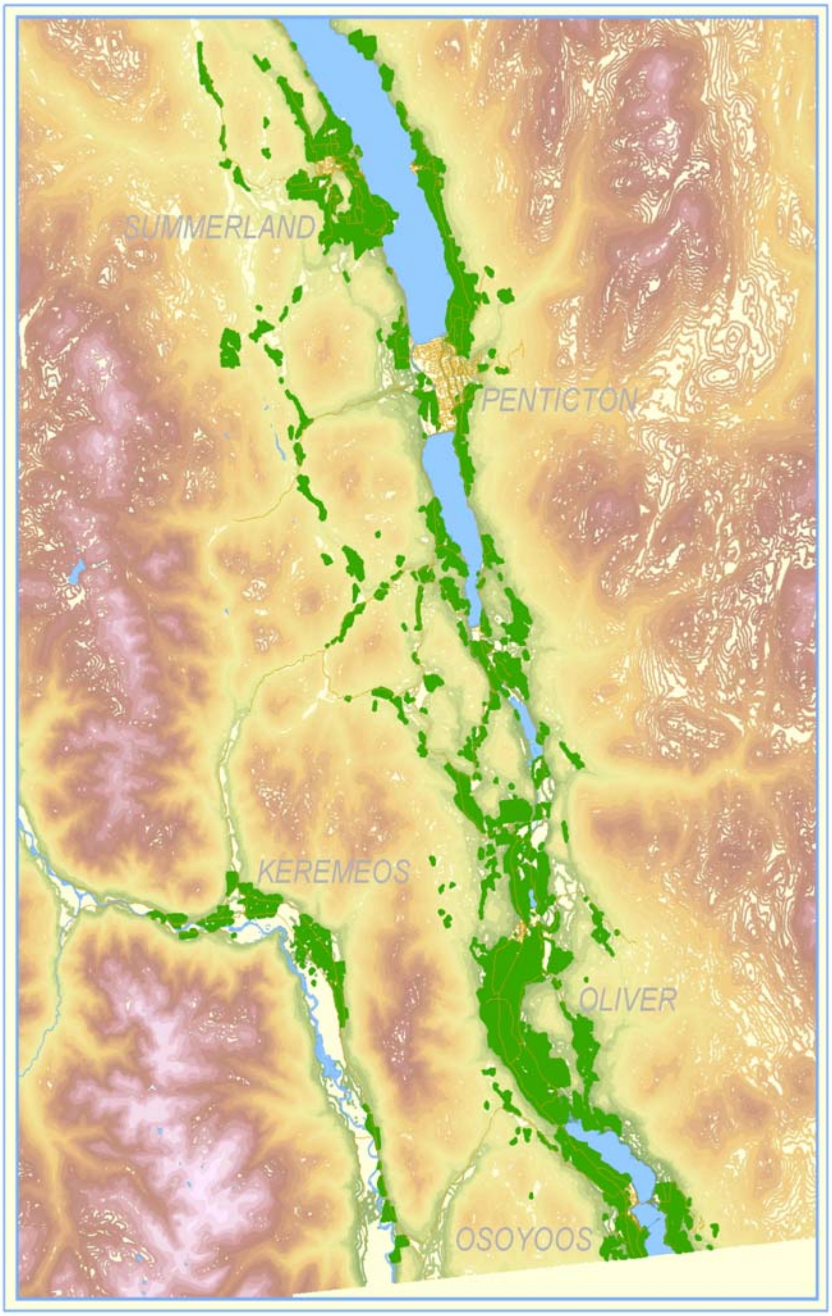

Impact of Climate Change on Crop Water Demand and Crop Suitability in the Okanagan Valley, British Columbia

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Executive Summary

Agricultural viability in the semi-arid, interior valleys of southern British Columbia is primarily determined by the availability of irrigation water to meet crop requirements. In the Okanagan Valley, there is increasing competition for the water resource from domestic and commercial users and there is also a requirement to maintain minimum flows to protect fish habitat on both sides of the international boundary. The objectives of the current study were to determine crop water requirements under climate change scenarios for three time intervals 2010-2039, 2040-2069, 2070-2099 and to compare predicted demand with current water use and water supply. A secondary objective was to determine changes in crop suitability for the region.

