as an excuse to delay difficult decisions or justify business as usual behaviors. This inadequacy can be real (scientific limitations) but other times is the product of a lack of ingenuity, dedication or perseverance. Overall, when lined up alongside difficult value trade-offs (i.e., willingness to make multiple interests equally unhappy) and solve multi-jurisdictional governance, lack of information is a major barrier to priority-setting, education and sound decision-making.

Several technical User Needs Assessments (UNA) have been held throughout the Okanagan Basin under various headings and for various reasons over the last few years. Amongst others, these include the Water Supply and Demand UNA (Alexander and Robson 2007), the sustainable planning for the Okanagan environment (spOke) UNA (spoke.pyr.ec.gc.ca/) and the OBIN needs survey (West Coast Consulting 2003). These assessments identified many goals and requirements, the most important one being to provide access to consolidated, basin-wide, science-based information to support water and land use decision-making. The most important organizing concept for satisfying these needs:

- Determination of the current basin-wide Okanagan **water budget**; and
- Development and execution of a plan to evaluate **future climate and population change driven effects on this water budget**.

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[1] This paper does *not* provide a comprehensive review of Okanagan Basin water information tools.

A water budget is a complete accounting of all sources, uses and losses of water including groundwater, lake evaporation, ecological (in-stream) flows and return flows (Figure 1). One of the reasons this need has emerged as a critical priority is because it is easy to match it with specific decisions that need to be made around water resources in the Okanagan. In the words of Jim Mattison (B.C. Comptroller of Water Rights), "*Frame the big picture question around whether we should reject a water license application. This is never popular, so we need a credible scientific water budget and related decision support tools that allow stakeholders to see and understand the* ***rationale for a water license decision***" (pers. comm. 2005).

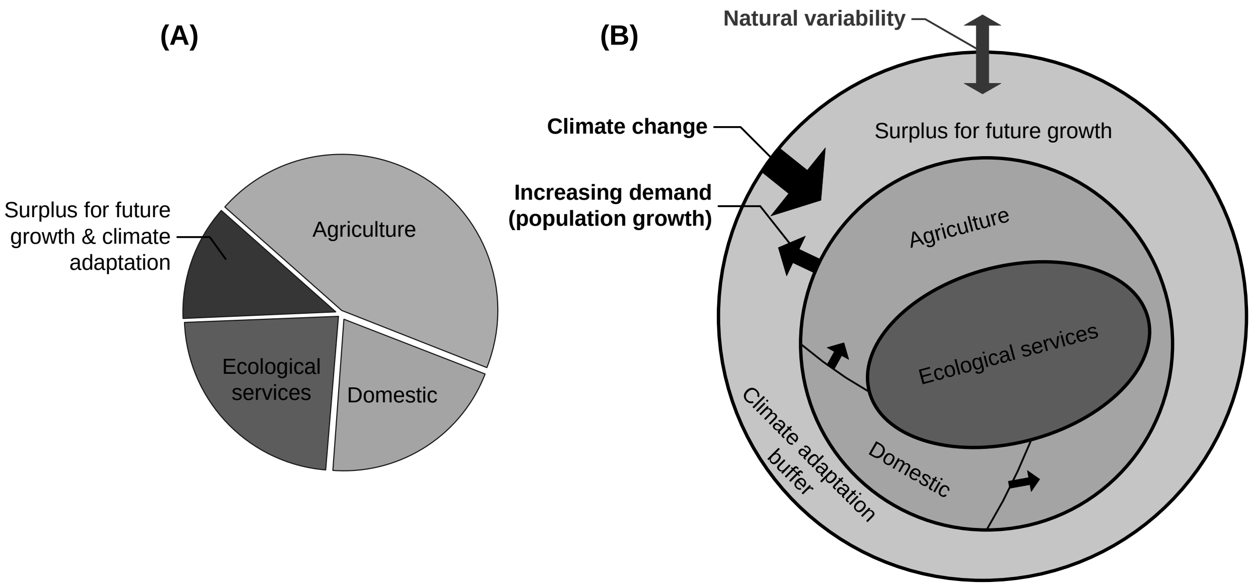

Figure 1: Two alternative conceptual models for a water budget: (a) as a static pie with slices allocated to major sectors and more perceptively (b) as an interconnected set of spheres, building outwards from ecological services, to human uses then to a water supply and climate adaptation buffer. The water budget in (b) is not static, but reflects climate change acting to reduce water availability at the same time as human demands increase, all while year to year variability creates uncertainty in water supplies. Not shown are important north-south spatial interconnections, where water use decisions in an upstream area impacts water availability downstream.

The next section highlights some of the recent progress towards the goal of generating a comprehensive basin-wide water budget, highlighting the role of information management and decision support tools in this process.

Recent Progress

Okanagan Water Supply & Demand Project

The Okanagan Basin Water Supply & Demand project is the first comprehensive water budget study conducted for the region in 35 years. The goal of the project is to provide a best estimate of present and future water need and availability, taking into account population growth, climate change, land use change, preservation of ecological services, and other factors. The project is using the best available science (Figure 2) and computer technology to generate an up to date Okanagan water budget. The project also aims to reduce a variety of critical knowledge gaps

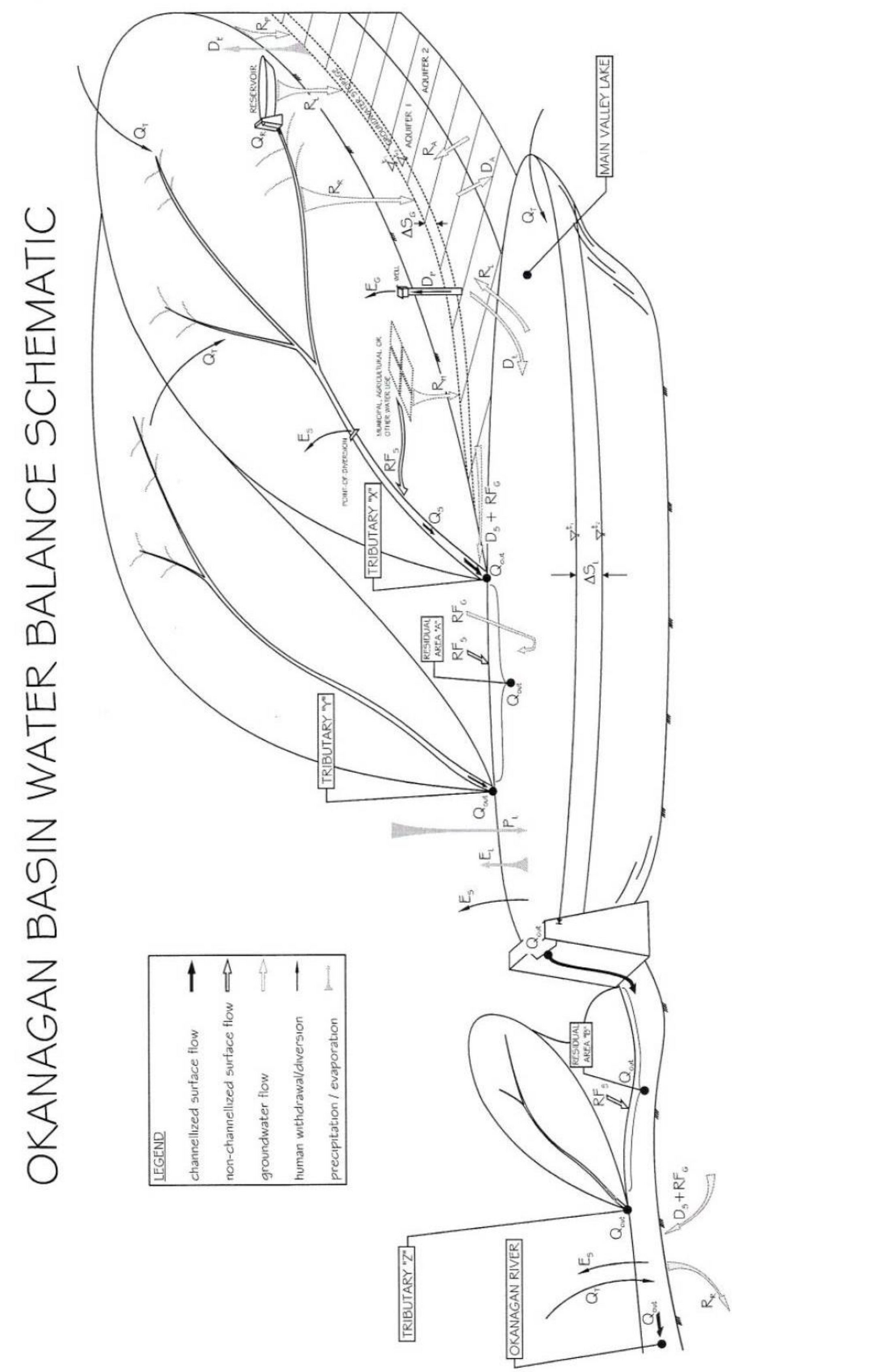

Figure 2: Detailed Okanagan Basin water budget schematic. The water balance framework used defines nearly 60 water variables. *Source*: Summit Environmental Consultants Ltd.

(e.g., groundwater supplies, lake evaporation rates, in-stream flow needs) and its outcomes will have significant implications for water related planning and decision-making in the Okanagan, in particular water licensing and land-use policy. Water budget information is at the core of rationale decision making in these domains. The study is being conducted as a partnership between the Okanagan Basin Water Board and the BC Ministry of Environment, with significant contributions from the BC Ministry of Agriculture, the BC Ministry of Community Services, Environment Canada, Agriculture Canada, Fisheries and Oceans Canada, and the Okanagan Nation. The current phase of the project is expected to be completed in 2009.

Information products from the Water Supply & Demand project will include:

- A cutting-edge, comprehensive web-enabled water balance database, called the Okanagan Water Database (OkWaterDB, Figure 3)
- A high-resolution, GIS-based agricultural crop water demand model
- Hydrogeologic models for surface and groundwater interaction (incld. naturalized streamflow datasets for ~80 sub-basin nodes)
- A water balance model for the Okanagan basin
- Climate change modeling results
- State-of-the-Basin reports on water supply and water use needs and trade-offs

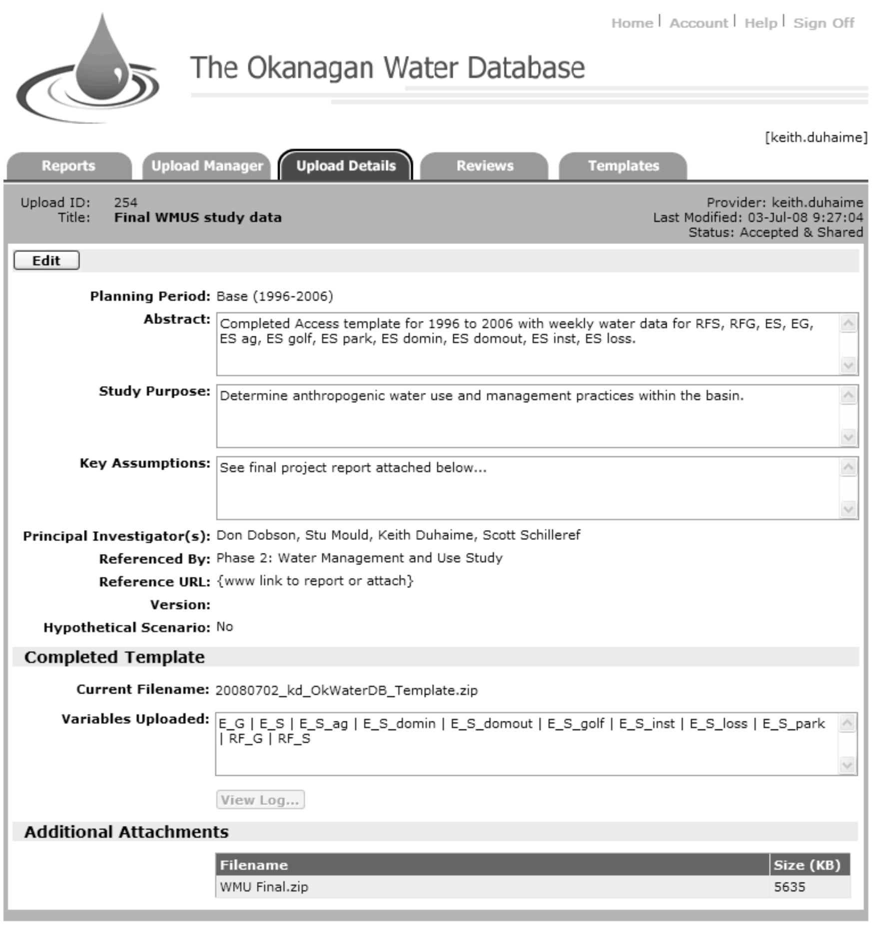

Figure 3: Screen shot of one element of the Okanagan Water Supply & Demand project's Okanagan Water Database (OkWaterDB).

The Water Supply and Demand UNA (Alexander and Robson 2007) identified a summary output approach involving exceedance plots tied to hazard maps. Participants were unanimously in support of ‘traffic light’ hazard coded map displays that quickly communicate the status of water availability. It is hoped that these types of results (Figure 4; Figure 5) will be a showcase synthesis output available from the Water Supply and Demand project. This output yields information that decision makers, not just technical experts can understand and use. Furthermore, different value judgments about desired/acceptable conditions can be readily expressed/built-into the approach.

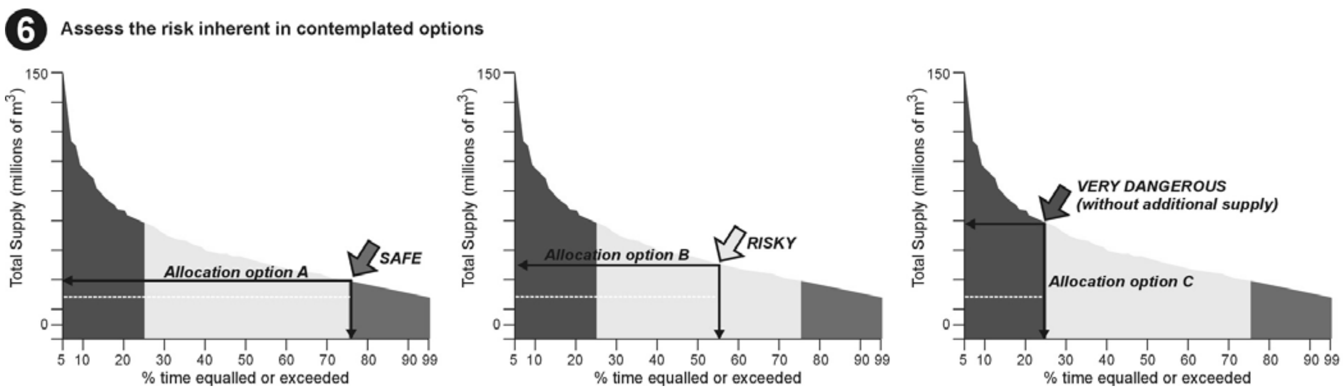

Figure 4: Example of the exceedance plot output approach for summarizing the inherent uncertainty and risk in time series data. By dividing these plots into different “hazard risk zones” (darkest shade = “red”, leftmost areas; lightest = “yellow”, middle areas; medium dark shade = “green”, rightmost areas) and plotting existing water demands (horizontal dotted line), the ability of supplies to reliably meet new water allocation options can be assessed. The best options are those that fall in the “green” (rightmost range, medium dark shade). Understanding this “traffic light” foundation, one can then move to a more intuitive graphical display – Figure 5.

There is a major education goal associated with these maps: a given sub-basin node might be ‘green’, but this does not necessarily mean that there will be additional water to allocate at that location. Doing so may negatively impact downstream sub-basin(s) – i.e., turn them ‘red’ even while the upstream sub-basin suggests there is surplus water availability (Figure 5). Unlike other types of outputs, these maps move water managers to a basin-wide perspective, rather than a “my backyard only” view of water allocation decision making.

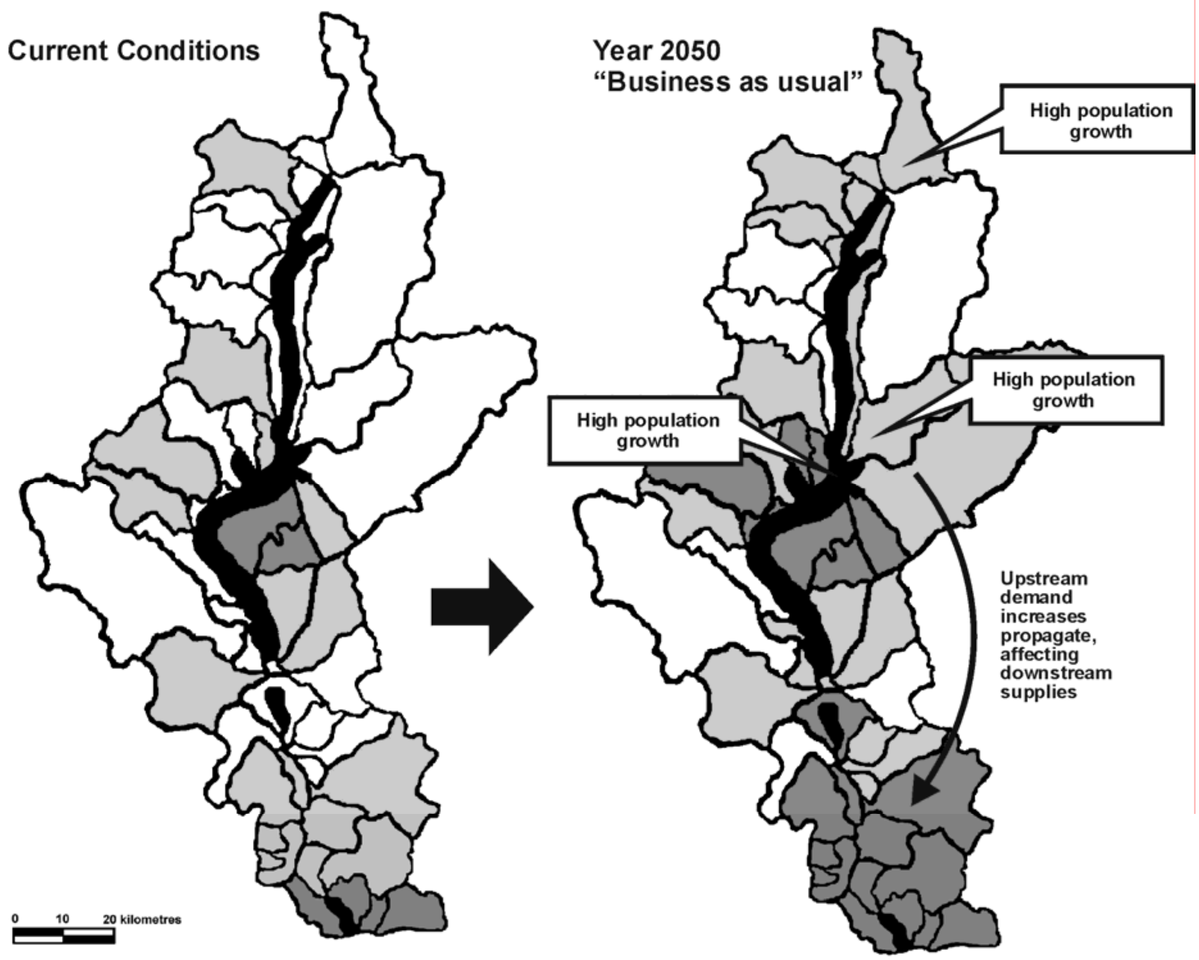

Figure 5: Hypothetical watershed sub-basin maps comparing different scenarios of water supply and demand linked to "traffic light" exceedance plots (Figure 4). In this made-up example "yellow" (medium shaded) sub-basin water demands are met between 25%-75% of the time. "Red" (darkest shaded) sub-basin water demands are met less than 25% of the time. "Green" (lightest shaded) sub-basin water demands are met more than 75% of the time. Using these maps, managers could rapidly assess how decisions in one sub-basin change water availability within that location, as well as downstream sub-basins.

Other Areas of Progress

The Water Supply & Demand project is only one area generating water information products. In the interest of brevity, other examples are not detailed here, but interested readers may consult Table 1.

Table 1: Other examples (incomplete) of water and land-use information management and decision support products relevant to the Okanagan Basin (and Canada), by category.