Methods were developed to integrate crop water use data with spatial climate and land use data. Equations for seasonal crop coefficients (the ratio of actual crop water use to estimated potential evapotranspiration) were developed for various crops. Equations to predict solar radiation, and daily maximum and minimum temperatures from monthly data were also derived and used to determine potential evapotranspiration. Future climate data were derived from the Canadian Global Circulation Model (CGMC1) and compared with 1969-1990 normals (Environment Canada). Climate data were spatially downscaled from a 3.75°latitude x 3.75° longitude grid output through the PRISM (Parameter-elevation Regressions on Independent Slopes Model) to a 4km x 4km grid. Land use data were acquired from a variety of sources and incorporated into a GIS and overlain with the PRISM grid to create unique units (polygons). Calculations of crop water demand using the equations described above were performed for each polygon in a database program. Boundaries of areas supplied by the major water purveyors in the basin (Irrigation Districts) were digitized and added to the GIS. Crop water demand was then totaled on a region and Irrigation District basis.

Overall average predicted water use for present day conditions was compared with values of expected water use provided by B.C. Ministry of Agriculture Fisheries and Food for sites within the region in order to test the crop water demand model. Predicted values were slightly lower than the BCMAFF values (745 mm/year vs. 820-1000 mm/year), which was likely the result of under-estimation of temperatures by

PRISM. This was attributed to the coarseness of the PRISM grid, which resulted in large elevation changes within cells. Total annual water consumption for the period 1996-1999, reported by the major Irrigation Districts within the region, was reasonably similar to that predicted by the model (46.9 m^3x 10^6 vs 51.8 m^3x 10^6). Thus the model was considered adequate for prediction of effects of climate change. For the region as a whole, estimated crop water demand increased by 37%, from 745 to 1021 mm/year (80 to 110 m^3x 10^6) between the present day and the 2070-2099 scenario. Analysis of water allocations to the 10 major Irrigation Districts indicated that those drawing water from the main channel and lake system would likely have sufficient water to meet increased demand, but some districts using tributary water may not.

Potential impacts of climate change on crop suitability were assessed based on several agroclimatic indices. These included length of growing season, growing degree days (base 5 and base 10), spring freeze risk and winter and summer threshold temperatures. There will be significant changes in these variables. Growing season will lengthen by 1.5-1.7 months by 2070-2099. There will be reduced risk of extreme minimum winter temperatures and winter damage to tree fruit and grape rootstocks, but increased risk of high summer temperatures, which may damage apples. Apple varieties with a longer growing season would be recommended. For grapes, there would be a general improvement advancing by two suitability classes from Winkler Region I to III.

Table of Contents

List of Tables

List of Figures

Acknowledgements

PRISM climate data were obtained courtesy of Bill Taylor, Environment Canada, Pacific and Yukon Region. Land use data were compiled with the assistance of the Okanagan-Kootenay Sterile Insect Release Program, Penticton office and with the technical assistance of Boyd Porteous, formerly of the Okanagan Valley Tree Fruit Authority, presently with the BC Land Reserve Commission in Burnaby.

This study was supported by funding under the Climate Change Action Fund, (Project A087), Adaptation Liaison Office, Natural Resources Canada, 601 Booth St., Ottawa, ON, K1A 0E6

1.0 Introduction

Agriculture in the interior valleys of southern British Columbia is dependent on irrigation water provided mainly by snow melt from adjacent mountains either as runoff or through ground water recharge. Agricultural sustainability in these semi-arid regions is thus primarily determined by water supply being adequate to meet demand.

Predicted responses to global warming are increased temperatures, altered precipitation patterns and changes in the amount of precipitation, all of which will have an impact on the crop water supply-demand relationship. These changes will likely cause increases in crop water use, extension of the growing season and decreases in water availability, depending on changes in the form of precipitation and the timing of precipitation events. If water requirements for agriculture increase, competition for the resource may limit supply.

Many of the waterways in the Okanagan basin in southern British Columbia that supply irrigation water also supply domestic and commercial needs and have minimum flow requirements to protect fish habitat and recreational values. As this watershed crosses the international boundary, basin trans-border flows are governed by Canada-US agreements. The International Joint Commission Agreement contains orders to maintain the level of Osoyoos Lake within certain limits. The 1980 'British Columbia Washington State Cooperation Plan for Osoyoos Lake Levels and Trans-border Flows' lists required minimum flows, by month, primarily to maintain minimum requirements for fish. The Canada-British Columbia Okanagan Basin Agreement, (Okanagan Basin Study) also contains recommended minimum flows for fish at Oliver, BC. Canada and US fisheries agencies meet from time to time to review fish habitat needs and the requirements to maintain (Okanagan River) channel capacity (pers. comm., B. Symonds, B.C. Ministry of Land Water and Air (BCMLWAP)).