<table>
<tr><th>Discovery portals & news/education sites</th><th>Geospatial catalogues & mapping products</th><th>Internet enabled databases & reporting systems</th><th>Multi-objective decision support simulation models</th><th>Discipline specific research models (+ major publications)</th></tr>
<tr><td>Sustainable planning for the Okanagan environment (Spoke) spoke.pyr.ec.gc.ca/</td><td>Community Mapping Network (CMN) www.shim.bc.ca/</td><td>Okanagan Water Database (OkWaterDB) www.essa.com/okwaterdb</td><td>Okanagan Fish/Water Management Tool (FWMT) <evaluates impacts of different weekly water releases from Okanagan Lake dam> www.ok.fwmt.net ; www.obtwg.ca/</td><td>Okanagan agricultural crop water demand model (Ted van der Gulik Resource Management Branch BC Ministry of Agriculture and Lands, Abbotsford)</td></tr>
<tr><td>WaterBucket www.waterbucket.ca/</td><td>GeoDiscovery Portal (Natural Resources Canada - CGDI) geodiscover.cgdi.ca/gdp/index.jsp?language=en</td><td></td><td colspan="2">Okanagan Sustainable Water Resources Model (OSWRM) (Langsdale et al. 2006)</td></tr>
<tr><td colspan="2">ResEau map.ns.ec.gc.ca/reseau/en/</td><td></td><td>Okanagan QUEST / SIM Okanagan <ultra high-level alternative futures gaming tool> www.okanaganpartnership.ca ; www.ourokanagan.ca/sim/website.html</td><td>UBC Watershed Model (Quick 1995)</td></tr>
<tr><td>Natural Resources Information Network (NRIN) nrin.forrex.org/</td><td>BC Integrated Land Management Bureau / GeoBC ilmbwww.gov.bc.ca/bmgs/</td><td></td><td></td><td>Integrated Assessment of Water Management and Climate Change in the Okanagan Basin, British Columbia (Cohen and Neale, 2006)</td></tr>
<tr><td>Farmwest website www.farmwest.com/index.cfm?method=climate.showclimate</td><td>Okanagan Lake Foreshore Inventory and Mapping (Regional District of Central Okanagan)</td><td></td><td></td><td>From Impacts to Adaptation: Canada in a Changing Climate (Lemmen et al. 2007)</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Mike SHE www.dhigroup.com/Software/WaterResources/MIKESHE.aspx</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Water Use Analysis Model (WUAM) www.ec.gc.ca/WATER/en/info/pubs/sss/ss28.pdf</td></tr>
</table>

Attributes of Successful Scientific Information Management Initiatives

Figure 6 presents a summary graphic of the major success attributes and barriers to information management initiatives. These ideas are derived from “home grown” observations made working with the Canadian Okanagan Basin Technical Working Group on the BC Premier's Award winning Fish/Water Management Tool’s project since 2001, along with several other large-scale water related decision support software projects in California. In the context of the OBIN, a couple of the more significant of these attributes are described further below.

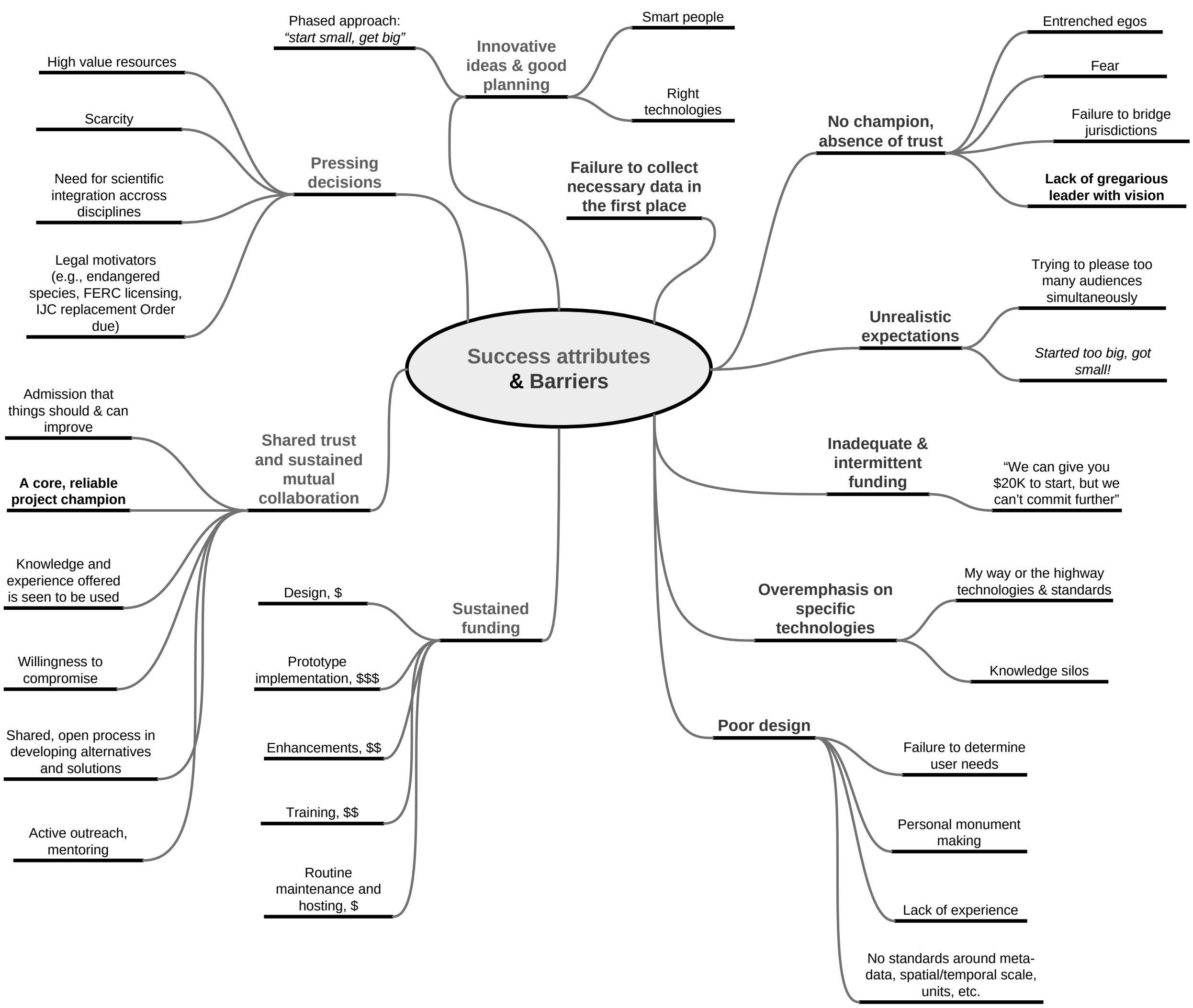

Figure 2: Summary of the major success attributes (left side) and barriers (right side) to information management initiatives.

Avoid Trying to be a Jack of All Trades

There are a wide variety of user needs for water information and decision support tools (Figure 7). It is a major error in expectation management to attempt to meet all of these needs with any one solution. While single point of entry portals are useful for the tasks of *data discovery* and *synthesis reporting*, tasks such as compiling, archiving and providing access to source models is best handled using a decentralized distributed system approach. This is the direction in which most scientific database projects have evolved (e.g., ISRP 2000). This is because needs are so diverse and the people who know and work with specific systems day to day understand best how to operate, interpret and train others. “Modularizing” various tasks and functions (e.g., data archiving) and giving this responsibility to multiple parties is often a more practical solution than a one-stop-shop – *so long as important high-level standards are followed* (e.g., storing critical metadata, standards for “mapping” the data fields between technologies or reconciling different spatial and temporal resolutions). This is akin to giving an orchestra the same music sheet – the instruments will sound different, but they will be in harmony, playing the same tune.

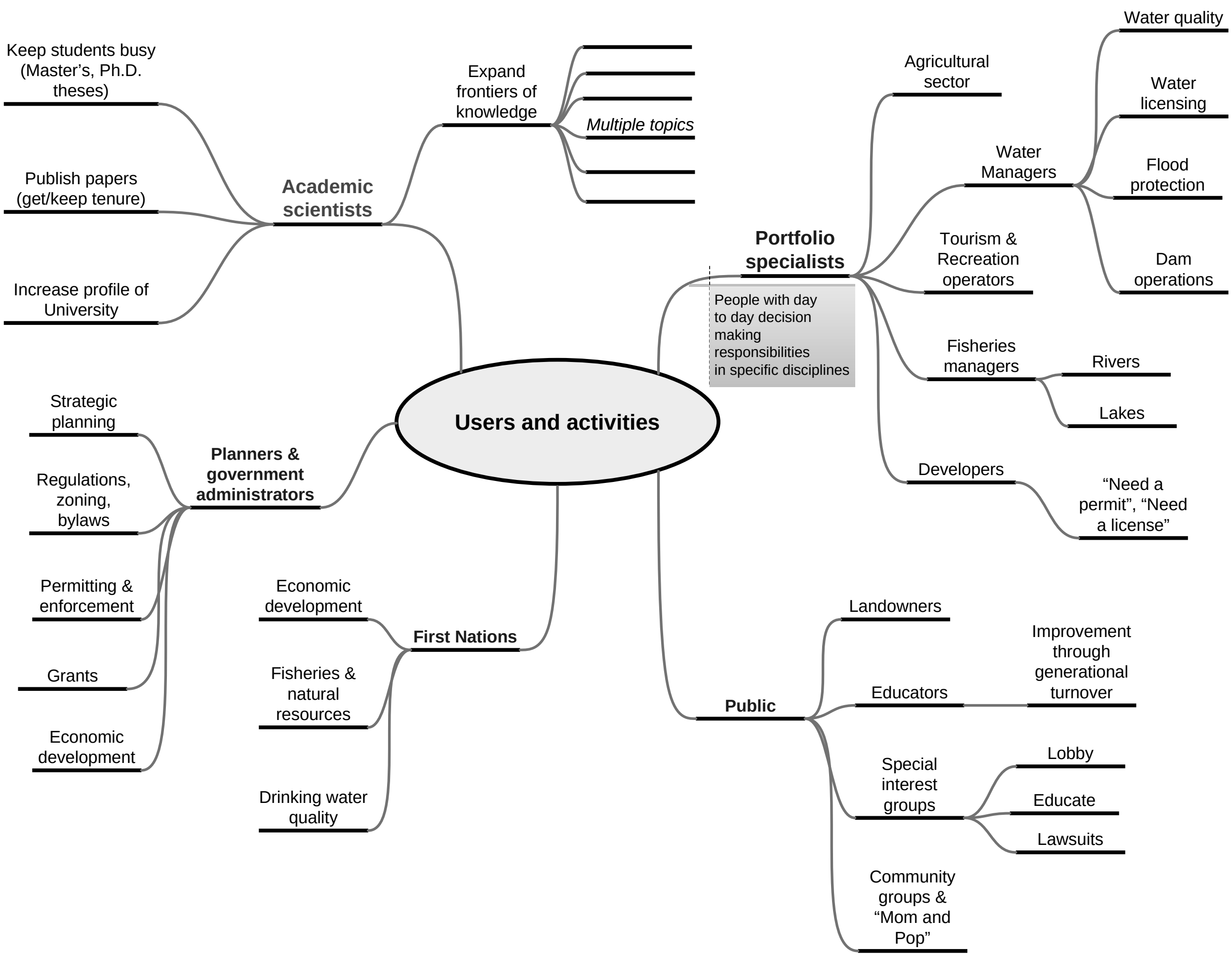

Figure 3: A diverse range of users leverage scientific information in different ways and at different levels of detail to assist in completing a multiplicity of tasks. It takes many information systems to meet all of these needs.

This does not imply that value added materials cannot be made available through a higher level system; merely that attempting to solve all user needs in one place is unrealistic. Because the articulation of a specific need will arise from an individual community of users, meeting these needs will occur most efficiently within a decentralized distributed system approach that defines connections to the higher level synthesis tool(s). This may be as simple as a web link to the other tool, or be a sophisticated web service that is added to one or more of the distributed tools that lets users get at the raw data (e.g., Environment Canada's real time hydrometric data service, http://scitech.pyr.ec.gc.ca/waterweb/disclaimerB.asp).

Focus on Specific Pressing Decisions

Information system projects are more likely to succeed where the tools developed are specifically focused on pressing decisions that need to be made (repeatedly). Pressing decisions are typically the ones most likely to sustain the development of a decision support tool, an act which often requires years rather than months to complete. If proponents of an information system cannot readily connect how their tool directly enables users to make an important decision, then it is assured that tool won't be widely used (Figure 8). For example, the aim for an information system of "increasing information exchange to improve understanding of complex land and water issues and contribute to more effective decision-making" is not entirely clear. *What* decisions will it support? Experience shows that these applications are quickly forgotten after the builders or marketing team leave the scene. This is a delicate point, and brings us back to the need to understand the difference between data discovery vs. the more complex functions needed to make a specific decision (e.g., about a water license or setting releases at Okanagan Lake dam). When a decision support tool doesn't yet exist to tackle a specific question head-on (e.g., like the Fish/Water Management Tool's ability to evaluate multiple performance measures associated with Okanagan Lake dam releases), users are still faced with one or more of the following quandaries: Where are the latest data for beginning the process of addressing my problem? How do I get access to a particular data source? Has this data been quality controlled? What are limitations that exist for using them? Who do I contact to find out more about these data? Tools that increase information awareness and exchange *in this context* are a worthwhile pursuit as an early step in the larger decision-making process. However, this step is just the first of many – the most useful decision support tools go much further.

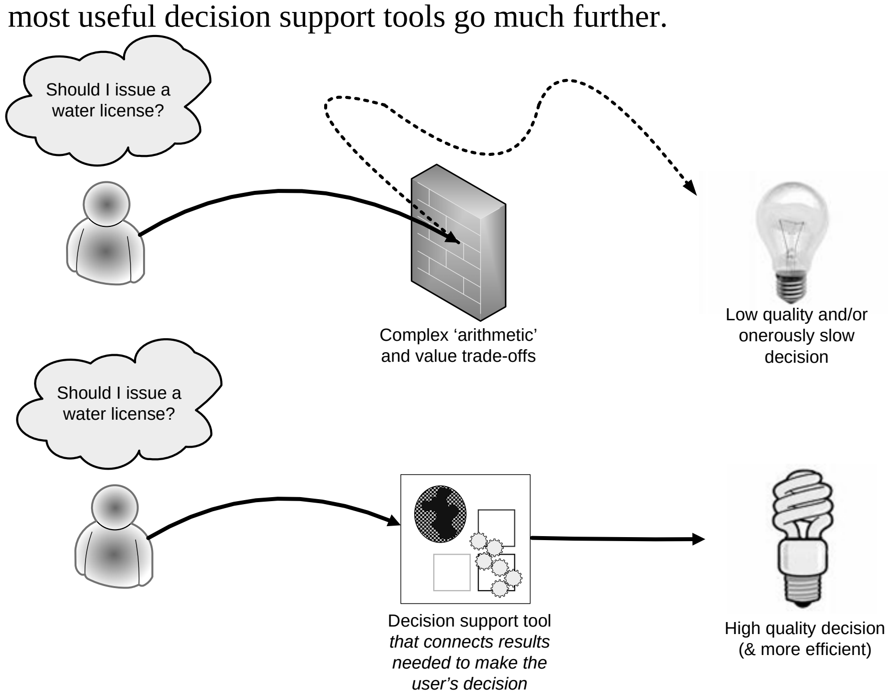

Figure 4: Decision support tools that connect directly to specific decisions that need to be made and synthesize information across disciplines will be the ones that get used. If well designed and implemented, they also improve the quality (and efficiency) of decision-making.

Start Small, Get Big

It is a challenge determining what amount of resources are worthwhile to invest in an information system. The best advice is to start small, focus on aspects of the problem for which the most pressing decisions exist, gather user feedback, improve, and get bigger over time. The matrix in Table 2 offers a helpful guide for evaluating the merits of directing different amounts of resources at an information management project.

Table 2: Important considerations for guiding decisions on the investment worth making in an information management tool or decision support system, with Okanagan Valley examples.

	No. of routine users*	**Frequency users re-visit specific decisions**	**Scientific research & synthesis requirements$^{\delta}$**	**Justifiability of sophisticated information management (IM) systems (prudent IM investment)**
Skaha sockeye reintroduction datasets	~ 5	~ 4 to 6 times a year	Moderate	**Low ($)**
Fish/Water Management Tools (FWMT)	~ 10	> 20 times a year	High	**High ($$$)**
Okanagan Irrigation Water Demand Model	~ 3	~ 1-2 times a year	Very High	**High ($$$)**
Okanagan Water Database (OkWaterDB)	> 100	~ 2 to 4 times a year (summary reports would be accessed multiple times per month)	Moderate-High	**High ($$$)**
WaterBucket.ca	>800	n/a	Low	**Moderate ($$)**

* People who would directly operate the tool or access the reports it offers (live).

$^{\delta}$ e.g., Tool requires integration of complex algorithms, or involves standardized calculations over a vast spatial scale. In other words, calculations cannot be efficiently performed “in ones head” or on the corner of the desk.

Conclusion

A centralized champion like the Okanagan Basin Water Board (OBWB) capable of sustaining an effort to make an OBIN happen is a critical step. The OBWB brings an understanding of evolving water management priorities, objectives and trade-offs at the basin-wide scale, and is committed to increasing awareness and education. However, even with an OBIN initiative, various entities throughout the Okanagan Basin will earnestly continue to focus on their own information projects. This is not “a problem”. That said, and while this paper *has* argued in favour of a decentralized, distributed approach to information system development, failure to increase awareness over what systems best serve different decision making needs will reduce opportunities to further leverage data and cause duplication of effort. Furthermore, the historic lack of a dedicated champion with sustained funding has been a limiting factor on what information management and decision support practitioners can accomplish. A focused OBIN service that is sufficiently resourced with trained staff and secure funding – who observe the success factors outlined in this paper – will go a long way toward enhancing regional understanding of current issues and future trends, truly helping to catalyze better decisions.

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Communication and Trust Building: A Focus on Water Resource Management

Nelson R. Jatel

Abstract

Communication in the arena of water management, bridging science and policy, in the Okanagan evoke some interesting questions: Why is communicating water management ideas in the Okanagan challenging? What communication strategies were developed over the past 35 years? What unique and new communication strategies have been developed recently? What tools do we need to develop and implement in the Okanagan in order to successfully communicate important water issues? Communication at a fundamental level requires a sender, a receiver and an understandable message. The Okanagan Basin Water Board (OBWB), a unique local government water management body, has an opportunity to learn from previous locally developed communication strategies and create a new forward looking strategy based on trust and clarity. A communication strategy will take into account various audiences including, local government, senior governments and the public.

Communicating water management ideas in the Okanagan has layers of complexity as a result of a number of factors:

- within the semi-arid Okanagan, large mainstem lakes falsely portray abundant water;
- climate change impacts are likely to increase variability resulting in an increased periodicity of significant wet and dry years; and
- although there is one shared water in the Okanagan, precipitation varies from north to south and from valley bottom to the upper plateau – translating into a need for varied sub-basin responses to drought and storage opportunities.

In addition to the myth of abundance, the Okanagan, like many Canadian watersheds, is multi-jurisdictional. The Okanagan contains three regional districts, 14 municipalities and four aboriginal communities.

Compounding a multi-jurisdictional policy environment and spatial and temporal variation inherent to the Okanagan's hydrology is the multidisciplinary arena of Limnology that incorporates subjects that range from chemistry to biology to geology. These traditional disciplines operate in silos – with unique language and terminology has traditionally not provided for strong, unifying policy recommendations. In contract, the current Okanagan Supply and Demand project is one example where a multi-disciplinary scientific framework has been developed, complemented by strong project management and communication strategy to ensure the development of good water science to support policy in the Okanagan Basin. This project is one example of communication success.

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During the Okanagan Basin Study in the early 1970s, it was identified that public input towards the planning and management of water and related resources in the Okanagan occurred in a haphazard way. As a means to develop a succinct communication strategy the1972 Basin Study implementation team developed a public involvement planning strategy called the Interested-based Planning Model (IPM). The IPM identifies a number of key findings including: strategic process elements, successes, areas for improvement and insights to support developing future Okanagan water communication strategies.

In the Spring of 2005, the Canadian Water Resources Association hosted a significant water conference titled: Water – Our Limiting Resource, Towards Sustainable Water Management in the Okanagan. Outcomes of the communication strategy resulted in significant impacts to water management in the Okanagan and specifically created a new water management function for the OBWB.

Building on the lessons learnt from the IPM strategy developed in the 1970s and the recent 2005 communication models – a roadmap for considering future communication strategies is developing. Emphasis needs to be placed on integrating various activities including the Okanagan Sustainable Water Strategy, the Water Supply and Demand project and ongoing activities of the OBWB water management function. The OBWB has a historic opportunity to act on the recommendations put forward by the Water Stewardship Council and integrate lessons learned and best practices to build on old relationships – including aboriginal people, forge new ones and create and environment of open, ethical water management decision making. The OBWB's ability to demonstrate leadership and continue to develop proactive, adaptive management strategies is critically important. In the Okanagan there is an opportunity to ensure that water resource management responds to- and does not react to- future drought, climate change and the safe drinking water and water quantity needs of a growing population.

The Osoyoos Lake Water Science Forum

Clint Alexander

Abstract

The Osoyoos Lake Water Science Forum, held September 16-18, 2007 in Osoyoos, British Columbia, was attended by over 190 enthusiastic and concerned presenters and participants representing the scientific community, government, business and residents from both Canada and the United States. The Forum reflected the growing public concern for the sustainability of Osoyoos Lake, its water quantity and quality, and the growing sense among area residents that their quality of life is threatened. Concerns were raised over ongoing water quality problems in Osoyoos Lake, the potential for future wars over water supplies, the need for sustainable land-use planning, and the restoration of endangered habitats and species populations. Osoyoos Lake is one of the few water bodies in Canada that straddles the U.S. border, and requires formal international collaborative governance. There was recognition of the importance of both the Canada and US governments to continue working effectively together, and to involve the First Nations and Tribes as well as local residents in decision making. Climate change was recognized as a broad concern that will affect all aspects of lake health and management. The Forum produced a total of 16 candidate actions that regulators, planners and politicians should consider to promote Osoyoos Lake (and the Okanagan Basin's) environmental sustainability. Some of these have already begun to be implemented. The thoughtful participants of the Osoyoos Lake Water Science Forum are part of a growing water sustainability movement in the Okanagan, a movement that will hopefully inspire governments, planners and regulators to move more purposefully and more rapidly on the issues.

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The International Watersheds Initiative: An Integrated Approach to Canada-US Transboundary Waters and its Potential Relevance to the Okanagan Basin

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Abstract

At the request of the governments of Canada and the United States, the International Joint Commission (IJC) is implementing the International Watersheds Initiative (IWI). The aim is to promote an integrated, ecosystem approach to issues arising in transboundary waters through enhanced local participation and strengthened local capacity. The IWI was conceived to facilitate the development of watershed-specific responses to emerging challenges such as intensified population growth and urbanization, global climate change, changing quantity and uses of water, pollution from air and land, and introductions of exotic species. The underlying premise is that local people, given appropriate assistance, are those best positioned to resolve many local transboundary problems. The initiative is being piloted in four river basins. In response to expressions of interest on both sides of the British Columbia/Washington State border, the IJC is ready and willing to facilitate a better integrated, binational approach to the Okanagan River/Osoyoos Lake basin. This paper describes the kinds of coordinated binational activities that might be feasible initially in Okanagan/Osoyoos area, and outlines the steps that, if locally desired, could lead eventually to the establishment of an international watershed board. A first map of the Okanagan drainage area, created using merged and harmonized Canadian and U.S. hydrographic data, is presented.

Introduction

Water managers, planners and environmental scientists broadly recognize the advantages -- and indeed the imperatives -- of adopting a watershed approach to the management of freshwater resources and the need to more explicitly marry aquatic ecosystem health with water management decisions (Bruce and Mitchell, 1995; Environnement Québec, 2004; EPA, 2008a). Although the watershed approach has been variously defined, most references to it include the following elements (EPA, 2008b): the watershed approach is geographically focused; hydrologically defined; and includes all stressors from air, land and water. It involves all interests and stakeholders (public and private), is community-based, and includes some sort of

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coordinating framework. It strategically addresses priority water resource goals, integrates a variety of programs, is based on sound science, is aided by strategic plans and uses adaptive management (i.e., management responses are refined and revised as our understanding of the system improves). In the water sector, this approach has also been referred to as integrated water resource management (CWRA, 2004; Environment Canada, 2005).

Notwithstanding the advantages of an integrated watershed approach, implementing it in a real-world situation can be a daunting task, especially so when the basin in question covers multiple jurisdictions and levels of government. The potential difficulties are exacerbated when the area of interest is bisected by an international border. In this paper we provide an overview of one approach to bringing together the various interests in a transboundary basin to resolve and to help prevent disputes, namely the IJC's International Watersheds Initiative. We also discuss possible activities that could lead to development of the IWI in an area where this approach has not yet been tried and the potential relevance and applicability of the IWI model to the Okanagan basin.

The International Joint Commission

The IJC -- a binational, independent organization established by the Boundary Waters Treaty of 1909 -- has a unique mandate to help prevent and resolve disputes relating to the use and quality of boundary waters and to advise Canada and the United States on related questions. It is therefore well placed to play a role in the implementation of a watershed approach along the common border.

The IJC consists of six Commissioners, half appointed by the U.S. President and half by the Canada's Governor General upon the advice of the Prime Minister, who are supported by a staff of about 50, with offices in Ottawa, Ontario, Washington, DC, and a Great Lakes Regional Office in Windsor, Ontario. Much of the IJC's work is accomplished through 16 boards with responsibilities oriented towards water management within specific transboundary water basins. Originally, these boards had mandates focused primarily on water quantity and quality, with separate boards for each aspect.

The International Watersheds Initiative

The IJC first articulated the need for a watershed approach in a report to the two governments in 1997 (IJC, 1997). The governments responded, in parallel letters dated November 19, 1998, that they "accepted in principle the proposal to establish international watershed boards" and asked the Commission to explore the options and develop a pilot board, in consultation with federal governments, provincial/state and local authorities, tribes, First Nations, and local interests. The early development and implementation of what came to be known as the International Watersheds Initiative are described in two reports to the governments (IJC, 2000; IJC, 2005).

The IWI approach was conceived to respond to emerging challenges such as intensified population growth and urbanization, global climate change, changing uses of water, pollution from air and land, and introductions of exotic species. These factors present a growing threat to water supply, water quality, aquatic and shoreline/riparian habitats and biodiversity.

The Initiative is based on the premise that local people, given appropriate assistance, are those best positioned to resolve local transboundary issues. Effective trust-building and problem-solving capabilities at the local watershed level can go a long way in preventing or reducing transboundary problems and potential disputes. This can reduce the need for involving either the two national governments or the IJC in a formal manner to resolve specific watershed issues.

The Commission therefore is working to strengthen the capabilities of existing IJC boards through:

- emphasizing a broader, ecosystem perspective of the watershed;
- expanding outreach and cooperation among organizations with local water-related interests and responsibilities;
- providing the tools and information needed to foster a better understanding of the issues in the watershed;
- developing a better hydrological understanding of the water-related resources; and
- creating the conditions for the resolution of specific watershed-related issues.

An important feature of the IWI is local empowerment, with the recognition that each transboundary basin is unique, ruling out a one-size-fits-all, cookie-cutter approach to watershed boards. The IWI aims to build on existing cooperative relationships and mechanisms, and foster their development.

In 2005, the Commission identified boards in three watersheds as pilots for the IWI concept: the St. Croix River, the Red River and the Rainy River. In 2007, the Souris River was added to the list of pilot boards. With support from the two governments, the IJC has been working to strengthen local capacity in these basins, providing catalytic funding for selected projects involving activities such as developing harmonized transboundary watershed maps and geographic information systems information layers, modelling river and reservoir hydraulics, and expanding outreach to the public. The St. Croix River Board is the furthest advanced in this process and in April 2007 was designated by the IJC as the first full-fledged international watershed board.

In March, 2008, the IJC organized a binational workshop in Vancouver, B.C., that included representatives from ten transboundary basins, with the aim of reviewing progress, exchanging ideas, sharing information and discussing the future direction of the IWI. Participants took note of various achievements under the IWI. They broadly endorsed the objectives of the IWI, and identified ways in which the initiative could be strengthened, including through the clearer definition of operating principles and procedures for the selection and funding of projects. There was also a recognition that the watershed approach could usefully be applied in other basins besides the four pilot areas identified by the IJC thus far.

Benefits and Challenges of an IWI Approach

Developing an international watershed board offers various benefits, both tangible and intangible. Such a board could provide a neutral framework under which agencies and interests from both countries can meet and exchange information. It could be a focal point to involve local communities more actively. It could identify gaps in existing information and knowledge and contribute to the formulation of an action plan with prioritized projects that could help fill those gaps. It could apply for funding under the IWI and other sources. The kinds of activities an IWI board could promote include mapping, data collection and harmonization, hydrological modeling and scientific assessments.

Developing an IWI board is not without its challenges. Participants would need to be willing to invest substantial time and effort initially in order to realize benefits in the longer term. Local groups and the public would need to be involved in the process from the start, so that they feel part of it. The process would need to be inclusive and open, in order to avoid any (mis)perception of outside interference and control.

Under the Boundary Waters Treaty, the IJC's role is circumscribed, and establishment of new boards would require a strong expression of local interest and a request to, and approval from, the two federal governments.

The Okanagan Basin: Geography and Jurisdictional Framework

The Okanagan (spelled Okanogan in the U.S.) River basin is a tributary to the Columbia River and covers about 23,200 km^2. Figure 1 shows the first attempt to create a unified map of the drainage basin by merging and harmonizing meso-scale hydrographic data from Canadian and U.S. sources. The basin is shared by Canada and the United States, with about 75% of the basin in British Columbia and 25% in Washington. In the vicinity of the international border, the river widens into Osoyoos Lake, a long and narrow lake covering approximately 23.2 km^2. Zosel Dam, built in 1927 about 2.7 km south of the lake, effectively controls the elevation of Osoyoos Lake, except during periods of very high snowmelt. Key issues in the Okanagan basin include the rapid pace of development and the growing population, and their possible impact on water quality and quantity and on the ecosystem as a whole.

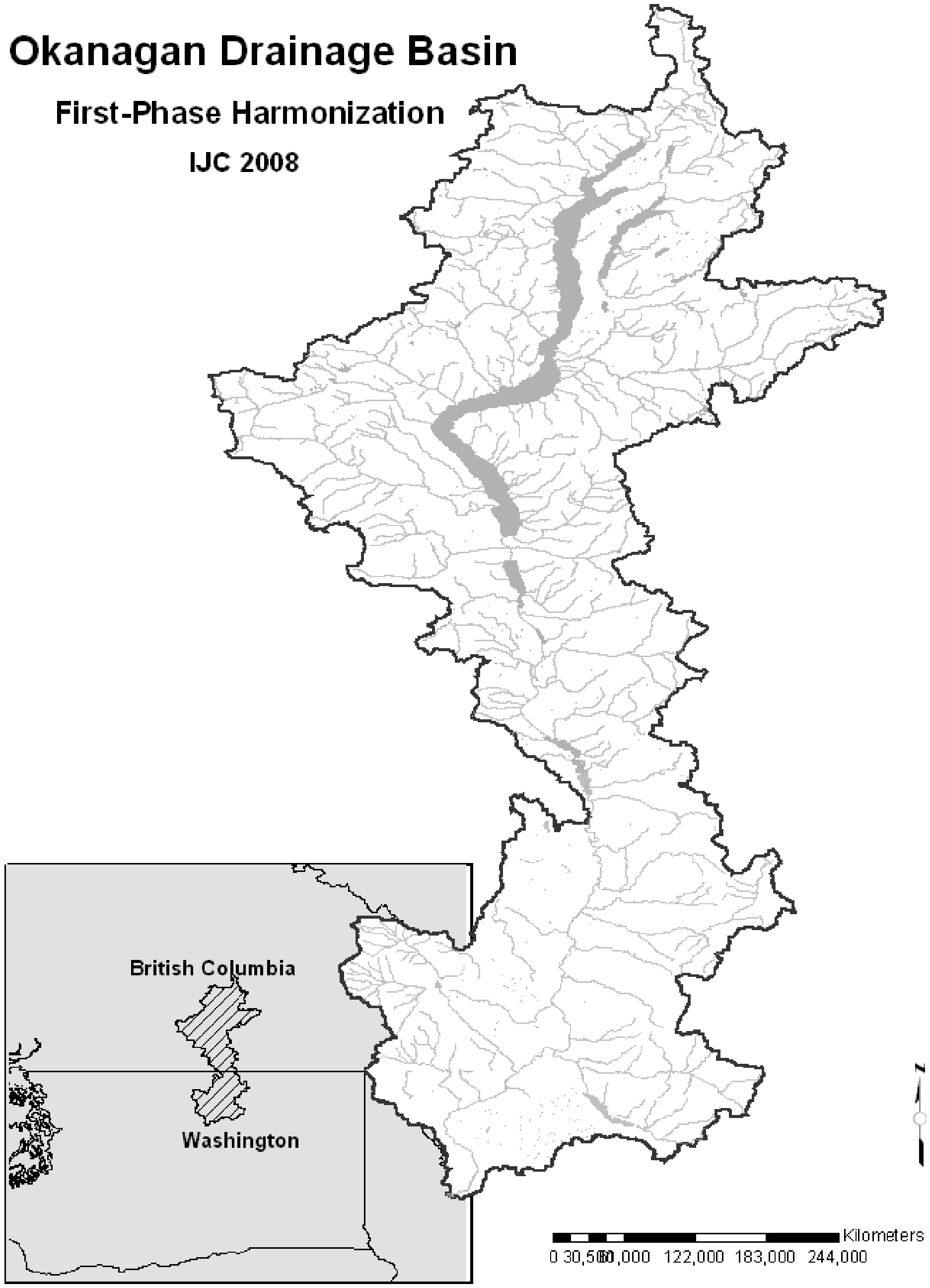

Figure 1: The Okanagan drainage area with Canadian and U.S. hydrographic data merged and harmonized. The GIS data used to create this map were obtained from online data sources publicly available on both sides of the border. The Canadian drainage area consists of an aggregation of 1:50,000-scale hydrographic working units, a component of the national Hydrographic Network (NHN). The U.S. portion is derived from the1:24,000-scale National Hydrographic Dataset (NHD). Streams and rivers depicted in the map graphic also were obtained from the NHN and the NHD products; they were not merged or harmonized. The stream networks and water bodies shown were simplified for display purposes. Elevation data shown have not been reconciled to cover the entire basin. The Canadian portion was derived from the 90-meter raster dataset downloaded from National Resources Canada's GeoBase (http://www.geobase.ca/geobase/en/index.html). The U.S. elevations were obtained from the USGS National Elevation Dataset (NED) geoportal (http://ned.usgs.gov/about.asp).

On the Canadian side of the basin, several provincial and federal entities have a role in water management, principally Environment Canada and the B.C. Ministry of Environment. On the U.S. side, the state and federal agencies with a leading role are the Washington State Department of Ecology, the U.S. Geological Survey and the Army Corps of Engineers. The only formally established, water-related, binational entity in the basin is the International Osoyoos Lake Board of Control (IOLBC), established by the IJC in 1946 to supervise the operation of Zosel Dam in compliance with the Commission's Orders of Approval. As presently structured, this board is concerned with the regulation of water flows and levels, and does not have a mandate to consider broader issues.

At present there is no permanent, ongoing mechanism to address water resource issues in a basin-wide, integrated fashion that takes into account concerns and interests on both sides of the border.

Ongoing Movement toward an Integrated Approach in the Okanagan Basin

There is evidence of growing momentum within the Okanagan Basin for a better-integrated watershed approach. Notable in this regard was the formation in 2006 by the Okanagan Basin Water Board of the Okanagan Water Stewardship Council, hailed as a major step toward coordinated regional water management – a broader approach where previously the focus had been on specific concerns such as the invasive watermilfoil and water pollution control (OBWB, 2008).

Further downstream, a noteworthy development was the Osoyoos Lake Water Science Forum, held in September 2007 (Alexander and Robson, 2007). This well-attended forum was a success largely thanks to the collaborative preparation and participation of the IJC, the OBWB, the Town of Osoyoos, U.S. and Canadian federal, state/provincial scientists Tribes and First Nations and other local presenters and participants. Among the themes emerging from the forum were the need for binational watershed planning, the importance of harmonized basin mapping and data-sharing, and a general interest in maintaining binational momentum and dialogue.

Relevant to these developments is the fact that the IJC's Orders for Zosel Dam will expire in 2013. The Commission will need to decide whether and how they should be modified, taking into account the changes that have occurred in the basin since the Orders were written in 1982. A Plan of Study is being initiated to define the various ecological, hydrological, climatic and other studies that would be needed to inform the eventual redrafting of the Orders.

Conclusion

The time seems to be ripe for a more inclusive, better integrated approach to the water resources issues of the Okanagan Basin on both sides of the border. The IWI provides a potentially useful model. Building on the existing structures and relationships within the IOLBC would be one way forward. If there is local interest, the IJC is prepared to facilitate these efforts in an inclusive way with all levels of governments, aboriginal groups, and concerned citizens and organizations. Among the possible activities that could prepare the way are public outreach and education efforts, GIS data harmonization, and various studies or assessments. The IJC looks forward to using this CWRA forum to discuss and explore the level of support there is for implementing the IWI concept, or some variant of it, in the Okanagan basin.

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Lake Tahoe: Operating in a Bi-state, Multijurisdictional Watershed

Larry Benoit

Abstract

Lake Tahoe was formed 2 to 3 million years ago by down-dropped geologic fault blocks between the uplifted Sierra Nevada to the west and Carson Range to the east. It is considered the second deepest lake and it is the highest elevation lake of its size in the United States. Lake Tahoe's surface and watershed are approximately two thirds in California and one third in Nevada providing a bi-state and water dispute basis of management. Lake Tahoe occupies approximately two fifths of the total Tahoe Basin watershed area including two counties and one incorporated city in California, and three counties in Nevada. Disputes over Lake Tahoe water between the states and other parties such as the Pyramid Lake Piute Tribe have existed for over 100 years and are proposed to be finally resolved by the US Congress' ratification of the Truckee River Operating Agreement expected by 2010. Water rights that will be administered under the agreement were assigned to the California and Nevada portions of the Lake Tahoe Basin under the California / Nevada Truckee River Interstate Compact signed by the two states in 1970-71, but not ratified by Congress. The legal Lake Tahoe elevation by Federal Court decree is 6229.1 ft., and the top 6 feet to the natural rim of 6223 ft. is operated as a reservoir by the US Bureau of Reclamation with a dam at the Tahoe City, California outlet. Lake Tahoe is designated as an Outstanding National Resource Water. The bi-state / Federal Tahoe Regional Planning Compact (1969, and updated in 1980) authorized the formation of the Tahoe Regional Planning Agency as the planning and land use regulatory authority in the Tahoe Basin. The Compact also required the agency to establish environmental standards, adopt and enforce a regional plan and implementing ordinances which will achieve and maintain such standards, and provide opportunities for orderly growth and development consistent with such standards. A restrictive clause states "No provision of this compact shall have any effect upon the allocation, distribution or storage [of] interstate waters or upon any appropriate water right."

A Lake Tahoe Story

Lake Tahoe has had several names, and there are many versions of the Lake Tahoe story. This limited one will attempt to rely on historic facts and descriptions, and predecessors ancient and otherwise, contemporary professionals in a variety of technical fields, in an honest effort to present a story while not trampling on the rights of others who have told such stories or covered such information. References are provided as much for further reading, as for source documentation and I trust that I may be forgiven for references that are not attributed to an original source.

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Before the “white or European discovery” of Lake Tahoe in 1844 by General John C. Freemont, one of the resident Washoe Tribe names for the lake was *Da aw ga* variously interpreted as “the lake, big water, high water, water in a high place” (James, 1915). Other political and historic names were used before the circle of official names returned to Lake Tahoe after the native name. The Washoe Tribe (and to a lesser and disputed extent the Paiute Tribe) had used the Lake Tahoe basin for hundreds of years as a source and center of subsistence and culture, especially during the summers (James, 1915).

Lake Tahoe Description

Lake Tahoe was formed 2-3 million years ago by down-dropped geologic fault blocks between the uplifted Sierra Nevada to the west and the Carson Range to the east. The outlet (rim, present Tahoe City) of the lake was formed by volcanic flows from Mt. Pluto following the faulting (1-2 million years ago). Precipitation and stream flow filled ancestral Lake Tahoe over time, and much of the modern lake was shaped and landscaped by scouring glaciers during the Ice Age a million or more years ago (Geology of Lake Tahoe). The lake is considered the second deepest lake and the highest elevation lake of its size in the United States (compared with Crater Lake in Oregon). Sixty three streams flow into Lake Tahoe and there is a single outlet to the Truckee River at Tahoe City on the northwest corner of the lake. The legal Lake Tahoe elevation is 1900 m (U.S. Bureau of Reclamation datum) and the top 2 m above the natural rim (1898 m) is operated as a reservoir with a 17-gate concrete dam at the outlet (USGS 2007). See water resources section below for more detail on water budget and operational regulations. Lake Tahoe has a maximum length of 35 km, width of 19 km, and a surface area of 497 km^2 in a basin total basin area of 1310 km^2 or a watershed area of 813 km^2. The maximum depth of the lake is 501 m and the average depth is 305 m (USGS, n.d.; Tahoe Environmental Research Center, 2008). Two thirds of Lake Tahoe and its watershed are in California and one third in Nevada and this political boundary provides a basis for the bi-state regulation and water resources management of the lake. The Lake Tahoe watershed is segmented into two counties and one incorporated city in California, and three counties in Nevada (Figure 1). Table 1 provides a comparison of Lake Tahoe facts with Lake Okanagan.