1.1 Objective of Study

Given the pressures on the water resources of southern British Columbia, understanding water demands by all sectors, including agriculture is critical to developing adaptation strategies for the region. It is recognized that the amount and distribution of water supply over the growing season may also be affected. The objectives of this study were to determine potential crop water requirements under conditions of climate change which may increase water demand; to compare these spatial changes in demand with licensed water supply in the southern portion of the Okanagan Basin; and interpret these changes with respect to crop suitability in the study area.

2.0 Okanagan Basin and Study Area

The Okanagan Basin encompasses approximately 8,000 km^2 of semi-arid landscape, the majority located in southern British Columbia with a minor portion in northern Washington State. In the current study, emphasis was placed on the southern Okanagan Basin within Canada, that is, on the agricultural land in the Okanagan Valley between north of Summerland and the US border (Figure 1).

Climate is governed by the location of the basin in the lee of the Coast Mountains. The mountains have the effect of decreasing precipitation, lowering humidity, and increasing sunshine during the growing season. During the winter, there is usually little rain or snow in the valley, but occasional penetrations of Arctic air can result in temperatures below -20 °C. Snowfall occurs when cold air masses are replaced by warmer, moister air from the coast. Summers tend to be warm and dry with brief showers or thunderstorms. Brief, very hot periods occur during the growing season when temperatures can rise to 35 °C or more. Although there are local anomalies, temperatures and the amount of solar radiation tend to decrease towards the north of the valley, while snow cover and rainfall tend to increase (Okanagan Valley Tree Fruit Authority, Field Guide, 1995). The annual mean temperature at Osoyoos is 10°C, with an average of just under 2500 growing degree days base 5°C accumulated during the growing season. In comparison, at Summerland, the annual mean temperature is 9°C with approximately 2200 growing degree days base 5°C accumulation. Both stations receive between 310 to 330 mm of precipitation annually (Environment Canada, 2000).

The basin receives approximately $431x10^6$ m^3 of precipitation annually. Earlier reports show irrigation water allotments at approximately $210x10^6$ m^3 /year (78% of total allotment), with demand increasing at 0.7% per year (Agrodev Canada Inc., 1994). A re-estimate of the basin's water supply in 1994 revealed $63x10^6$ m^3 per year available from Okanagan Lake in excess of current demand and present day operational requirements (Obedkoff, 1994).