Figure 1 Lake Tahoe Jurisdictions

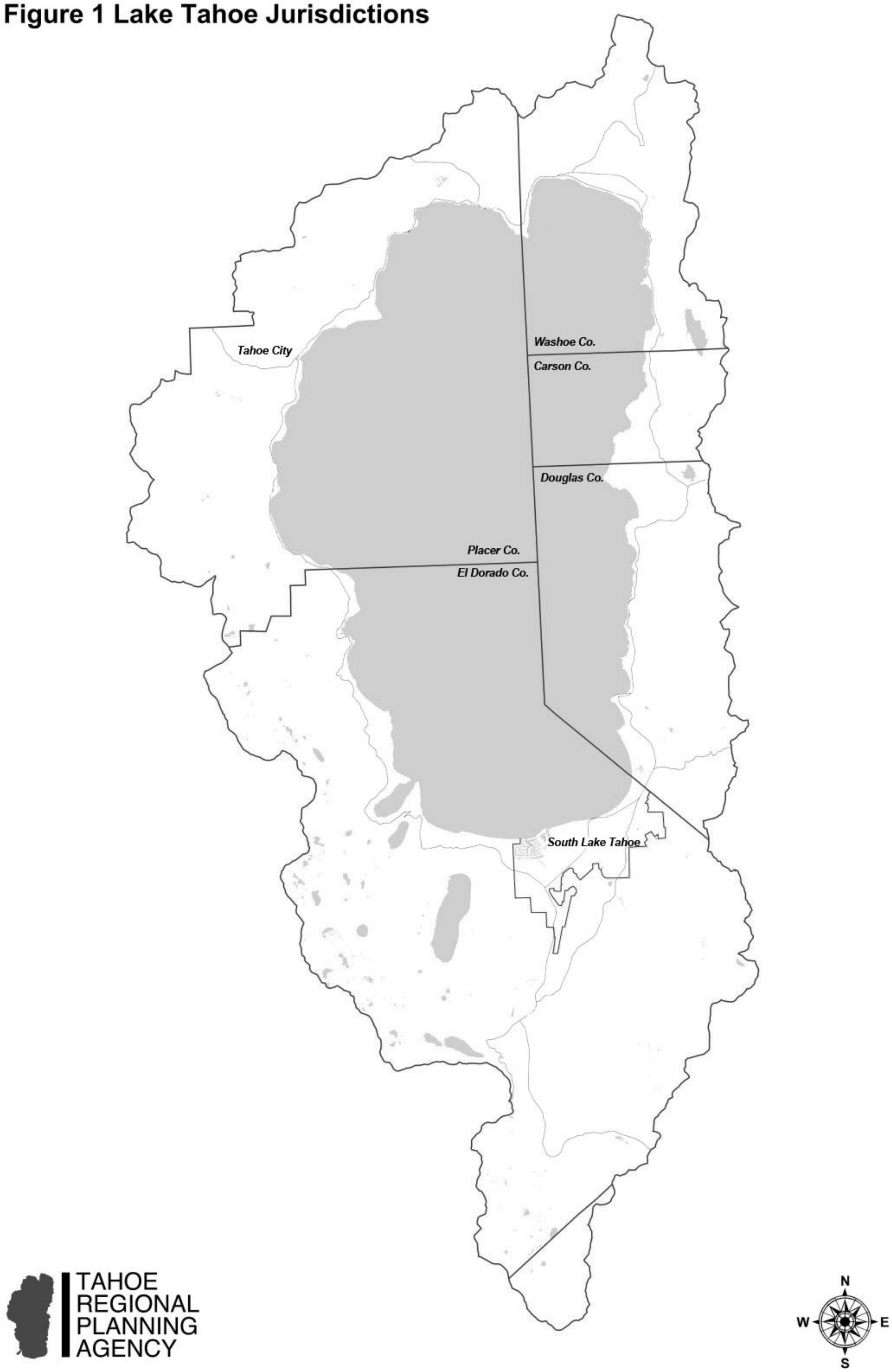

Table 1: Lake Tahoe and Lake Okanagan.

Lake Tahoe	Metric Value	Lake Okanagan	Metric Value*
Maximum depth	501 m	Maximum depth	232 m
Average depth	305 m	Average depth	76 m
Lake surface area	495 km^2	Lake surface area	450 km^2
Watershed area	800 km^2	Watershed area	6200 km^2
Length	35 km	Length	135 km
Width	19 km	Width	4-5 km
Length of shoreline	116 km	Length of shoreline	270 km
Maximum volume of water	150 km^3	Maximum volume of water	24.6 km^3
Number of inflowing streams	63	Number of inflowing streams	many
Number of outflowing streams	1	Number of outflowing streams	1
Average residence time of water in the lake	600 yrs	Average residence time of water in the lake	52.8 yrs
Average elevation of lake surface	1898.6 m	Average elevation of lake surface	342 m

* Wikipedia source not cross referenced.

Lake Tahoe Caught Between Gold, Silver, and Eventually Bronze

The discovery of gold on the South Fork of the American River in 1848 brought thousands of gold seekers going west passing near (and some through) the Tahoe Basin on their way to the gold fields. The discovery of Comstock Lode silver deposit 24 km east of the Tahoe Basin at Virginia City, Nevada brought the first major impacts of European civilization the basin in1858. The native forests of the Tahoe Basin were essentially clear-cut between 1858 and around 1890 largely for timbers to shore up the underground works at the silver mines. Virginia City and Carson City, Nevada were also built during this time with timber from Lake Tahoe. Tahoe City was founded as a vacation resort for Virginia City in 1864 and those who had became wealthy from the timber harvest or the silver continued to establish vacation homes and resorts around Lake Tahoe in the first half of the 1900's (James, 1915). After World War II there was a population and building boom, followed by construction of gambling casinos on the Nevada side of the basin by the mid-1950's, and the completion of interstate highway links for the 1960 Squaw Valley Olympics resulted in a dramatic increase in development within and around Lake Tahoe. The permanent residential population increased between 1960 and 1980 from around 10,000 to 50,000 with a summer population up to around 90,000 (USGS and TRPA, 1997; Ingram and Sabatier, 1987; and Twiss, 2004).

Lake Tahoe California-Nevada Water Resources

Water Use, Disputes, and Court Decrees

The first major exploitation of Tahoe water was during the Comstock logging to move logs to mills and timbers toward the Virginia City mines. Water from Marlette Lake above Lake Tahoe on the Nevada side was diverted through a flume, tunnel and pipeline system to provide water for Virginia City and to a lesser extent Carson City, Nevada (this relatively minor diversion and established water right continues today). Contour flumes were used to capture water from tributary streams for this purpose and down hill flumes either delivered logs to Lake Tahoe from the steep slopes on the west shore, or over the Spooner Summit on the Nevada side to the Carson Valley. The outflow of Lake Tahoe into the Truckee River has been regulated by a dam at Tahoe City, California since 1874 when a log crib structure was built by water and timber interests later to be more valuable for electric power generation and ownership of the dam passed to the Truckee River General Electric Company (James, 1913). The current dam was completed in 1913 by the U.S. Department of Interior, Bureau of Reclamation [which had entered into a condemnation suit against the General Electric Company in 1908 according to James (1913)] to provide irrigation water for the Newlands [after Senator Newlands the sponsor of the Reclamation Act of 1902] Project in the Fallon, Nevada area. The Derby Dam diversion on the Lower Truckee River brought the Pyramid Lake Paiute Tribe into the disputed use of Lake Tahoe / Truckee River water. The tribe was promised flows by treaty to maintain their historic fishery at the Pyramid Lake mouth of the Truckee River for threatened Lahontan cutthroat trout and the endangered cui-ui sucker fish, but by 1967 Pyramid Lake had dropped by about 26 m (McLaughlin, n.d.). The regulated Lake Tahoe reservoir represents a maximum of just less than 1 km^3 compared with the maximum lake volume of approximately 150 km^3 or about 0.6%. The Lake Tahoe storage reservoir remains a major water source for western Nevada including the cities of Reno-Sparks, other towns and agriculture downstream. The dam is operated by the U.S. District Court Water Master under a complex set of legal agreements [following the Truckee River General Electric decree settling the above mentioned condemnation suit] and operating rules to maintain levels between the maximum elevation of 1900 m and that of the natural rim of 1898 m. During droughts the lake level can fall below the natural rim and it is expected to do so in the fall of 2008. Once the lake level reaches the natural rim there are no rights of export to the Truckee River, although there were one or two incidents of attempts to pump below the rim or bypass the rim at gunpoint during droughts in the 1920s and 1930s (McLaughlin, n.d.; USGS and TRPA, 1997). Higher lake levels in the past with the General Electric operation of the dam brought flooding and shoreline erosion along with the disputes from lakeshore owners who sued the company in 1913 (McLaughlin, n.d.). The extreme levels of record were 1900.5 m in July of 1907 and 1897 m on November 30, 1992 (USGS, 2007). The legal Lake Tahoe elevation impacted the January 1997 flood on the Truckee River through Reno (estimated 45% of the flow), since the water master was required to open all 17 gates on the dam when the lake elevation rose suddenly to slightly over 1900 m releasing 74.5 m^3s to the already swollen river flow (McLaughlin, n.d.). Shoreline erosion remains a concern today under the legal lake elevation of 1900 m in particular when the lake level is within the upper meter of the reservoir (Adams *et al*, 2004).

A Litany of Water Agreements and Decrees on Lake Tahoe and the Truckee River

One almost needs a tally sheet to track all the decrees and agreements that cover the operation of the Lake Tahoe storage dam at Tahoe City, California and the Truckee River. I resort to a summary provided in the Final EIS for two of these agreements the *Truckee River Water Quality Settlement Agreement (WQSA) – Federal Water Rights Acquisition Program* and *Truckee River Operating Agreement* (U.S. Dept. of the Interior, Bureau of Indian Affairs, 2002; TROA, 2008) for the following abbreviated listing.

The *Truckee River General Electric Decree* in 1915 granted the United States (Bureau of Reclamation) an easement for operation of the dam at Tahoe City and maintenance of the storage reservoir on Lake Tahoe including the legal lake elevation. The court enjoined the United States to maintain certain flow rates at Floriston downstream of Truckee, California based on Lake Tahoe elevation.

The *Truckee River Agreement* of 1935 as binding among the signatories: Sierra Pacific, Washoe County [Nevada] Water Conservation District, Truckee Canal Irrigation District – operator of the Newlands Project, and individual Truckee River water users, along with the U.S. Dept. of the Interior. The 1935 agreement set certain Lake Tahoe and Truckee River operating guidelines in addition to providing for construction and operation of the present day Boca Reservoir downstream of Truckee, California.

The *Donner Lake Agreement* in 1943 provided for acquisition of waters of Donner Lake, dam and controlling works, for use on the Newlands Project and Sierra Pacific.

The *Orr Ditch Decree* of 1944 decreed rights and priorities to use the waters of the Truckee River in Nevada including: private water rights; and to the United States trust water rights for the Pyramid Lake Paiute Reservation; diversions at Derby Dam for the Newlands Project and duties for project lands; Lake Tahoe reservoir storage and dam operation rights in the 1915 *Truckee River General Electric Decree*; and to Sierra Pacific [Power Co.] rights for certain hydroelectric generating facilities.

The *Tahoe-Prosser Exchange Agreement* of 1959 provided for construction of the Prosser Creek Dam and Reservoir and for exchange of water to maintain flows immediately downstream of Lake Tahoe "at times when releases of water from Lake Tahoe for Floriston Rates may not be otherwise required".

The *Stampede Reservoir Decision* of 1970 (United State District Court for the District of Nevada) required that the Secretary of the Interior operate Stampede Reservoir to provide water for the threatened and endangered fishes of Pyramid Lake and could not be required to operate Stampede for municipal, industrial or other purposes until such time as the fishes are no longer threatened or endangered.

The *California-Nevada Interstate Compact* of 1971 was an agreement between the two states that allocating water in the Truckee, Carson, and Walker Rivers. The compact would have created an interstate water commission to resolve disputes, but it was not ratified by Congress.

The *Tribe v. Morton* in 1972 required that all Truckee River water not obligated by court decree or contract [for the Newlands Project] go to Pyramid Lake.

The *Alpine Decree* of 1980 adjudicated the rights and priorities to use surface waters of the Carson River in California and Nevada, storage in the Lahontan Reservoir in Nevada and use of said water on the Newlands Project [this is related to diversions at Derby Dam based on water available from the Carson River for the project], and established water duties for use on various lands.

Several laws affect the use of water resources for Lake Tahoe and the Truckee River: the *Endangered Species Act* of 1973, *Clean Water Act* 1977 Amendment, the *Truckee-Carson-Pyramid Lake Water Rights Settlement Act* of 1990. Three provisions of the Settlement Act are of affect the broader operation of the Lake Tahoe and Truckee River water resources: Implementing the interstate allocation between California and Nevada to equitably apportion the waters of the Tahoe, Truckee, and Carson River Basins [*California/Nevada Truckee River Interstate Compact* approved by California and Nevada in 1970 and 1971]; Negotiating an operating agreement for the Truckee River reservoirs under Section 205 of the Settlement Act (*Truckee River Operating Agreement* below); Establish fee account accrued from storing non-project water to operate and maintain Stampede Reservoir, support fish and wildlife programs for the benefit of Pyramid Lake fishes, and support Lahontan Valley wetlands. Under the *WQSA*, Reno-Sparks, and Washoe County, Nevada and other downstream jurisdictions and the Pyramid Lake Tribe were required to acquire water rights for municipal and industrial uses.

The Truckee River Operating Agreement

The *Truckee-Carson-Pyramid Lake Water Rights Settlement Act* (1990), Public Law 101-618, required the development of a negotiated Truckee River Operating Agreement (TROA). The Final Environmental Impact Statement/Environmental Impact Report was release in January of 2008, with the negotiated Truckee River Operating Agreement as a Negotiated Agreement Appendix. As required by the Settlement Act, the five mandatory parties to the Agreement – California, Nevada, the U.S. Department of the Interior, the Pyramid Lake Paiute Tribe and Sierra Pacific Power Company (and now the Truckee Meadows Water Authority) are expected to sign that agreement on September 6, 2008 in Reno, Nevada. Parts of the agreement will not go into effect until approved by the *Orr Ditch* Court and it becomes Federal law (expected by 2010). The agreement will provide for the equitable apportionment of the waters of the Truckee River, Carson River, and Lake Tahoe between the states of California and Nevada. Specifically TROA will implement the Act's allocation of 0.039 km^3/year to California in the Truckee River Basin (of which 0.012 km^3/year is surface water) with the remainder of the flow to Nevada. The Lake Tahoe allocation is 0.028 km^3/year for the California side of the basin including both surface and groundwater, and 0.014 km^3/year for the Nevada side surface and groundwater (the main source use on the Nevada side is from Lake Tahoe intakes). The Tahoe Basin California portion allocation has been proposed to be divided between public lands (~15%) and three zones which represent the three California public utility districts largely supplying services to private lands in the basin (~85%) (CA, Dept. Water Resources, 1984). The Nevada portion of the Tahoe Basin allocation has been fully allocated through permits to date (NV, Div. Water Resources, personal communication and 2006). TROA will preserve all existing water rights, decrees and agreements, and will recognize initiation of new water rights in California and confirm rights in Nevada within the Act's allocation. California has not regulated groundwater use to date, but TROA will require such regulation, tracking, and annual water use reporting (measured or estimated). TRPA must not allow development to exceed these water rights (Compact 1980). TROA will create California municipal and industrial credit water and environmental credit water [similar to non-project water fees in Nevada]. Credit water means additional water for specific purposes. Project water is defined by reservoir. TROA is expected to enhance water management flexibility, water quality, conditions for Pyramid Lake fishes, as well as instream flows and reservoir recreation (TROA, 2008). Both sides of the Lake Tahoe Basin are at or close to the allocated water rights, but public water agencies in the basin plan to measure water at the user end of their distribution systems, rather than at the production end or estimating use where non-occupancy will lead to higher estimates than actual use. The administration of TROA will fall to the Truckee River Watermaster, and the current water master says he will retire when TROA goes into effect.

Lake Tahoe Water Budget

There have been several estimates of the annual water budget for inflows and outflows of Lake Tahoe (1902 to 1999) (Table 2); I will rely on the most recent for this discussion (Trask, 2007). Except for evaporation from the Lake surface and groundwater net inflow all long-term estimates of inflow and outflow were based on measurements. Trask (2007) used methods to calculate evaporation from Lake Tahoe and to provide long-term estimates for evaporation from the lake surface. Groundwater flow measurements were insufficient on a local and regional scale so groundwater inflow was estimated as a residual term (subtracting non-groundwater outflow from non-groundwater inflow). The long-term total annual inflow (precipitation on the lake, runoff, and minor groundwater residual) and outflow (evaporation from Lake Tahoe surface, Truckee River discharge) for water year 1968 – 2000 were set equal and accounted for 0.80 km^3 / year (Trask and Fogg, 2001). In 2007 (Trask) provided a much more detailed update for the previous long-term period (Fig. 2 Lake Tahoe Annual Average Water Budget). The overall balance for the more detailed analysis provided an annual average of 0.735 km^3 / year over 32 water years. Evaporation from the lake is on average (0.464 km^3 / year) the greatest loss of water from Lake Tahoe. Those desiring greater detail on the Lake Tahoe Water Budget and analysis should go to the more exhaustive source (Trask, 2007).

Table 2: Lake Tahoe Annual Average Water Budget*

Source of water into Lake Tahoe	**Inflow to Lake Tahoe (cubic kilometers)**	**Effect on lake level (cm)**	**percent of total**	***Loss of water out of Lake Tahoe***	**Outflow from Lake Tahoe (cubic kilometers)**	**Effect on lake level (cm)**	**percent of total**
Inflowing Streams	0.460	+92.9	63	Evaporation	0.464	-93.4	63
Direct Precipitation	0.264	+53.2	36	Truckee River outlet	0.249	-50.3	34
Groundwater (Net)	0.010	+2.1	1	Diversions (1 year average)	0.022	-4.5	3
Total (1 year average)	0.735	+148.2	100	Total (1 year average)	0.735	-148.2	100

* Annual average estimates for water years 10/1998 to 9/2000 (Trask, 2007).

Regional and Land Use Planning and Regulation

This section will of necessity be exceptionally brief due to time and space limitations. Please refer to the two main references in this section for greater detail and appreciation of the complex history of interaction: Ingram and Sabatier (1987); and Twiss (2004). There have been a series of efforts to approach Lake Tahoe and the Tahoe Basin on a national scale since the early part of the last century. As public appreciation for the nature of the Tahoe Basin grew there were efforts between the 1912 and 1918 congressional sessions to designate the basin as a national park (USGS and TRPA, 1997). There were efforts in the 1950's to establish regional land use planning in the basin, eventually culminating in the first Tahoe Regional Planning Compact in 1969, and later in the updated Compact in 1980. The question of federal designation still had some life in the 1990's prior to the 1997 Presidential Forum on Tahoe as to the possibilities and benefits of National Monument or National Forest designation. Lake Tahoe has been designated for its exceptional transparency and deep blue color as an Outstanding National Resource Water by the state of California and the U.S. Environmental Protection Agency, and a Water of Extraordinary Ecological or Aesthetic Value by the state of Nevada. These two designations provide a greater level or protection for the water quality and beneficial uses of Lake Tahoe than federal and state water quality standards in general under the Clean Water Act.

Early Environmental and Regional Efforts

The early attempts to designate the Tahoe Basin as a national park and subsequent interests in a national designation appear to be rooted in appreciation of the environmental and cultural significance of Lake Tahoe. At the turn of the 19th century the Lake Tahoe Forest Reservation (1899) started what became the US Forest Service acquisition of land in the Tahoe Basin and this federal and state land (California and Nevada State Parks) acquisition and conservation has continued in the Tahoe Basin (Ingram and Sabatier, 1987). By the 1950 it was becoming apparent to many around the Tahoe Basin that the clarity of Lake Tahoe was decreasing and there was a need for a more regional approach to planning particularly since the county jurisdictions in the basin had out of basin seats of government. The League to Save Lake Tahoe was formed in 1957 for the purpose of restoration and preservation of Lake Tahoe. In 1957/58 the Lake Tahoe Area Council (LTAC) was formed to promote the "preservation and long range orderly development of the Lake Tahoe Basin". The LTAC mainly sponsored studies and research on Tahoe Basin problems and supported the formation of a bi-state multi-county planning group [of Tahoe Basin Counties] which was without authority and short lived (Ingram and Sabatier, 1987; Twiss, 2004). LTAC also supported a study and report (1963) which concluded in recommendations for sewage export from the Tahoe Basin discussed below (Ingram and Sabatier, 1987). Conflicts between development interests were becoming more obvious with the 1959 dredging and filling of a large portion of the Upper Truckee Marsh for the Tahoe Keys development (Fig.1), the 1960 Squaw Valley Olympics, and development of Incline Village in the early 1960s (Twiss, 2004).