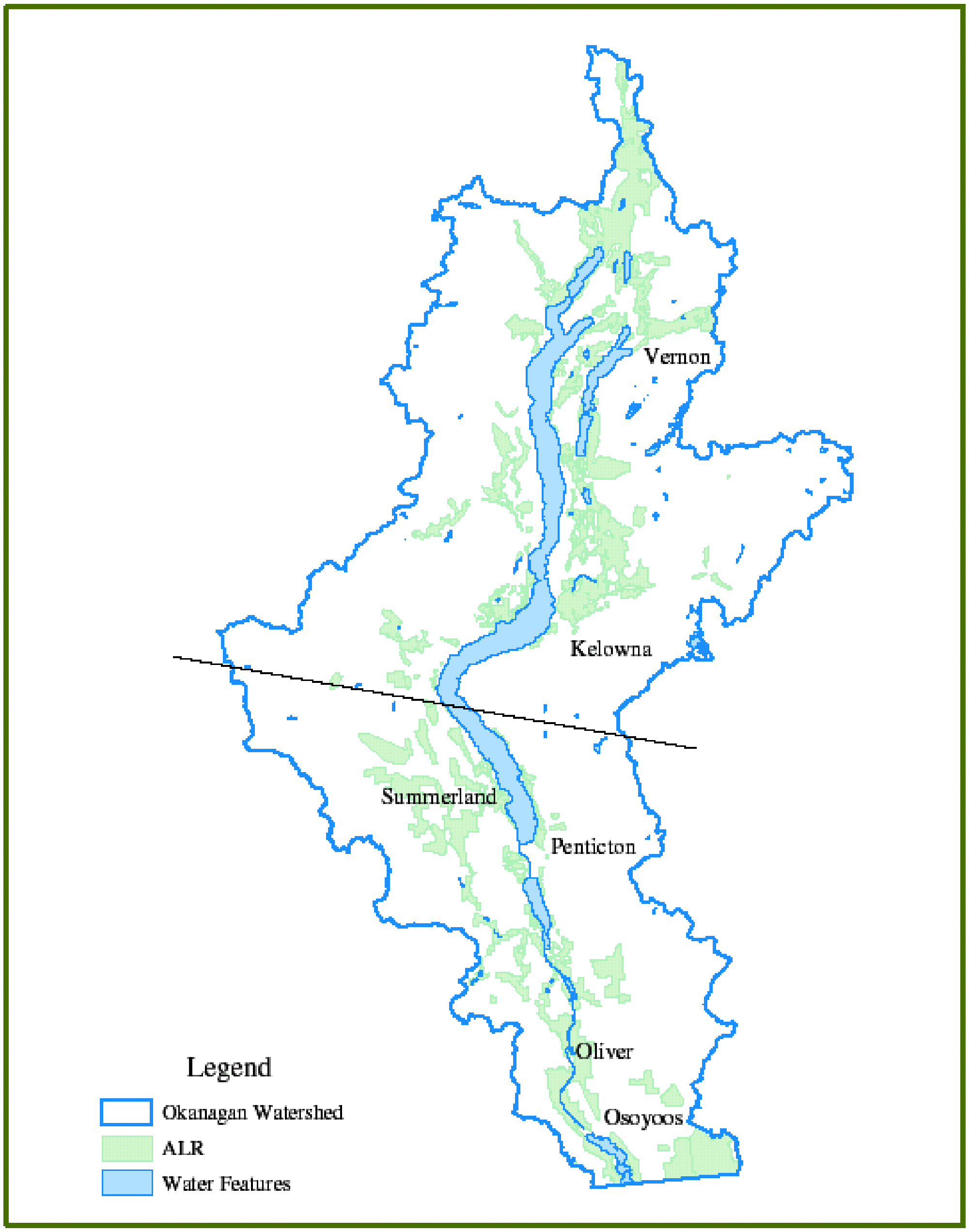


Figure 1. Agricultural land reserve and study area in the Okanagan valley, B.C.

3.0 Methods Development

In order to make an analysis of regional crop water demand it was necessary to develop methods to integrate estimates of water use with spatial land use data and climate. To achieve this, we compiled information about the spatial distribution of different crops throughout the study area, estimated water requirements utilizing crop coefficients for each crop type in response to current climate, obtained climate change scenario data produced by the Canadian GCM1 (Global Circulation Model) and evaluated their effects on crop water requirements. The following outlines the data sources, assumptions and methodology used in calculating regional crop water demand.

3.1 Estimating Crop Water Requirements

Equations for estimating seasonal crop coefficients (Kc) were derived for tree fruits and grapes. Equations to predict maximum and minimum daily temperature from monthly data, solar radiation and potential evapotranspiration were also derived. When combined, these sets of equations allow a first estimate of crop water use.

<u>Seasonal Crop Coefficients</u>

The crop coefficient is the ratio of actual crop water use to estimated evapotranspiration. The crop coefficient varies with canopy size and for a perennial crop increases to a maximum both over the growing season and as the plant matures. In general, crop coefficient maxima for fruit trees are close to the Penman reference (grass) ET_o (1.0) despite the potential for greater transpiration in response to the increased wind speed and boundary layer conductance resulting from tree height. This has been attributed to the diurnal pattern of stomatal conductance in which stomatal closure occurs mid-afternoon regardless of water demand (Jarvis, 1985). Maximum mid-season crop coefficients (based on Penman ET_o) range from 0.9-0.95 for apricot, peach, pear and plum and from 0.95 - 1.0 for apple and cherry under clean cultivated conditions (Fereres and Goldhammer, 1990). These may be expected to be 20-30% higher under a cover crop (Doorenbos and Pruitt, 1977).

Water balance data from the Summerland lysimeter, have indicated that a maximum crop coefficient for drip irrigated apple is around 1.3mm ET/mm evaporation measured using an Etgage atmometer (Etgage Company. Loveland CO.). The atmometer is constructed with a ceramic evaporating surface covered by green baize cloth that is considered to be equivalent to a well-watered grass surface (the standard condition for the Penman ET_o). A relationship was derived from measured daily ET_o (atmometer-based) and corresponding daily weather data at PARC, Summerland (R^2 = 0.58).