Two Tahoe Regional Planning Compacts, Two Regional Plans

During the 1960s while the initial efforts toward regional planning were under way, and even after the passage of the first bi-state and federal Tahoe Regional Planning Compact (1969) there was a rush to subdivide land and acquire development permits based on local county rules before the new land use ordinances could be put into effect (Twiss, 2004). The first public hearings held in 1967 by the California and Nevada legislatures to discuss the conceptual bi-state agency were paralleled by formation of a California Tahoe Regional Planning Agency [CTRPA] (Twiss, 2004) and followed the next year by the formation of the Nevada Tahoe Regional Planning Agency [NTRPA] (Ingram and Sabatier, 1987). The 1969 Compact effectively put the Tahoe Basin [Region] under the jurisdiction the Tahoe Regional Planning Agency (TRPA) with the authority to regulate all aspects of land use including type [zoning], intensity [density], and location (Twiss, 2004). The first TRPA Regional Plan and ordinances were adopted in 1972, including a land capability system [Bailey, 1974 including seven classes of land and their level of hazard or capability to recover from disturbance of development] to proscribe the intensity and location of land use (Twiss, 2004). The Compact (1969) limited new development of land to low hazard land [Class 4 – 7 with lower slopes and deeper soils]. The Bailey system remains the basis of land use development today and limits the development of impervious coverage by land capability class. The pitfalls, opposition and complexity of adopting the 1972 Regional Plan and TRPA operations under the plan (including duplication of regulation and inherent conflicts involving CTRPA and NTRPA) are described in great detail by Ingram and Sabatier (1987).

Twiss (2004) lists six shortcomings and structural weaknesses in the 1969 Compact that effected the development of the Regional Plan and the effectiveness of TRPA under the Compact:

1. No development moratorium during the planning period [development of the Regional Plan], TRPA spent half it's time approving subdivision of land under prior county zoning.
2. After adoption of the 1972 Regional Plan the urbanization and environmental impacts continued.
3. Sweeping powers of the Compact were curbed by a weak voting structure requiring an affirmative vote by a majority of each state's members [Governing Board dominated by local jurisdiction members] to <u>deny</u> a project. [There was also a 60 day approval period noted by Ingram and Sabatier, (1987) causing projects not acted on to be approved by default].
4. Grandfathering allowing lots in previously approved subdivisions (regardless of land capability hazard) to proceed to construction requiring only building permits.
5. The 1969 Compact guidance encouraged TRPA's planning to balance the region's economy with environmental protection.
6. The Compact made a finding that the environment of the Basin <u>may</u> be threatened by development which forced the agency to prove and reprove the impacts of every separate action.

After the adoption of the 1972 Regional Plan and ordinances two federally sponsored studies and reports set the stage for the 1980 Compact update by recommendation of such and update to remove some of the flaws noted above and a federal buy-out of private lands for conservation (US EPA, 1974); and a second effort recommended the establishment of Environmental Threshold Carrying Capacities (standards) (Western Federal Regional Council, 1979). See Ingram and Sabatier (1987) and Twiss (2004) for more detailed discussions on the complex developments and operations of the TRPA Regional Plan during the 1970s. The second (current) TRPA Compact was adopted about a year after the 1979 federal recommendations and incorporates most if not all those recommendations (Compact, 1980). The 1980 Compact made findings that the waters of Lake Tahoe and other resources of the region <u>are</u> threatened, that maintenance of social and economic values requires the maintenance of significant environment values of the Lake Tahoe Basin and required TRPA to "establish environmental threshold carrying capacities and to adopt and enforce a regional plan and implementing ordinances which will achieve and maintain such capacities while providing opportunities for orderly growth and development consistent with such capacities". The voting structure of TRPA Governing Board was changed to remove the presumption of approval, required threshold findings for project approval, and made it more difficult to amend the Regional Plan (Twiss, 2004). Out of Basin Governing Board members were added to reduce local jurisdiction dominance (Ingram and Sabatier, 1987). The Environmental Threshold Carrying Capacities in nine resource areas were adopted by TRPA in 1982 including Water Quality, Soil Conservation (Impervious Cover and Stream Environment Zones), Air Quality, Vegetation Preservation, Wildlife, Fisheries, Noise, Recreation, and Scenic Resources (TRPA, 1982). The 1980 Compact did not remove grandfathering entirely, but listed specific restrictions on development until the Regional Plan was amended under the Compact or until May 1, 1983. In May 1984 the revised Regional Plan and EIS were adopted by TRPA, and the League to Save Lake Tahoe and the California Attorney General filed suit protesting the perceived weakness of the plan. At nearly the same time the Tahoe Sierra Preservation council filed suit protesting the plan being to strong in its impact on property rights (Twiss, 2004). A Federal Court Preliminary Injunction blocked implementation of the plan. A series of Consensus activities and agreements were completed to resolve the outstanding issues, and the development of Individual Parcel Evaluation System (IPES) scores for the reclassification of land capability on small vacant parcels determining which parcels could be built on, led to the development and adoption of a revised Regional Plan and Supplemental EIS in 1986 (including the timed development of the court moratorium affected projects and parcels). The Code of Ordinances and Supplemental EIS was adopted in 1987 implementing the Regional Plan (TRPA, 1986 and 1987). The TRPA web site is the best access to current documents, updates and activities (TRPA, n.d.).

Sewage Export Required for the Tahoe Basin

Increased development pressure in the late 1950s and early 1960s, and a few large sewage spills into Lake Tahoe, led to an engineering study and report supported by LTAC which recommended treatment and export of sewage from the Tahoe Basin. This recommendation was opposed by Nevada water resource interests until the singing of the *California/Nevada Truckee River Interstate Compact* was approved by California and Nevada (1970 and 1971). The state of California passed a law requiring sewage export from the Tahoe Basin and banning septic systems in 1969 [Porter-Cologne] and the Nevada Governor's executive order made the same legal requirements in 1971 (Ingram and Sabatier, 1987). The result of these efforts and the current status is that the Tahoe Basin has a non-discharge standard for domestic and industrial wastewater.

Limits on Development and Public Buy-out Programs

Two US Supreme Court rulings have affirmed TRPA's authority to limit development (Twiss, 2004). The limit on development has only affected vacant parcels at the time of the revised Regional Plan adoption, but programs such Transfer Development Rights and federal and state public buy-out programs have greatly reduced the inventory of vacant parcels (especially sensitive parcels under IPES or high hazard land). The number varies by perspective but only around 12 percent (some say 10%) of the basin remains in private lands (TRPA, 2007).

The Lake Tahoe Clarity and Plan Update Challenges

In 2001 four basin agencies (TRPA, the U.S. Forest Service Lake Tahoe Basin Management Unit, California Regional Water Quality Control Board – Lahontan Region, and Nevada Division of Environmental Protection) embarked on a process to cooperatively lay the basis for updates of the Regional Plan, Forest Plan, and Lahontan Basin Plan (after adoption of the TMDL for Lake Tahoe – Clarity Restoration). The Pathway Evaluation Report for eleven resource areas and Technical Supplements (2007) serve as the reports on this process leading to the plan updates for the region. Updates of the regional plans are in process and TRPA expects to adopt the Updated Regional Plan by fall of 2009 (TRPA, n.d.).

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Wastewater Treatment Plants as Sources of Contaminants in the Aquatic Environment

Chris Metcalfe

Abstract

Contaminants released into municipal wastewater include industrial chemicals, personal care products and pharmaceuticals, as well as natural hormones that are excreted by the human population. Once discharged into surface water, the contaminants from wastewater can have impacts on aquatic organisms. Examples of impacts on fish include bioaccumulation of synthetic musks to part per million levels, alternations to spawning behaviour, feminization of males and in severe cases, complete reproductive failure. Case histories that illustrate these responses include laboratory studies conducted with the aquarium fish, the Japanese medaka, whole lake addition studies that evaluated the effects of synthetic estrogen on the reproduction of fathead minnows and other native species, and sampling of white perch from the Great Lakes to determine whether there have been alterations to the gonadal development of males of this species. These studies all lead to the conclusion that contaminants carried in municipal wastewater have the potential to affect the development and reproduction of fish. The increased use of pharmaceuticals as a result of changing population demographics, the growth in populations in some areas and continued low investment in municipal wastewater treatment infrastructure in Canada may lead to greater impacts on aquatic resources in the future.

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The Social Life of Water

John Wagner

Abstract

As water cycles through the Okanagan watershed, providing essential ecosystem services, it also flows through our houses, workplaces and sites of recreation, and as such acquires social as well as ecological and economic characteristics. Its social characteristics include, for instance, its capacity to transform less desirable, arid landscapes, into irrigated, more highly valued landscapes such as orchards, vineyards, and golf courses. Water views of lakes, rivers and creeks acquire aesthetic values and these values also become commoditized within real estate markets and recreational industries. As commodity and symbol, water thus mediates our social lives and becomes a source of conflict among different interest groups and among those who endorse quite different visions of what the Okanagan is and might become. From this perspective, choices about water management must be understood as choices about development, cultural values and social relations. In this paper I review some of the social, economic and political changes occurring in the Okanagan region today and analyze these changes in relation to water allocation practices and future policy options.

Introduction

In recent years Okanagan residents, politicians, planners and scientists have become increasingly aware of the fact that we will soon be facing significant water shortages if we do not adopt more sustainable water use practices. It is widely understood that these shortages will come about as the combined outcome of climate change and increasing demands on our water supply as a result of rampant growth. Climate change researchers and water managers often focus their attention on the hydrological characteristics of the Okanagan watershed, and I will do the same in this paper, but I will analyze Okanagan hydrology as a social and economic as well as a physical system.

Most of us learn about the 'water cycle' early on in our lives, typically in elementary school science classes. We learn that water falls as precipitation, is captured by soil and the roots of plants and trees, is carried by creeks, rivers, lakes and groundwater systems back to the ocean, that evaporation and evapo-transpiration move water back into the atmosphere where clouds form and the cycle begins anew. We learn that the water cycle operates on the basis of natural law and perhaps we learn a little bit in the same science classes about the ways in which human societies capture and use water at various points throughout this cycle. Water that cycles through our homes, businesses, sewage and storm water systems, also returns to the world's lakes and oceans and it also falls again as precipitation. But when water inhabits space constructed by

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human beings, even though it continues to follow 'natural' laws, it also acquires a social life in the sense that human beings use water in various ways, symbolic and economic, to construct their social identities.

For over a hundred years now, the hydrological cycle in the Okanagan has included large flows of water from creeks and upland lakes through irrigation systems to lands that formerly received very little water during the summer months (Wilson 1989). Much of this water eventually percolates down through the soil to assist in the recharge of groundwater systems, but some is taken up by the roots of fruit trees, grape vines, and other crops and has thus facilitated the development of commercial agriculture, population growth and virtually everything we identify today as characteristic of Okanagan culture, or at least Okanagan 'settler' culture. Needless to say this type of 'hydraulic' settler society is very different from that created by the indigenous *Syilx* peoples whose relationship to water did not include the particular type of sociality made possible by irrigation systems (Sam 2008).

The settlement pattern of all societies, historical and contemporary, including the *Syilx*, can be predicted to some extent by the location of water and from that perspective water always acts as a mediating influence on culture. But all the societies referred to in historical texts as the first great 'civilizations', or in anthropological texts as the first 'state-level' societies, were hydraulic societies; that is, their growth and power was entirely dependent on the effective functioning of irrigation and domestic water supply systems (Steward 1955; Wittfogel 1957; Worster 1985). Irrigation was necessary to support the forms of intensive agriculture that developed in centers like Mesopotamia, Egypt, China, India/Pakistan, Mexico and Peru. Intensive agriculture was necessary to generate food surpluses, allow for labour specialization, population growth, the emergence of cities and highly stratified societies. But it is important to keep in mind that the first great civilizations were empires built on the backs of subjugated people. Water can draw people together in a spirit of community but it can also divide them on the basis of class and privilege.

Water also occupies a special place in the imagination, mythology, and religious practices of people around the world. The particular form of Hinduism practiced today in Bali, for instance, known in their language as *Agame Tirtha*, translates into English as the religion of holy water (Lansing 1991). An elaborate irrigation system has existed for at least a thousand years on Bali and Hindu priests have traditionally played a leading role in water management. The water within this system is most holy at the place where it arises, in the springs that surround the lake located near the summit of one of the island's highest mountains. In virtually all cultures of the world, water is valued for its cleansing properties; it is central to baptism ceremonies in Christian culture, to various rites of passage among indigenous North American societies, and the entire Ganges River in India is understood to be the physical embodiment of the goddess Ganga (Alter 2001). In both economic and symbolic terms, water thus occupies a powerful, though highly variable position in human social systems.

In this paper, however, I rely more heavily on work of Arjun Appadurai (1986) who coined the phrase "the social life of things" in order to draw attention to the ways in which human societies construct social and economic relations through the exchange and commoditization of material objects of many kinds, including food, technology, natural resources, and art. According to

Appadurai, objects acquire their value through the process of economic exchange but exchange, in his analysis, is much more than a simple playing out of the laws of supply and demand. Objects of exchange often acquire symbolic value and in many cases people are motivated to acquire such objects because of the status associated with their possession. The term "conspicuous consumption" is used, for instance, to emphasize the fact that public display is essential to some exchange systems; in the absence of any opportunity for public display many high status items (clothing and jewellery for instance) would lose much or all of their economic value. Many high status exchange items have very little intrinsic value but become valuable because they are hard to acquire, for various reasons, and can therefore, through public display, become markers of economic power and prestige (Bourdieu 1984). The Kula ring of Papua New Guinea provides a very different though equally good example of this type of prestige trading system. In the Kula system, ceremonial objects are exchanged for one another rather than for cash. It is called a ring because objects are traded among individuals living on a group of islands that form a roughly circular pattern. The most valuable objects, elaborate shell necklaces and armbands, can move in only one direction around the circle and strict rules govern the ways in which such items can be exchanged. However, these objects cannot become the permanent possession of any one individual, and must be traded again within a year or two. Prestige in this system then is acquired through skill in trading as well as public display, rather than outright possession or consumption (Malinowski 1984; Leach and Leach 1983).

Water in the Okanagan Valley

Water is also capable of acquiring value as an item of exchange within a prestige economy. The Okanagan provides a classic but by no means unique example of how this can occur. It would be far-fetched to compare the Okanagan to Egypt or Mesopotamia in terms of social stratification based on control of water but the valley has operated as a hydraulic society in miniature for over a century now and the early history of the valley is especially significant in this regard. Most of the first large irrigation systems were built by land companies who recognized the potential of the area for fruit growing and who were able to sell large tracts of land at sizeable profits once water systems were in place. Virtually none of those companies were local in origin and some, even then, were transnational corporations based in other countries, the Belgo-Canadian Fruit Lands Company, for instance, which was based in Antwerp (Dendy 1976). This history of corporate ownership of the Okanagan Valley was virtually erased by the end of World War Two, by which time most corporate landholdings had been disposed of and their waterworks systems taken over by farmer-run irrigation districts (Wilson 1989). The Okanagan landscape today is thus not dominated by large fruit growing, agribusiness corporations, as tends to be the case in many of the fruit growing areas of the western United States. Okanagan agriculture developed along quite different lines, as a primarily, family-farm based, cooperative system in which control over water did not function as a way of generating extreme forms of economic inequality.

The Okanagan now appears to be entering a phase of re-corporatization, however, as orchards give way to vineyards, resorts and golf courses and as land prices soar. One surprising outcome of the research I have done to date on these issues has to do with the relationship of land prices to the price of fruit. It is readily apparent that the price of land bears no relationship to the price orchardists receive for their fruit. The price per pound of the most profitable crops (currently cherries and a few varieties of apples) is sufficient for a grower to make a decent living if he or she is not carrying a hefty mortgage. It is not nearly high enough, however, to allow an outsider to buy into the industry. Why, at $100,000/acre or more, would someone want to buy into the industry since the minimum acreage needed to make a living, say 20 acres, is likely to cost at least two million dollars? The bank interest from two million dollars will earn more money than the profit from a farm worth the same amount. This has been true for some time in the Okanagan and comes as no surprise, however, what I have found surprising is the general agreement among those I have interviewed that the same logic now holds true in the case of vineyards. Neither grapes nor wine sell for enough money to pay for the land on which they are growing. Even when combined with restaurant and bread and breakfast operations, vineyards are, at best, economically marginal in relation to the current price of land. But outsiders are buying into the vineyard and wine tourism industry – on a massive scale in fact. In some cases these purchases are being made by affluent hobby farmers who typically buy a five acre lot and lease the farming operation to a professional grower. In a few cases hobby farmers pool their resources and purchase larger operations. But Okanagan vineyards are also being bought up by large transnational corporations. Constellation Brands Inc., for instance, the world's largest purveyor of wines and spirits, own six vineyards and operate two joint ventures in the Okanagan according to their website information (Constellation Brands Inc. 2008). Andrés Wines owns at least five Okanagan vineyards (Andrés Wines 2008).

It makes good economic sense for large corporations to invest in Okanagan vineyards since they constitute a lucrative real estate market as well as a source of increasingly popular wines. It is not my purpose in this paper to explore the likely outcomes of a re-corporatization of the Okanagan by wine and resort development corporations, but the future of the Okanagan may well rest in their hands. This has huge implications for the future of the agricultural land reserve as well as for water and quality of life in general in the valley. Water, as an agricultural commodity, was essential to the development of the valley over the past century. Water today, as a 'resort commodity', is essential to the re-development of the valley as a playground for tourists, retirees and the wealthy.

As a resort commodity water also has a long history in the Okanagan but its value within the resort industry has only recently surpassed its value in agriculture. Advertising literature was referring to the Okanagan as the "California of the north" a full hundred years ago (Bulman 1908; Vernon News 1905:3), thus preparing the ground for our current designation as "Napa of the north" (Gill 2001, Tsui 2006). The landscape aesthetic used by land development corporations to sell the Okanagan today as recreational playground is virtually identical to the one employed a century ago by land and irrigation companies. One or another of the large valley-bottom lakes is almost always a prominent feature of advertising images; the foreground is occupied by panoramic views of the irrigated, green 'oasis' surrounding the lake; more arid and mountainous regions dominate the background (Wagner 2008). This image of the Okanagan, this particular landscape aesthetic, has not arisen as a 'natural', human response to the Okanagan landscape. It is a culturally constructed aesthetic manufactured with a particular economic goal in mind. It is also important to note that it is not a "made in the Okanagan" aesthetic; it is an aesthetic manufactured elsewhere that has been marketed very successfully here, as one site of many within a global marketplace Our ideas of "locality, as Appadurai (1986) has pointed out, are profoundly conditioned today by global flows of capital, information, people and technology.

When commoditized in this way water is not, of course, under the management of any local water authority and because of its symbolic form it constitutes a very different type of commodity than the substance that flows through our taps and irrigation pipes. This type of water flows through our imaginations. This is where the hydrological cycle becomes, perhaps, most fully social in nature. Because of our imagined, culturally constructed association of leisure and lakefront lots with lives of privilege and prestige, mere proximity to water can become a marker of social status. It is this 'imagined' water which now brings more and more people to the region, however, so in the end it exerts very real and physical pressures on the abundance and quality of water as a physical resource.

Managing Okanagan water as a commons

The argument I wish to make here is that water management in the Okanagan is intimately bound up with decisions about the kind of society we want to become. In effect, whoever controls the ways in which water is commoditized and marketed has a much larger say in managing our future than the rest of Okanagan society. Corporate marketing of Okanagan water, as agricultural resource, as lakeview, as playground, perpetuates a settler culture committed to continued ecological degradation, not sustainability.

Now that the issue of Okanagan water governance is on the table for discussion by all levels of government (Chong 2008), I would like to propose that we develop a governance approach that mirrors and embodies our values as a democratic society and our aspirations for ecological sustainability. A commons model of governance, I believe, provides an ideal but practical way forward. We often treat water as if it is, or should be, a 'public good'. Public goods, as defined by economists, are goods that are non-excludable and non-rival, i.e. they are freely or readily available to all and one person's use does not limit use by others. Classic examples are the air we breathe (at least up to the point at which it becomes polluted) and various kinds of information (where availability is not restricted by patents or copyrights). But public utilities also typically operate in this fashion: medical services, for instance, transportation, policing, and so on. In the case of private goods, by contrast, it is possible to exclude unauthorized users and one person's use of the resource does reduce its availability for others (lakefront residential lots are a good Okanagan example). Intermediate to public and private goods are common pool resources which are typically defined as resources that are rivalrous but where the costs of exclusion are high enough that they cannot readily be converted into private goods (Ostrom 1990).

Common pool resources, with water as a classic example, are often managed as commons, which is to say, they are managed collectively by all those who are in a position to use the resource in question. In many settings in the world, everyone within accessible distance of a coastal fishing area, for instance, can join together with other local users to reach collective use decisions about that resource. The resource cannot be privatized because it is either impossible or uneconomic for one individual to effectively exclude other local users. In many instances, however, a local, collective group can effectively exclude individuals who live further away from the resource and within certain bounds they can also regulate their own members' use.

In a few parts of the world, commons institutions continue to operate as relatively autonomous institutions with little interference by outside agencies such as national governments and external markets. Typically, however, commons today operate as one level of a multi-level governance system (Armitage 2008; Berkes 2008; Dowsley 2008). Unfortunately, these multi-level systems are often poorly integrated and, in fact, national and provincial level governments often create legislation and policy explicitly designed to curtail or even eliminate the authority of local commons institutions. This often results in the breakdown of the local system, since the legally sanctioned 'regulators' now live far away, have insufficient resources and little or no knowledge of what is happening at the local level. In other cases, the local institutions continue to function effectively, but without official recognition by higher levels of government. Irrigation systems in Bali represents a classic example of this last situation, a fact that became readily apparent when the provincial level government attempted to implement agricultural policies that disrupted local irrigation arrangements. The failure of the government's agricultural program exposed the fact that government planners had no working knowledge of local ecology and local irrigation systems and no capacity to manage them (Lansing 1991). Such actions are typical of the governance approaches of nation states everywhere in the world, today as in the colonial era.

In the Okanagan, the commons governance approach of the *Syilx,* the indigenous peoples of the Okanagan, was overwritten by colonial and provincial governments beginning in the late nineteenth century. But then, following a subsequent period of corporate irrigation management which ended during World War I, a new form of commons management was instituted – that of the farmer-operated 'irrigation district' (Dendy 1976; Wilson 1989). Many irrigation districts continue to operate in the Okanagan today though they generally provide more water now to non-agricultural, domestic customers than to agriculturists. Out of five water purveyors in the greater Kelowna area, for instance, three are irrigation districts. By contrast, in Penticton, Naramata and Summerland, the local irrigation districts have folded, handing their authority and water licenses over to either the local municipality or regional district. These handovers have been motivated mainly by concerns over water quality but they have been coerced, quite deliberately, by provincial government policy which prohibits the granting of water quality improvement grants to irrigation districts.

Analyzing the current situation then, from the standpoint of a multi-level, governance system, the centre of gravity of the system appears to be moving higher, away from the level at which commons work most effectively, and toward a more top down approach. Top down approaches have been demonstrated to be among the most ineffective of all governance systems when evaluated in relation to the principles of equity and ecological sustainability. They have, however, proven to be an extremely effective means of privileging elite, often outside interests, at the expense of local communities. This characteristic of top down approaches has been demonstrated in a wide variety of case studies, for contexts as varied as Canadian fisheries (Dyer and McGoodwin 1994; McGuire 1997) agricultural development (Ferguson 1994; Lansing 1991), irrigation and hydro-electric projects (Donahue and Johnson Kerr 2008; Mehta 2005) and even conservation projects (Harper 2002; Wagner 2005).

An effective commons governance model for the Okanagan will require that decision-making processes remain as low in the multi-level hierarchical governance structure as possible. Which is to say that many should rest at the 'mini-watershed' level – the level at which most irrigation districts and a few municipalities now operate (Kerr 2008). Summerland, for instance, a town of about 12,000 people (District of Summerland 2008), is mainly reliant on water from Trout

Creek, one of the larger mini-watersheds within the Okanagan basin. Similarly in Naramata, a much smaller community, residents have historically relied mainly on water from Robinson Creek. The City of Penticton, though it now pumps more water from Okanagan Lake than from upland sources, has also historically relied on water from Penticton Creek. Though larger than most historic commons, these are manageable units.

A modern commons structure, however, requires effective integration of governance institutions within a multi-level system. There is an urgent need then, for an agency such as the Okanagan Basin Water Board (OBWB), to provide a basin wide perspective and a forum for collective action by the commons institutions needed to manage each watershed within the basin. The Water Stewardship Council created by the OBWB, which is composed of a broad range of stakeholders from throughout the valley, represents an excellent first step towards creating the second institutional level of a commons governance model. The sustainable water strategy being developed by the Stewardship Council articulates principles that are very consistent with this approach (OBWB 2008; Okanagan Water Stewardship Council 2008).

Organizations like the Kelowna Joint Water Committee, which has representation from all five water purveyors in the greater Kelowna area, represents another significant initiative in this direction. A valley wide organization of this type could work together with OBWB to facilitate basin wide coordination of management activities. It is at this level of the management system that the most work would have to be done if a multi-level commons approach is to be taken.

Since provincial legislation vests all significant authority over local water resources in provincial agencies, most notably the right to issue and regulate water licenses, no changes in governance will take place unless they are endorsed by the Province. Recent provincial initiatives encouraging local political leaders to develop a valley wide governance model are thus very promising (Chong 2008), though worrisome at the same time since the Province is under no obligation to follow local preferences. The interests and perspectives of the Province can be directly opposed to those of local communities – a fact that was dramatically demonstrated this year by the conflict over the Province’s proposed sale of leased crown lots on upland lakes and water reservoirs. The Province’s decision to sell these lots to the lessees, cottage owners for the most part, was made unilaterally and, as they were surprised to discover, against the wishes of every local level government in the region. Only in the face of concerted public pressure did the Province offer to review its decision and no resolution of the issue has yet been reached (Baker 2008).

The rationale for vesting current levels of authority over water in the provincial government arose during the colonial era, and was well suited to the goals of that era which were to transform *Syilx* territory and the indigenous life way it supported into an area of intensive irrigation-dependent agriculture capable of supporting a much larger population of European settlers. The impetus today is towards a further, no less radical transformation of an agricultural society into a resort community with a valley wide population predicted to reach half a million by the middle of this century. The question I would like to pose to political leaders at all levels, as well as to local residents and water managers, is: whose interests are being served by this radical transformation? Is it perhaps time to rethink and dispense with policy developed during the colonial era and begin to develop policy to serve the interests of today?

A recent initiative and publication by the Province entitled “Living Water Smart” emphasizes the principles of stewardship, ecological sustainability, and equity of access to clean water for all British Columbians. Realization of these goals may well require that the Province divest some of its authority over water management to mid-level and local-level commons governance institutions. This is not a recommendation for a delegation or ‘downloading’ of management roles without a commensurate transfer of legal authority and tax revenue. But done gradually, in cooperation with local management institutions, it could represent a step towards achieving a governance system that could satisfy the goals of ecological sustainability and equitability without sacrificing economic well-being.

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POSTER PRESENTATIONS

Beyond Conservation – Applying Water Sensitive Urban Design to Vernon, B.C.

Jennifer Miles

Abstract

Current land use planning in Canada considers water to be in unlimited supply; that water will always be available to support new development. When limits are encountered, restrictions on use are instituted to ensure sufficient supply. Conservation based on restrictions cannot provide sufficient "new water" to meet demand, based on population growth and climate change projections. Water Sensitive Urban Design (WSUD) is a management approach that goes beyond use restrictions to understand how water is used by all aspects of a community and the local ecosystem it inhabits. WSUD offers an alternative mode of urban development, addressing supply shortfalls by maximizing the use of water (precipitation, stormwater, or greywater) within the urban distribution system, thereby reducing demand on high elevation reservoirs.

WSUD is being developed in Australia because of years of drought and concern over the allocation of water between human and ecological uses. An analysis of the potential for applying the WSUD approach to Vernon will be presented through a conceptual framework that identifies three key water management principles:

- Recognize connections between human social systems and ecological systems – collectively, the biosocial system – to determine shared needs;
- Develop resilient systems by encouraging functional diversity – use the right type of water for the need, diversify sources; and
- Recognize management limits – we cannot control complex ecological processes (e.g. climate) due to uncertainty but we can manage human interactions with those processes and take advantage of the ecological goods and services provided.

WSUD tools will be applied to Vernon to illustrate the potential of sustainability-based municipal water management to reduce stress on natural hydrologic systems as well as ageing utility infrastructure. Tool selection will be driven by the above principles, which require an understanding of the local biosocial system context. Barriers to implementing WSUD will be assessed to recommend priorities for intervention, based on the Vernon context as well as challenges faced by Australian water managers. This research will suggest how WSUD can help water managers move beyond restricting use (conservation) to help achieve Vernon's goals for long-term water security.

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The Use of Stable Isotopes to Assess the Origin and Fate of Nitrogen in Shallow GW in Osoyoos, BC

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Abstract

Elevated levels of nitrate are present in shallow groundwater throughout the Okanagan valley, and due in part to intense agricultural activities, primarily from the application of fertilizer.

Here we present the results of two years of research (funded by the Canadian Water Network, Agriculture and Agri-Food Canada, NSERC, Geological Survey of Canada, B.C. Ministry of Environment, and Environment Canada) conducted in one of these agriculturally intense areas, west of Osoyoos, where shallow groundwater beneath agricultural fields is collected in two tile drainage systems and discharged directly into Osoyoos Lake.

In addition to classical hydrogeological methods (drilling, piezometer installation, and water level measurements), isotopic and geochemical methods were used to characterize the potential source(s) of shallow groundwater and tile drainage water discharging into Osoyoos Lake and to confirm the origin and fate of nitrate present in the shallow groundwater and tile drainage waters. These analytical techniques included:

- field and laboratory measurements of major dissolved ions in the groundwater ($n = 105$) and tile drainage water (from 1997 to 2008, $n = 198$);
- stable isotope analysis of $\delta^{15}N$ and $\delta^{18}O$ of nitrate in the groundwater ($n = 32$) and in tile drainage water (from 1997 to 2006, $n = 87$);
- stable isotope analysis of $\delta^{2}H$ and $\delta^{18}O$ of the groundwater ($n = 122$) and tile drainage water (from 1997 to 2008, $n = 153$);
- stable isotope analysis of $\delta^{18}O$ of dissolved oxygen in the groundwater ($n = 15$); and
- tritium/helium ($^{3}H/^{3}He$) age dating of groundwater ($n = 9$).

The results of this research were used to: (1) determine the extent of nitrate contamination of the shallow groundwater, (2) evaluate historical trends in nitrate concentrations; (3) determine the source and age of this nitrate contamination, and (4) estimate the impact of the groundwater and tile drainage systems on the quality of Osoyoos Lake.

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Cumulative Effects Monitoring of Okanagan Streams Using Benthic Invertebrates, 1999 to 2004

Vic Jensen

Abstract

Rapid bioassessment procedures often use benthic invertebrates as indicators of stream water quality thereby integrating physical, chemical and biological stressors associated with watershed disturbance. To date, Okanagan stream water quality assessments have relied on chemical and physical assessments which may not fully assess cumulative effects within this rapidly urbanizing landscape. Benthic invertebrates were collected from riffle habitats on 23 low elevation Okanagan stream sites between 1999 and 2004, and analyzed using the Benthic Index of Biological Integrity concept. Sites represented a range of watershed disturbance and expected stress. Stress levels were estimated using GIS at the watershed level, and field inspection at the site for in-stream and near stream habitat condition. Five benthic invertebrate measures, total taxa, number of plecoptera taxa, number of ephemeroptera taxa, number of intolerant taxa, and number of clinger taxa, responded predictably to cumulative stress. Scores were high for Equesis, Peachland, Shorts, Whiteman, Ellis upstream of Penticton, Chute, McDougall ups of Hwy 97, Coldstream, and Lambly Creeks. These sites had high biological diversity and many benthic invertebrate taxa sensitive to disturbance. Sites with much lower species diversity and fewer sensitive taxa were Mill in Kelowna, Ellis near Okanagan River, Vernon Creek in Vernon, Trout Creek near Hwy 97, Shuttleworth in Okanagan Falls, Eneas and Prairie in Summerland, and BX Creek in Vernon. Urban stream sediments were often elevated in PAH and are associated with reduced benthic scores. This information should be useful to stream and watershed protection initiatives, sustainability reporting, and stormwater management planning efforts in the Okanagan Basin.

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The Soft Path for Water in a Nutshell

O.M. Brandes, D.B. Brooks, E. Reynolds

Abstract

Many Canadians believe that our fresh water resources are boundless. The truth is that only a small proportion of our water is renewable and located close to where most Canadians live. Continuing to take more and more water from nature while ignoring wasteful use at farms, factories and households will likely lead us to an "arid" future of our own making. The best way to secure the future for fresh water is to develop a plan that draws all "new" water from better use of exiting supplies (efficiency) and to change habits, attitudes and economic structures (conservation). This poster presentation will outline a new approach to water planning that has the potential to begin developing water sustainability in Canada. "Soft path" planning for freshwater management differs fundamentally from conventional, supply focused water planning. It starts by changing the conception of water demand. Instead of viewing water as an end product, the soft path views water as the means to accomplish certain tasks, such as sanitation or agricultural production. Soft path planning allows us to unleash the full potential of demand management strategies. It is an innovative planning approach that explores the changes that are needed today to move water management and policies onto a sustainable path for long-term ecological and social prosperity.

Soft Path for Water In A Nutshell
http://www.waterdsm.org/publications.htm

Keywords/phrases: soft path for water, water conservation, demand management, sustainable water management.

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Changing the Game: Harnessing Consumer Trends to Restore Habitat and Improve Water Quality in the Okanagan

Michelle Boshard and Larry Bailey

Abstract

How do we make it economically attractive to restore habitat and improve water quality, rather than destroy or degrade it? That is the question answered at the heart of Watershed Wealth. This poster/paper describes the goal and structure of this new coop-based social purpose enterprise, whose first pilot Delivery Agent is being developed in the Okanagan Basin. From site preparation to long-term monitoring and maintenance, every stage of a Watershed Wealth restoration site will generate income, and simultaneously support both local community environmental stewardship and economic development. The machinery, strategies and consumer-driven trends traditionally employed for profit by business will now be put to work to drive restoration of the physical world humans have destroyed.

Watershed Wealth is “the business of restoration” - it restores lost or degraded habitat in ecologically compromised areas using scientifically sound and locally appropriate native planting regimes that include commercially valuable species which will be selectively collected and marketed by certified program Delivery Agents. Basic principles will include preservation of ecosystem function, biodiversity and native species. There has been considerable encouragement from Provincial and Federal agencies.

Watershed Wealth is designed to be suitable for participation by farmers, small and large landowners, land developers, volunteer groups and various government departments at all levels, in both rural and urban landscapes. Implementation will be simplified and based on farming, forestry and wildcrafting skills, but the science informing the process will be of the highest order and include soil sciences, hydrology, the whole range of biological and ecological disciplines and the nutritional and pharmaceutical analysis of the end products for market. The enterprise will use cutting edge technologies, from nanotechnology to monitor plant growth, soil/water/plant/pollutant cycles, carbon sequestration and product chain of custody, to the newest online open-source community based social marketing techniques to promote and logistically support the program.

This program breaks down traditional barriers between the environmental and economic sectors, bringing together major partners who may have never previously considered their potential connections or collaboration. The poster / presentation describes background need and rationale, applications and benefits, and how it fits in the Okanagan and beyond.

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Context

Each day we lose ground on water quality and quantity issues in the Okanagan because the rate of mitigation and restoration is outstripped by the rate of degradation. Financial and staff resources are assigned to reactive and quickly outpaced planning and coordinative processes, band-aid restoration activities, inadequate monitoring and policing, or perfunctory level educational messaging that leaves the public feeling guilty but with no motivating means to engage.

There are four core drivers to degradation of water quality and quantity, well articulated previously in relation to salmon recovery in the Pacific Northwest (Lackey, Lach & Duncan, 2006):

- the drive for economic efficiency and low-cost production for consumer benefit establish “rules of commerce” that tend to work against us
- the demand for critical natural resources, especially for high quality water, will continue to be great (and increase) through this century.
- the number of humans in the region will continue to increase, as will their aggregate demands to support chosen life styles; and
- individual and collective preferences directly determine the future, and substantial and pervasive changes must take place in those preferences if the current long-term, downward trends are to be reversed.

Lackey *et al.* (2006) contend that any policy or plan must at least implicitly respond to these four core drivers or that plan will fail, adding to an already long list of prior, noble, earnest, and failed attempts.

Management plans or conferences address human needs – human ideas, human communication and coordination, human discussion of their interference with natural processes, human consumption etc. – not water itself. Water does not consult management plans before flowing downstream, requires nothing in order to be cleansed or stored via plant uptake or soil percolation, and does not care about arguments going on between humans over where, when, and how to use it or who owns it. It effortlessly makes its way through a cycle from which humans have removed vegetation and have added impervious surfaces, pollution, and extraction pipes.

To date, our development of intangible “comprehensive” management plans as the primary strategy to deal with tangible water quality and quantity issues has neither physically protected and restored water quality, nor reduced demand for water in the Okanagan, because these plans do not substantively address the drivers of degradation identified by Lackey *et al.* (2006). There are instances of progressive local municipal bylaws and other regulations or reactive programming that curb some impacts and should be continued, but don’t deal with root causes and are inconsistently applied between jurisdictions. Aligning these regulations will take more time - meanwhile, impacts accrue.

Lackey *et al.* (2006) suggested that observing actual human behaviour—not opinion polls, nor production of massive, impenetrable management plans, but our individual and collective behavior—provides the best indication of the relative priority and measure of achievement of a public policy objective. Thus far, actual public behaviour change has not been a measurable used to determine success of water quality and quantity management in the Okanagan. If it were, there would be a stronger collective sense of time-sensitivity about moving on implementation of workable solutions, because the true management gap between "where we think we are" and "where we should be by what date" would be more obvious, and possibly more embarrassing. Despite admirable attempts to coordinate across an unreasonable array of jurisdictions, we still are very much in danger of "being at the airport when our ship comes in" in terms of successful implementation of a strategy to improve water and its management in the Okanagan. This vulnerability arises from our consistent failure to monitor, consider, and appropriately incorporate strategic approaches that address the root source of all water problems we want to respond to: daily human behaviour.

We can, and should, plan and develop new approaches and measurables to implement our water quality and quantity goals in the Okanagan. Completely original approaches with unfamiliar or undeveloped components can be difficult to visualize, be costly, and can take a long time to develop. This, plus institutional, political or personal investments in current processes, are often the reason new approaches are immediately sidelined before adequate consideration - even when the new approach would bring faster and better results and it can be demonstrated from other cases the current approaches will not likely achieve the desired level of success. The authors suggest instead that the best approach is to suspend disbelief in new approaches long enough to consider the logic of rearranging the best components of previously successful approaches from other sectors and applying it to improvement of water quality and quantity and ecosystem function generally.

We need to redesign the detrimental mechanisms by which humans interact with water daily so we can physically restore and protect it. To repeat the same types of unsuccessful natural resource management planning approaches tried and failed elsewhere and to expect a different result is insane. Equally as insane is the pathological pursuit of corporate economic gain as discussed by Bakan (2004) which is currently at the base of our economic system and degrades water quality and habitat. The authors therefore propose we try another method: use previously unrecognized or undervalued non-economic natural system components, plus untapped economic drivers to create a specific set of business-based activities that both take advantage of, and change, daily human behaviour. This approach resolves conflicts at the base of costly, endless reactive management planning processes and studies in order to put us ahead of the curve both in terms of physical restoration of water quality and harmonization of demand issues with ecosystem function. One conceptual starting point to consider is the intersection of the strongest and most desirable features of both the natural functional ecosystem and the human economic system, then to determine how these two systems could be connected more appropriately for the mutual benefit of each.

Nature provides the most time and energy efficient, functionally effective and low-cost water quality improvement and storage infrastructures, while simultaneously supporting the rest of biodiversity. Human economic systems provide the greatest motivation for human behavioural activities and often change rapidly with exponential expansion upon consumer demand. Consumer demand for natural processes, habitat and products has shown exponential increase in recent years, and can be used as the driver to increase demand for installation of nature's most effective components, benefitting both nature and human water quality and quantity improvement. Demand for, and impacts on, water can be changed at a consumer level, eliminating altogether the need for repetitive, reactive and costly management planning and taking on-ground steps to change the current situation before it gets worse.

Various sources recognize that non-economic values tend not to be considered in decision making (Pearce, D., D. Moran, D. Biller, 2002; Lackey, 2006; Linder, 1986; Botterill, L., Date Unknown.), even though it has been broadly recognized that non-economic functions of ecosystem have economic value (Wikipedia, 2008; Natural Capital, 2008; Government of Canada, 2008). To this, the authors would add there are currently no specific, daily business level mechanisms by which to directly translate the per-transaction value of a non-economic natural system component into human economic system values. This is especially true on a day-to-day household product or consumable service sale transaction level. We can, however, simply co-design human and natural systems so they help each other on a daily basis.

Individuals in our current society generally experience neither tangible and financial repercussions for undertaking activities that degrade the natural system, nor tangible or financial benefits to restoring it. This enables a neutrality of position and fosters the questions "what's in it for me?" and "why should I?". This position affords individual humans and the aggregate human economic system a footing that is used to out-compete other species and nature's aggregate ecosystem (this is supported by the generally observable fact that human-sourced degradation rates are higher than combined human- and natural-restoration rates). While more people in our society are indeed asking "does this hurt the environment?" they cannot really tell how much, or in what way, their daily purchases or activities help reduce impacts, and have had basically no options in terms of purchasing products that they can know actually restored the environment instead of simply protecting it.

Rather than allowing this underlying situation to continue, the authors have developed a social enterprise based system that directly and specifically addresses the "what's in it for me" and "why should I" questions by converting environmental restoration into financial profit, and creating new "restorative product" purchase options for consumers to drive demand. This system integrates missing but valuable non-economic components of natural systems (e.g. native plants) into the more successful human economic system by creating consumer demand for them. It also provides a source of non-tax based revenue from which to fund further restoration (the social purpose of the enterprise).

The market system will determine the economic values of the non-economic components of natural systems in the same manner as any other human economic system component. Undervalued natural system components would finally have an equal footing and this will change both the level of their consideration in decision making and in public estimation of their value (especially in relation to daily consumer behavioural patterns).

Human industry and individual consumerism may be the source of the problems at the root of water quality degradation, but they can also become the source of the solution. An enterprise based approach will also address community economic development, plus funding needs for habitat restoration, water stewardship and public education. The Watershed Wealth program is a "less talk, and more action" approach needed to implement cost-effective, socially motivated physical solutions that affect immediate habitat and water quality change, and cause public behavioural change *en mass*.

Description of Watershed Wealth

The authors have, with other major NGO and industry partners, incorporated the Watershed Wealth Coop. The Coop and its certified Delivery Agents are the underlying business structures that will facilitate solutions to a number of environmental issues, including water quality improvement and storage issues such as peak runoff attenuation. The Coop will harness and generate consumer-demanded re-installations of vegetation-based natural ecosystem processes across all land use types (in other words, across the watershed). This is one of the first social entrepreneurship (Dees, J.G. (1998); Social Entrepreneurship (2008); What is Social Enterprise (2008)) business-based models of the emerging "restoration economy" (Western Governors Association (2006); Cunningham (2002)) to create a specific, non-grant based business from habitat restoration.

Watershed Wealth connects consumer demands for the "products" from restoration sites (e.g. native plant material) to drive replacement of native plants in lost or degraded habitats in urban, agricultural and forestry settings. The first pilot Delivery Agent for the newly launched Watershed Wealth Coop (WWC) is in the Okanagan and the structure of the Watershed Wealth business model offers a broadly publically available revenue generating system to increase demand for their services.

Watershed Wealth Delivery Agents, certified under the WWC, restore human impacted areas anywhere in any watershed using scientifically sound planting regimes that include commercially valuable species which are subsequently selectively collected and marketed. Implementation is simplified and based on farming, forestry and wildcrafting skills, but the science informing the process will be of the highest order and include soil sciences, hydrology, the whole range of biological and ecological disciplines and the nutritional and pharmaceutical analysis of the end products for market. In addition to brokering product to market, there are a number of services the Coop offers to the public, to agencies, and to its member Delivery Agents.

Basic principles of Watershed Wealth include:

- restoration of ecosystem function, including normalized hydrographs
- increase in biodiversity and native species
- development of local community economic opportunity, control & benefit
- improvement in citizen education & engagement
- increase in funding for stewardship and program expansion
- use of both sound science and traditional ecological knowledge.

Sale of collected materials is through existing ornamental, food and nutraceutical markets. Feasibility studies indicate that products produced in such carefully designed carefully monitored and ecologically sound environments will demand the highest prices. Consumers will now have the option to purchase products that restore the environment, not just protect it. Niche market branding will maximize return and outreach. Well conceived and executed environmental projects almost always result in increased property values, and will attract previously reticent landowners interested in additional income streams.

Watershed Wealth is specifically designed to address the near "perfect storm" of issues of current global concern, including climate change, food security, energy crises and biodiversity collapse, by employing new developments in technology, including open-source software, wireless technology, genetic and nano-technology, and social networking on the internet. In doing so, the enterprise builds on the growing momentum in social entrepreneurism, the restoration economy, consumer health trends, urban housing and smart growth movements, carbon credits, and physical habitat needs. The Okanagan is an excellent testing laboratory for the enterprise, as it exhibits symptoms or opportunities associated with all of these current issues.

There are a number of marketable goods and services provided by WWC and its franchised Delivery Agents, described in Table 1.

Table 1: Identified revenue streams and description.

Revenue Stream	Brief Description
PRODUCTS	
provision of plant materials as "nursery stock"	sales of hard-to-find native plants for restoration projects, WWC sites, or landscaping programs / jobs
"direct sales" of raw botanical product to markets	sale of plants that have specific values in edible, neutraceutical, medicinal or ornamental commodity markets
sale of seeds	sale of locally appropriate seeds in retail market / as promotion for program
"value added" product sale	sale of small scale products that use WWC raw product as ingredients
SERVICES	
invasive plant removal	removal of invasive species. Some have commodity markets, harvested materials feed into raw product stream above
organizational support	sliding-scale fee provision of administrative software, webpages and other web-based solutions (to WWC members only)
operational support	various member-based services including but not limited to marketing & promotion materials and support, certification and training, value-added processing
training and information	online and Regional Coop delivered certification training
data collection & reporting	wireless state of the environment data collection, data interpretation and reporting to natural resource managers
online services / sales	provision of sales portal for raw and value added products
carbon credit verification & trade	creation / verifications of carbon credits generated as a result of WWC plantings, facilitation of their exchange
Consulting	advice in the areas of restoration projects, WWC related small business development

Generally, WWP will use cutting edge technologies whenever possible, from the newest online open-source community based social marketing techniques for promotion and logistical support for the program, to nanotechnology to monitor plant growth and soil/water/plant/pollutant cycles, carbon sequestration and product chain of custody. When a WW site includes a riparian area, various water quality parameters will be monitored.

Monitoring

Unlike traditional governmental or non-profit monitoring programs for which it is difficult to find ongoing long term funding and to coordinate with other data, monitoring done by the Watershed Wealth Program will be paid for as a regular business expense and undertaken / contributed to by anyone and everyone interacting with the program. Coop site scouts will collect information on previously un-assessed habitat, expanding state of the environment data. Social marketing will encourage online participation. Delivery Agents will monitor various environmental parameters when they are assessing product maturity. Wireless remote dataloggers purchased by landowners, consumers, and Delivery Agents will feed data to online coordinative systems to augment additional easy online community stewardship data-entry systems and produce GIS map-based mashups that support both state of the environment reporting and program marketing.

Applications

One of the most frequently asked questions the authors receive about Watershed Wealth is “what kind of plants do you use?”. There are numerous sources describing what native plants work best in restoration sites on various land-uses or biogeoclimatic settings (as two examples, Klinkenberg (2007); Gayton, D. (2004)). There is also much market information on the monetary value of native plants (two examples of which include De Guse (1995) and SAC Inc. (2002)). The response to the question about what plants Watershed Wealth uses quickly becomes “what kind of plants do *you* use for restoration?”. Plant mixes are site dependant and developed on a case by case basis as appropriate to local circumstances.

To satisfy the curiosity at the basis of how this concept could actually be profitable or what potential it might hold, the authors have cross referenced established markets for plant materials, native plant lists for various biogeoclimatic zones, and common products that require plant materials as ingredients. There are many native plant species that have economic value that can be collected (BC and Alaska Examples are discussed in Hallman, Hatfield and Macy (1998) and Downing (1996)), and the Watershed Wealth Coop will actively develop more.

A more narrative description of how the service-based components of Watershed Wealth could generate consumer interest or serve other user sectors (such as the ecosystem itself, farmers, and small scale producers) is included in the “user perspectives” in Appendix A, the first portion of which on the Consumer / Homeowner perspective is quoted below.

The Consumer / Homeowner Perspective

While you’re in the nursery section at Home Depot with the kids, you see a Watershed Wealth kiosk. Its giving free CDs, showcases products that are made from Watershed Wealth grown plants, and has a built in computer screen where you can click a map to see your house, local Watershed Wealth planting sites, and Delivery Agents nearby. There’s a sign that indicates the plants around the kiosk are ones you can grow on your property for Delivery Agents to collect while you get part of the profit. You hear another customer remark they’re going to download the files from the CD from the website www.watershedwealth.com

When you get home, you run the CD in your computer. It gives you a great deal of information on the Watershed Wealth Coop and native plant gardening and maintenance, plus interactively connects to a website which has valuable information on local conditions and recommended plants, planting, care and value in habitat, and the financial terms of the program. The website shows you live data feeds from Watershed Wealth monitoring sites using maps with available multiple overlays for everything from climatic zone, to species presence, to government jurisdiction maps. There are links to information about other topics such as water quality. The computer recognizes where you are and the necessary contacts and permit forms for appropriate government agents show up, along with plant selections & growing information, coupons for native material & hand tools, the name of the closest delivery agent or contractor and the nearest collection point for harvested materials. There's current product market information on plants and products, an explanation of how the profits from the Co-op go to fund a local stewardship group, and a website for that group. You can shop and order Watershed Wealth products on the site, then direct that the sales profits go to your local stewardship group. The site is linked to others such as Salmon Center (another RRA project) that has includes live news feeds, blogs & forums, personal garden calendars, "ask an expert" section and other interactive information. The contact is forwarded to the nearest Delivery Agent for service follow up.

An example demonstrating the restorative and educational potential of the enterprise, is a proposed restoration site within the Town of Osoyoos. Figure 1 below is a picture of the proposed site, which would be integrated with Master Waterfront redesigns underway by the Town, as well as with efforts of the Osoyoos Lake Water Quality Society (to restore water quality) and the Canadian Okanagan Basin Technical Working Group (to restore wild sockeye).

Figure 1: Looking north on the "Triangle" restoration site – part of a proposed interpretive end loop incorporated into the Osoyoos Master Waterfront Plan, and a future potential juvenile sockeye rearing pond.

Why This Will Work

Watershed Wealth addresses the core drivers of degradation identified by Lackey in the following manners:

- it satisfies the drive for consumer benefit, and simultaneously changes the "rules of commerce" by focusing business on sustainability and local self-sustenance rather than centralized collection of profit via economic over-efficiency and low-cost production
- it creates the public demand for installations of critical natural resources that physically improve water in cost-effective ways
- it reduces the aggregate impacts of individual human demands; and

- it provides financial and educational motivation to change individual and collective preference and behavioural changes to reverse current long-term, downward trends.

The Watershed Wealth Coop business model is one of subcontracting, franchises and minimal overhead or staff, with online coordination and support to minimize costs and enable quick up- or down-scaling of activities in response to real-time operational needs. The WWC model has been influenced by business models of custom development contracting from the construction industry and old-time farmers' coops. Simply put, the current social, economic and environmental climates are suitable, the business model is sound, and the need is great for this approach.

End Benefits

Watershed Wealth is a social purpose enterprise because the primary goals are restoration of lost habitat (and thereby improved water quality and quantity), money for stewardship and community, and information for better natural resource management. It is not simply business for business' sake, even though it will use very standard and aggressive business practices. Rather than an extraction and profit-centralization model, this business uses a dispersed collection and profit re-distribution model that mimics water cycle function itself. Consumer demand for physical product (plants) will generate installations which, due to the specific species composition and installation designs, will cumulatively provide the following water quality and quantity benefits:

- affect impervious surface runoff peak attenuation and result and water quality changes,
- filtration: plant and soil,
- storage: aquifer replenishment,
- fish and wildlife benefits,
- climate mitigation

and yield the following social and financial benefits:

- cost reductions for municipal works
- expanded and low cost information source for agencies
- economic opportunities (DAs, value added producers)
- increased public awareness of the economic and non-economic aspects of plants
- daily human behaviour change
- money for stewardship initiatives

The true impact of this initiative is cumulative positive change via reversal of non-point source mechanisms that are currently our largest cause of degradation of water quality (British Columbia Ministry of Environment, Lands and Parks, 1999). This "non-point" concept is also paralleled in the business income streams: on any given single site there may be limits to what can be extracted due to either economic or profitability constraints resulting in small amounts of profit from each site, but by monitoring then collecting product across the whole watershed (and beyond to any other watershed), there will be enough product and service income generated to sustain the Coop coordinative function, provide work for Delivery Agents, and create financial incentive to improve water quality, fish and wildlife habitat, and climate and the homeowner / consumer level.

Table 2 discusses the aligning motivations of various user groups for this initiative (why various sectors of society would all engage in this because it benefits them), as well as the benefits they each incur and any special interactions they might have with the Coop or its Delivery Agents.

Table 2: General expected user group benefits.

User	Benefits
Volunteers & NGOs	• Volunteers activities (restoration, landowner contact) could generate funds for initiatives of their choice • NGOs would develop not only skills and technical capacity, but diversify funding sources • Volunteers could assist Coop / DA with landowner contact, administrative tasks, site installation
Homeowners / Landowners	• Large and small scale farmers, urban streamside dwellers and other owners of degraded habitat such as developers want to preserve their way of life and develop new ways to generate income. • Well conceived and executed environmental projects almost always result in increased property values. • Non-extractive yet productive use of sensitive areas will appeal more to landowners and the public than restrictive set-asides and buffers.
Natural Resource Managers	• The first target habitat for this program would be heavily altered or denuded habitat and sites with low or no biodiversity or function. WWC helps natural resource managers meet their mandated agendas by decreasing (and reversing) habitat degradation rates and resulting violations they must deal with • Creating incentive-based economic activities in degraded habitats will create the missing "on-ground" focal point around which the accomplishment of regulatory goals (from provincial streamside regulations to SARA) can be achieved with eager, rather than recalcitrant, responses by landowners. • Natural resource agencies are realizing they need new ways to meet their regulatory requirements for habitat restoration and species protection because they do not have adequate enforcement capacity to deal with the scale of impact from human activity, and because heavy handed approaches have produced negative legal and public perception results. • Random and destructive public access to WWC sites would be less than now, when much of the target land base is completely unsupervised. • The program provides an easily adoptable option municipalities can offer to developers that meets RAR and other environmental standards but provides property value increase and selling points
Consumers	• Consumers get high quality products and services that are healthy for them and environmentally restorative (not just sensitive). • Community benefits would include improved environmental health, skill development and job creation potential as well as many tourism, educational and interpretive opportunities. • Watershed Wealth products would create income, job opportunities, skill training, social program development (from volunteer environmental monitoring programs to business development for the unemployed).
Product Manufacturers	• Have access to high quality, easily traceable, locally sourced ingredients for products and an online and retail marketing structure for expansion.
Retailers	• Can cash in on the cache of a product not having just protected the environment, but restored it • Logistical and promotional support
Funders	• In addition to habitat benefits and community social programs that will bring many participants into the habitat restoration process willingly, this program will provide several cost efficiencies to funders of environmental projects. Ongoing maintenance and monitoring, often the twin downfalls of restoration projects, become a self-sustaining economic activity and do not require continuous funding or management. • The program is diverse enough in scope that there are significant funding leverage and synergistic partnership opportunities. • It builds capacity of groups applying for their funds.

How This Fits in the Okanagan

Watershed Wealth applies geographically everywhere and conceptually anywhere in the Okanagan, or any other watershed. The plant lists may change, but the business opportunity does not. The human impacts that this initiative addresses are ubiquitous in the Okanagan. The approach is novel as it has not been done anywhere yet and occupies a previously unidentified niche that bridges the traditional gap between economic and environmental sectors. Existing partners in the Okanagan are afforded a new project and mechanism on which to interface, and integrate.

Examples of the environmental activities the Watershed Wealth program compliments in the Okanagan include ongoing efforts by Okanagan Basin Water Board, Okanagan Nation Alliance, Provincial and Federal environmental and agricultural agencies, the South Okanagan Similkameen Conservation Program, all municipalities and regional district planning and environmental department initiatives, NGO efforts operating in the area, and international water and environmental initiatives.

As an example of how Watershed Wealth could integrate and support existing and ongoing intergovernmental coordinative planning and assessment activities in the Okanagan, the monitoring data collected by WWP could provide real-time information feeds to water management information systems and decision tools such as the Fish Water Management Tool for sockeye management on the Okanagan River. Site assessments to determine the potential financial profitability for particular landowners or managers become defacto habitat assessments that are done and paid for in the regular course of business, the information from which could build into or supplement SHIM and other GIS based municipal or regional planning department databases.

For more information on the Watershed Wealth Coop, or to become a Delivery Agent, Shareholder or Shopper, visit www.watershedwealth.com often.

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Appendix A - Perspective Narratives

The Habitat Perspective

A neglected property lies along a small, salmon bearing stream in your local watershed. The riparian habitat has been degraded by illegal plant removal, illegal dumping, unchecked erosion and invasive species. A Watershed Wealth Coop Delivery Agent is engaged for restoration. A survey of the site followed by a consultation with the appropriate agencies is performed. A restoration plan is developed and approved and necessary permits obtained. After clean-up, invasives removal and planting with a range of native species, monitoring dataloggers are installed. The DA returns on a monthly basis for photos, data download and physical inspection. As plantings reach harvestable stage the DA performs a carefully recorded harvest under WWP guidelines previously approved by agencies. The landowner receives an agreed percentage of the revenue from the harvested material.

The Farmer's Perspective

A farmer is having trouble making ends meet. Equipment is under-utilized, crops barely make a profit at best and labor is expensive and difficult to find. This farmer has considered organic certification but the transition period will threaten farm income. A farm advisor suggests the Watershed Wealth Delivery Agent program which the farmer investigates and decides to participate. The Co-op assesses the farmer's capacity and decides that the main needs for him to become a DA are training in habitat issues including regulations, methods and materials, and best management practices including monitoring protocols. This training is flexibly available online through the WWP Co-op centre via seminars, and site visits and other in-person events scheduled to accommodate his operating business.

After training, the farmer who is now a DA, begins to service Watershed Wealth clients in the area. These clients include other small farmers, developers, local governments, stewardship groups and homeowners. As a project begins, an assessment team from the Co-op visits the site, talks to the owner and prepares an initial plan. The DA reviews the plan, locates plants, seeds and other materials and prepares an estimate for site-prep and installation. The Co-op assists the DA in negotiating a contract for the work. The Co-op also negotiates the umbrella WW agreement which includes long-term commitments, access agreements and profit sharing.

After installation, the DA visits the site monthly to monitor both habitat/scientific and business elements. If there is an onsite datalogger, that data is downloaded to a portable device. All information is input to the database coordinated by the WWP. A Co-op monitor visits once a year, or when requested by DA or owner.

When plants reach harvestable stage, the owner is notified and arrangements for harvest are made. Harvest is supervised by the DA and done according to strict BMP protocols developed by the Co-op. The raw products are warehoused, processed as necessary for the market. The Co-op coordinates sale and shipping of products. Where possible local sales through farmers' markets and other retail outlets are encouraged. The next tier of market is the small local producers of value-added botanical products such as cosmetics, teas, herbal medicines and crafts of many kinds. Beyond that, products will be packaged for sale through the Co-op online store which sells to individuals and businesses on both a retail and wholesale level. Any remaining products enter the commodity markets. When sales are complete the landowner and DA receive percentages of the revenue based on individual contracts.

The additional capital and knowledge provided by the WWC DA franchise allows the farmer to establish an organic native plant nursery as well as to grow various species for sale through Co-op. This nursery provides material for WW projects, DIY projects and the general market.

The Small Scale Product Producer's Perspective

A small scale value-added producer (who makes food, soap, teas, nutraceuticals, or crafts with plant-sourced ingredients) has a product that many people love and it sells readily at farmers markets, bazaars and a few small shops. A website offers the product but is lost in the flood of online stores. Fees for ebay or Amazon stores are unaffordable. Larger retailers require that the product be available through usual distribution channels. Supply of quality raw product is erratic and prices volatile. The business also is limited by lack of access to professional equipment for manufacture and packaging.

The producer hears about the Watershed Wealth Co-op and joins. The Co-op helps locate a source of local, certified raw product at a stable price. Part of the manufacturing process is moved to a WWC Community Processing Facility to take advantage of more professional equipment. The product is sold through the Co-op online store and offered to retailers through the Co-op wholesale distribution system in addition to the existing sales. The producer uses the Co-op online resource center for free accounting and other business software as well as informational and educational material including WWC certification courses. A Co-op product consultant helps develop the product line and the branding and promotional material. The products are promoted through WWPs online advertising, tradeshow appearances and media campaigns.

Salmonid Distribution in Relation to Stream Temperatures in Fortune Creek, British Columbia – The Influence of Surface and Groundwater Interactions

Elinor McGrath, Adam Wei, and Craig Nichol

Abstract

Surface water and groundwater interaction in a stream can greatly influence the physical and chemical characteristics of stream water (i.e. temperature, dissolved oxygen etc.), and consequently aquatic biology. In an attempt to quantify whether surface water and groundwater interaction affects salmonid use of Fortune Creek in the North Okanagan, British Columbia, the relationship between water temperatures and salmonid occurrences was explored. Over the summer of 2008, temperature data were collected at 22 sites along the creek, and weekly salmonid counting was conducted at eight sites. Piezometers were installed in the streambed in a known groundwater upwelling area to examine how the hydraulic gradient changes over the summer as streamflow is reduced and groundwater pumping pressure increases. Temperatures at the salmonid count sites were measured at 30–minute intervals in the air, the water, and at two depths below the streambed. The measurements in the streambed were intended to verify the presence of cool groundwater upwelling through the gravel. Piezometers were equipped with water level loggers and installed in the stream with the screen at 3 m below the streambed. In addition, a water level logger was installed in a nearby agricultural well to determine how pumping affects the hydraulic gradient in the creek. Water releases from a reservoir located on the headwaters of Fortune Creek were tracked along the length of the creek to assess whether they had an impact on stream temperatures. This data, together with water chemistry samples, was used to quantify mixing ratios of surface water and groundwater at several selected sites.

Salmonid counts of juvenile coho (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*) were conducted weekly with baited minnow traps set over night. Preliminary results indicate that salmonids are absent in the lower valley bottom reaches of the creek during periods of high stream temperatures. Upper reaches of the creek, where temperatures are cooler, showed abundant salmonid numbers throughout the summer.

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Inventory and Mapping - Okanagan Lake, Creeks and Wetlands

Michelle Kam

Abstract

Kelowna, placed in the heart of the Okanagan, borders Okanagan Lake and has a significant number of creeks and wetlands within its boundaries. As development continues to rise, the City of Kelowna recognizes the importance of accurately identifying, locating and creating an inventory of waterbodies and their associated habitats and attributes. Therefore, the City embarked on a journey to map the foreshore of Okanagan Lake, the creeks and the wetlands within Kelowna.

In 2004 the City of Kelowna and the Regional District of the Central Okanagan completed the Central Okanagan Foreshore Inventory and Mapping project. This project provides agencies with easily accessible inventory of land use, shore type, existing riparian condition and anthropogenic alterations throughout the study area.

In 2005, the City of Kelowna hired Ecoscape Environmental Consultants Ltd to conduct Sensitive Habitat and Inventory Mapping (SHIM) of both Mill and Bellevue Creeks. In 2006, the City was able to re-hire Ecoscape to complete an additional 52 kilometres of creek SHIM.

In 2007, the City of Kelowna hired Ecoscape Environmental Consultants Ltd to complete a Wetland and Inventory Mapping (WIM) project. It is estimated that over 85% of the valley bottom wetland and associated riparian habitats have been lost in the Okanagan. Many of the remaining wetlands are highly fragmented. A total of 278 wetlands including 172 previously unmapped wetlands were inventoried and mapped.

In 2008, SHIM will be completed on the remaining creeks within Kelowna. All of the SHIM and WIM data will be forwarded to the Community Mapping Network so it can be uploaded for other levels of government, the public and consultants.

Funding from City of Kelowna, Central Okanagan Regional District, Okanagan Basin Water Board, Real Estate Foundation and Ducks Unlimited has made the above projects feasible. This data and mapping has provided urban planners with up-to-date information, allowing for more informed planning decisions to better protect, improve or enhance remaining foreshore, creek and wetland ecosystems. Numerous departments including Environment, Drainage, Planning, Parks and the Fire Department are using the information to date.

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Managing Middle Vernon Creek for Humans and the Environment: Understanding a Highly Connected Surface and Groundwater System

Natasha Neumann, Lorne Davies, Adam Wei, and Jeff Curtis

Extended Abstract

The Oceola Fish and Game Club (OFGC) has been working on management issues in the Middle Vernon Creek watershed since 2000. The OFGC has implemented an adaptive management planning process that re-assesses its priorities as new information is collected and knowledge gained. This project, a partnership between the OFGC, the University of British Columbia Okanagan and the District of Lake Country (with support from First Nations, the local community and businesses), is the latest step in that planning process.

The southern portion of the Kalamalka-Wood Lake basin has been broken down into sub-watersheds for management purposes (Figure 1). The Swalwell (Beaver) Lake and Oyama Lake sub-watersheds in the headwater areas east of Winfield are important reservoirs. This project focuses on the Ellison (Duck) Lake, Middle Vernon Creek and Winfield Creek sub-watersheds, located in the valley bottom.

Upper Vernon Creek drains Swalwell (Beaver) Lake, flowing west into the main valley and into Ellison (Duck) Lake. Where Upper Vernon Creek enters the valley it flows over a highly permeable alluvial fan deposit. Considerable volumes of water infiltrate the ground where the creek flows over the fan, and it has been identified as a groundwater recharge zone (Le Breton, 1974). Ellison (Duck) Lake drains to the north through Middle Vernon Creek to Wood Lake. Spring-fed creeks on the west side of the valley contribute to Middle Vernon Creek along its path. At approximately halfway between Wood and Ellison (Duck) Lakes similar springs combine to create Winfield Creek which also flows north

Surface water sources (creeks and lakes) as well as groundwater are used in the Winfield area for domestic and irrigation water. At present priority water licencees on Middle Vernon Creek are not receiving water for irrigation during the summer months. There are over 200 wells in the valley bottom, ranging in depth from very shallow (10 feet or 3 metres) to more than 200 feet (61 metres). Most wells are used to support single-family domestic use, but there are a number of large capacity wells that supply trailer parks, resorts and suburban neighbourhoods.

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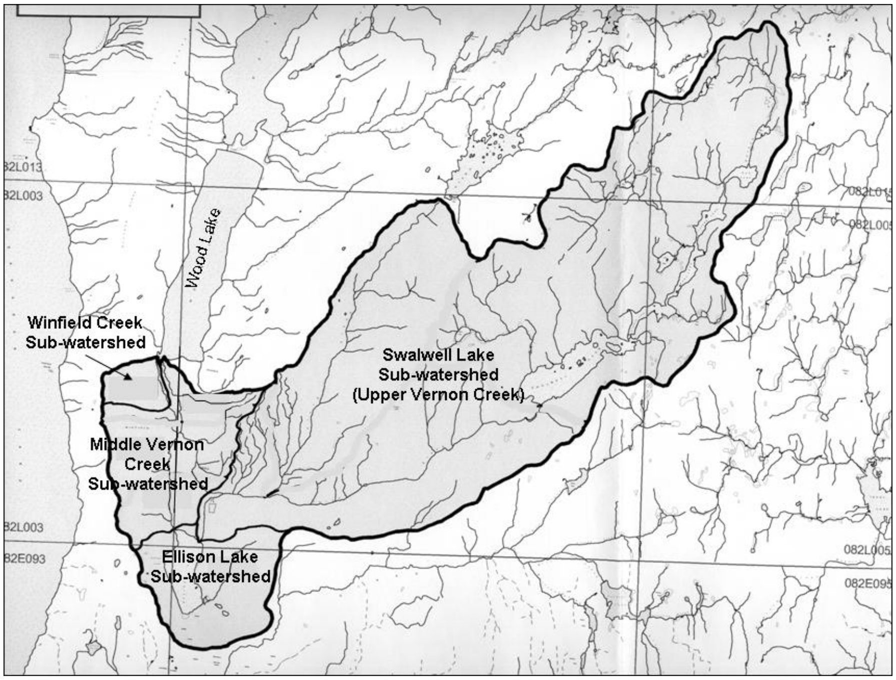

Figure 1: Map of southern Kalamalka-Wood Lake basin.

Middle Vernon Creek went dry in 2003 and 2004 due to low water levels in Ellison (Duck) Lake. The creek went dry again in 2007 and 2008 as a result of beaver dam construction in the upper reaches. Between 1972 and 1990 flow was augmented when the Hiram Walker Distillery released 5,000,000 m^3 of Okanagan Lake cooling water into Upper Vernon Creek. In 2007, urban development was responsible for reduced flows in Winfield Creek. Because this creek is an important Kokanee spawning channel, groundwater management has become an issue of concern in the local community.

The most comprehensive study of the surface and subsurface hydrology of the Winfield Flats area was conducted in the 1970s as part of the Okanagan Basin Study. It is apparent that groundwater and surface water are very closely connected in this area, and that to effectively manage one requires management of the other. Since the 1970 studies more data has become available on such things as the area's geology, and there has been an increase in water use as agriculture, industry and populations have expanded. The OFGC has concurrently been collecting hydrometric data and developing adaptive management strategies to address low flows in Middle Vernon and Winfield Creeks. Effective management requires cooperation by all users. It also requires an understanding of the regional hydrology, including the identification of sources, flow control structures, withdrawals and the flowpaths that connect surface and subsurface waters. This project was initiated to take advantage of the OFGC monitoring network and to address the need for a better understanding of the regional hydrology to support planning.

One of largest challenges to effective community watershed management is that management is based on jurisdictional boundaries, not watershed boundaries. The Middle Vernon Creek watershed spans the Duck Lake Indian Reserve No.7, the District of Lake Country, the City of Kelowna and the Regional District of the Central Okanagan. Other issues that complicate the situation include the need to address First Nation water rights and source protection for both surface and ground water.

The main objectives for this project are to:

- Establish a network of surface water and shallow groundwater monitoring stations
- Complete a strategic well inventory and water quality sampling program
- Produce aquatic resource maps at different scales, ranging from the watershed to sub-watershed scale, and
- Develop terms of reference for a Water Use Plan (WUP) that incorporates both surface and ground water resources. The Mission Creek WUP is being used as a template

The OFGC has maintained a hydrometric monitoring network in the area for the past few years under their guiding principle that "you have to measure it to manage it". This network has been expanded for this study to identify where creeks gain from or lose to groundwater. These measurements will be enhanced by a study of the natural chemistry of the waters (surface and subsurface), which will refine our ability to identify the different sources of water to the creeks, and therefore the dependence of the creeks on these sources during periods of low-flow.

A series of aquatic resource maps will be generated, including community watershed boundaries, aquifer locations and more detailed point information on springs, major wells, major source water intakes and groundwater recharge and discharge zones. These maps are intended not only as management tools, but also for public education, to develop the community's awareness of its watershed and areas of sensitive habitat. The OFGC is very engaged with the community and puts considerable effort into outreach on resource and conservation issues. The club's experience and infrastructure will be critical in disseminating the results of this study. It will also be important to create a central repository of existing reports and data, to have ongoing discussions with community partners, and to make the results available to planners and managers.

The Middle Vernon Creek watershed is an example of a highly connected surface and groundwater system that supports a human population as well as a variety of aquatic and terrestrial ecosystems. Local, regional, provincial and First Nations governments, private industry, public interest groups, individual landowners and the UBC Okanagan are working together on this project to improve understanding of the regional hydrology, an important step towards developing a management plan that considers surface and subsurface water flowpaths as a single, interacting resource.

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What is Happening to Wild Salmon in Your Community?

Camille Rivard-Sirois

Abstract

The ***Canadian Okanagan Basin Technical Working Group (COBTWG)*** is a tri-partite working group dealing with technical issues associated with management of salmon and resident fish stocks and their associated habitat requirements in the Canadian portions of the Okanagan River basin. Participants to the COBTWG include Fisheries and Oceans Canada, Okanagan Nation Alliance Fisheries Program and B.C. Ministry of Environment.

The ***Reintroduction of Sockeye Salmon into Skaha Lake project*** is a 12-year initiative to reintroduce and re-establish the indigenous sockeye salmon back into their historic habitat in Skaha Lake. This project reaches to stabilize and rebuild the declining wild Okanagan Sockeye population, to return sockeye to their former habitat and migration range, and to revitalize the Okanagan Nation salmon fishery.

The ***McIntyre Dam project*** is a plan to refit the actual gates at McIntyre Dam (Oliver) in order to allow sockeye salmon passage. With this modification, salmon will be able reach Vaseux Lake, an important historic habitat which they have been unable to access for the last several decades.

The ***Okanagan River Restoration Initiative project*** (ORRI) is a plan to re-naturalize one of the most biological sections of the Okanagan River. By re-creating a wider floodplain, restoring the riparian vegetation and re-meandering a part of the channelized river, ORRI will provide a better habitat for salmon and trout, reduce risk of flooding and improve water quality.

The ***Fish Water Management Tools project*** (FWMT) is a computer model developed specifically to help authorities manage water flows in the Okanagan River in a “fish friendly” manner. The model uses real time field data to make predictions and decisions witch benefit kokanee and sockeye salmon while respecting the needs of other water users.

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Duteau Creek Watershed Assessment and Protection Plan

Tricia Brett and Renee Clark

Abstract

Source water quality is a primary concern for Greater Vernon Water (GVW) and it is the initial barrier in a comprehensive drinking water protection plan. GVW initiated a source assessment and watershed protection plan on Duteau Creek in July 2007 to comply with the water system operating permit issued by the Interior Health Authority (IHA) under Section 8 of the *Drinking Water Protection Act*. As Duteau Creek Watershed is a multi-use community watershed, it is also important to understand anthropogenic impacts, impacts of climate change, impacts of mountain pine beetle and to collect relevant information for evidence based action. The key elements that have been considered in this project are modules 1, 2, 7 and 8 of the *Comprehensive Drinking Water Source to Tap Assessment Guideline* released by the Ministry of Health and the Ministry of Water, Land and Air Protection (now Ministry of Environment) and the Interior Watershed Assessment Procedure (IWAP) that focused on drinking water.

GVW identified a need for a technical advisory committee which includes members from Ministry of Forests and Range, Ministry of Environment, UBC-Okanagan and IHA. Members of the committee bring expertise, background knowledge and a wealth of resources to the table which in turn will produce a superior product.

The threats to drinking water that have been identified are significant increases in forestry activity due to the Mountain Pine Beetle infestation, sediment/turbidity from anthropogenic activities, pathogenic organisms from human and animal waste and a significantly undersized intake pond. A recommendation has been made that GVW work with licensed stakeholders to use best management practices regarding operations within the watershed as well as provide education material to individuals using the watershed. Finally it has been recommended that the Source Protection Plan be a living document containing a monitoring and reporting plan that is looked at each year. Following these opening recommendations, a cattle impact reduction plan has been initiated with funding from the OBWB and in kind works from multiple partners, as well as the intake pond upgrades are being put into the capital works budget.

By working with a large network of people and multiple stakeholder meetings, a document is being produced which many people take ownership of and respect. This results in stronger working relationships within the community watershed and increased knowledge within the groups.

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Long-Term Water Quality Trends in Okanagan Basin Lakes

Michael Sokal, Vic Jensen, and Hailey Goode

Abstract

The Okanagan Valley is one of the most rapidly developing regions in Canada. Widespread urban development along with extensive agricultural activities challenge water resource management of five large lakes (Wood, Kalamalka, Okanagan, Skaha and Osoyoos lakes) in the Okanagan basin. These water bodies provide important habitat for aquatic life, community drinking water, irrigation water to orchards and vineyards, and provide a variety of tourism and recreational opportunities. Consequently, protecting the water quality of these lakes is essential.

Phosphorus is a key nutrient driving the aquatic food chain and limits overall water clarity and quality in freshwaters. Decreasing water quality and nuisance algal blooms in the 1960's led to improved municipal sewage treatment and reduced phosphorus loading to Okanagan, Skaha, and Osoyoos lakes. The current Ministry of Environment monitoring program (Okanagan large lakes water quality monitoring program) was initiated in the 1970's to provide water quality data to decision makers within government, industry and to inform the public. These data are used to identify current status and trends in lake water quality within the Okanagan Basin, to determine success and challenges remaining in the control of excessive nutrient or other contaminant loading from point and non-point sources. Increasingly, this monitoring benefits from collaboration with senior and local governments, academic institutions and stewardship groups.

The monitoring shows that nutrient concentrations in Okanagan basin lakes have changed through time as a result of both natural and anthropogenic influences. Different watersheds, surface area, volume and land use, result in varying effects of nutrient enrichment or reduction. Phosphorus concentrations in all lakes show the influence of climate variation, however, trend assessment can be complex particularly in the two largest lakes, Okanagan and Kalamalka. For smaller lakes where phosphorus reduction actions have been implemented, there are marked decreasing trends. This is most evident in Skaha Lake which has significantly decreased phosphorus concentrations, increased water clarity and increased dissolved oxygen. Although not as apparent, Osoyoos Lake is also showing signs of improvement (decreasing phosphorus). These improvements can take decades to manifest themselves, re-enforcing the need to be proactive in identifying emerging water quality issues and working towards timely solutions.

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Polybrominated Diphenyl Ether Flame Retardants in the Kelowna Wastewater Treatment Plant: Concentrations, Patterns, Influence of Treatment Processes, and Potential Effects on Okanagan Lake

Sierra Rayne

Abstract

Concentrations and patterns of the mono- through deca-substituted polybrominated diphenyl ether (PBDE) flame retardants were determined in all major unit operations/processes within the Kelowna wastewater treatment plant (WWTP). PBDEs do not appear to be substantially degraded or otherwise removed by wastewater treatment processes such as anaerobic, anoxic, and aerobic biological treatment, anaerobic digestion, dissolved air flotation, or sand-anthracite filtration. An overall removal efficiency of 93% was observed for PBDEs in the Kelowna WWTP due to sorption onto wastewater sludges, well below that predicted by equilibrium partitioning models. High levels observed in the resulting WWTP biosolids may contaminate a wider environment and pose a long-term risk to human and ecological health through their use as a soil amendment ("Ogogrow"). Lower concentrations of PBDEs contained within high volumes of the aqueous WWTP effluent may result in a large PBDE flux into receiving waters, posing a potential threat to both aquatic and terrestrial ecosystems. Subsequent modeling of Okanagan Lake examined the potential long term effects of various wastewater-derived PBDE loading scenarios on this unique aquatic system. If current environmental input patterns of these commercial flame retardants continue over the next three decades, total PBDE concentrations in the Okanagan Lake water column and in suspended and surficial sediments are expected to increase significantly. Following implementation of a hypothetic halt on PBDE releases into Okanagan Lake, PBDE concentrations in the water column and sediments decline by less than 35% over the ensuing 17 year modeling period after the ban, illustrating the potential long-term problems arising from persistent contaminants into this poorly flushed aquatic system. The results also suggest PBDEs likely represent one of the largest halogenated aromatic loadings to Okanagan Lake.

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Balancing Demand Side Management in a Semi Arid Climate

Carolyn Stewart

Abstract

Identifying areas of opportunity in demand side management can be challenging, mostly due to inherent social needs linked to lush, green landscaping in our semi arid desert. Therefore, in order to reduce the impact of reaching maximum capacity on the Penticton Water Treatment Plant as well as infrastructure upgrades, the water conservation program was created in 2004. The focus of this poster is on measurable outcomes when establishing effective, results driven demand side management programs.

The objective of this poster is to provide details on social marketing drivers such as developing a reward based program by identifying positive behaviours as well as modifying behaviours by introducing eye catching signals targeted to induce acceptable behaviour changes, and measuring how these behaviours affect Summer Demand, Peak Day Demand and Annual Demand.

Penticton's downward trend in water consumption can be attributed to the three following factors which were identified and classified as those which influence behaviours;

- Predisposing factors – knowledge, beliefs, values and attitudes,
- Enabling factors – barriers
- Reinforcing factors – feedback and rewards, both positive and negative

Using any or all of these three factors, many barriers have been quenched in order to celebrate the water conservation program's numerous successes including Peak Day plummeting from 54 million litres (2003) to 42 million litres (2007) and Average Daily Demand dipping from 700 lpcd (2003) to 610 lpcd (2007). These results indicate Penticton effectively provides solutions which are adopted by the community at large.

As the City of Penticton water conservation program advances, many assessment response tools have been favoured. With the use of various media, voluntary watering scheduling and education, annual water demand has been trimmed by 604 million litres (2003/2007), despite increases in our population base.

This poster will provide innovative practices which can be adopted by any community including those under limited budgets and reduced labour force.

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Ellis Creek Flow Measurement Project

Brent Edge

Abstract

Watershed Management provides a comprehensive tool, incorporating land and water uses in a sustainable community. Therefore, the City of Penticton in collaboration with Dobson Engineering, are evaluating the Ellis Creek irrigation demand and creek flow in isolation as one of many water balance projects in our semi arid region.

This project was conducted using a range of stage and discharge magnitudes (freshet and low flow conditions) to determine flow triggers over the spillway as well as irrigation and creek flow trends. Taking seasonal variances into consideration, a total of four creek profiles were explored over six days in order to establish baseline data for statistical analysis. Upon project completion, automation will enhance real time watershed management tools.

With the assistance of $15 000 in OBWB grants, the City contracted Dobson Engineering Ltd. to design[1] a hydrometric station on Ellis Creek in order to reach the City's goal of becoming better water stewards. Several locations along the creek were reviewed, and the stream reach near Industrial Avenue had the most optimal conditions for analyzing the dynamics of flow.

The stage and discharge data will be used to manually create a stage/discharge curve which correlates water levels in Ellis Creek to discharge values. These flow dynamics create a stage discharge table which cross references variances (mm) in water level to the corresponding discharge value. Although this task is currently in progress, once completed the stage discharge table will be incorporated into the City's SCADA system allowing established baseline flow data to integrate real-time low flow alarms below the City's intake. A permanent reference gauge installed in the streambed provides visual verification when referencing stream flow.

Prior to receiving grant approval from OBWB, monitoring of Ellis Creek involved manually manipulating irrigation flow. Upon completion of Ellis Creek Monitoring project, total creek flow will be monitored under various conditions improving watershed management during peak irrigation season as well as assessing the creek's impact on land and water use in the Okanagan Water Basin.

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