For the purpose of the current climate change study, the seasonal crop coefficient curve derived from the Summerland lysimeter was applied for maximum canopy development in apple (Figure 2).

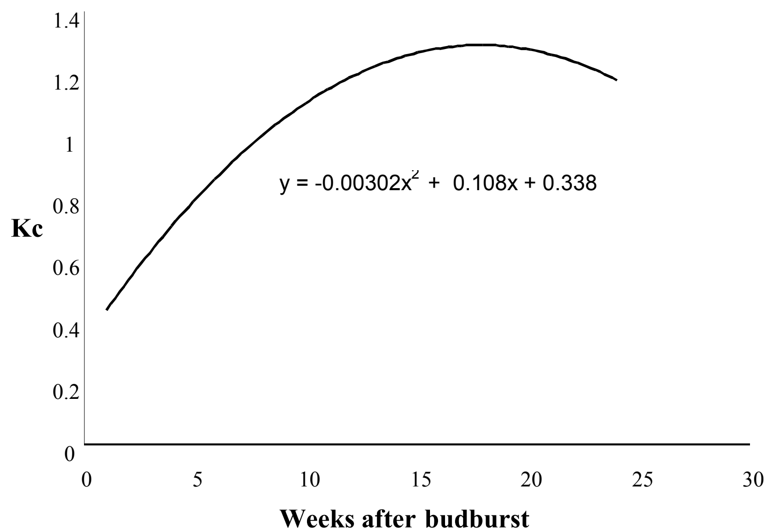


Figure 2. Seasonal crop coefficients (Kc) for mature deciduous fruit trees in the Okanagan valley (mm water use/mm potential evapotranspiration).

Under the following assumptions the same curve was applied to other types of tree fruit:

1. Crop coefficients reported in the literature for different tree fruit crops are similar.
2. When the factor for cover crops (20-30% increase) is included, the crop coefficients for mature canopies of other fruits are similar to that derived at Summerland for apples.
3. To determine maximum demand, all orchards were considered mature.
4. All tree fruits were considered to be under sprinkler irrigation and an ‘efficiency factor’ was built into the equation (75%) (British Columbia Sprinkler Irrigation Manual 1989).

5. Despite slight differences in growing season lengths, irrigation duration is, in practice, similar for most tree fruits (first week of April to third week of October).
6. Dates of bloom as presented in Table 1 were used to establish the beginning of the growing season and the onset of crop water demand under present climate conditions. Under future climate scenarios, the beginning of the crop water demand season for all fruits was set as the date when the accumulation of growing degree days above base 10°C began. In all cases, daily crop water demand was calculated until evaporative demand ceased in the fall.

Table 1. Average bloom dates expressed in Julian Days for fruit trees in the south Okanagan Valley

Fruit	Bloom Dates
Apple	Late April (JD 116)
Apricot	Early April (JD 95)
Cherry, Nectarine, Peach	Mid-April (JD 105)
Pear	Mid-April (JD105)
Plum	Mid-April (JD105)

There were no water use data available for grapevines in the Okanagan valley. Published water use data for grapes in other regions are often presented as annual totals (Williams and Matthews 1990) and were consequently inappropriate for the current study where daily water demand estimate were required. Literature crop coefficients for wine grapes, where crop water use is directly measured in lysimeters (e.g. Evans et al., 1993) are greatly affected by local water management practices that are adopted to influence grape quality. Thus, crop water use in the fall may drop off considerably compared with peak demand. In the absence of any appropriate data for water use by grapes under Okanagan conditions, crop coefficient curves were derived from data presented by Peacock et al. (1987) for clean cultivated table grapes in the San Joachim valley, California, where water deficit management techniques were not imposed. The absence of imposed water deficits in this study allowed for crop coefficients to be based on potential crop water use irrespective of management techniques which may differ according to variety, site and to the state of current knowledge regarding their benefits.

These crop coefficient data (Peacock et al., 1987) were linked to phenological stage and could thus be adapted to growing seasons of different length. Generalized crop coefficient curves for both clean cultivated grapes and for grapes with a cover crop are shown in Figure 3. Data for grapes with a grass cover crop were generated from the findings of Kottwitz (1984) who showed that 50% of total water use in centre-pivot sprinkler irrigated wine grapes was due to a 50% grass cover.

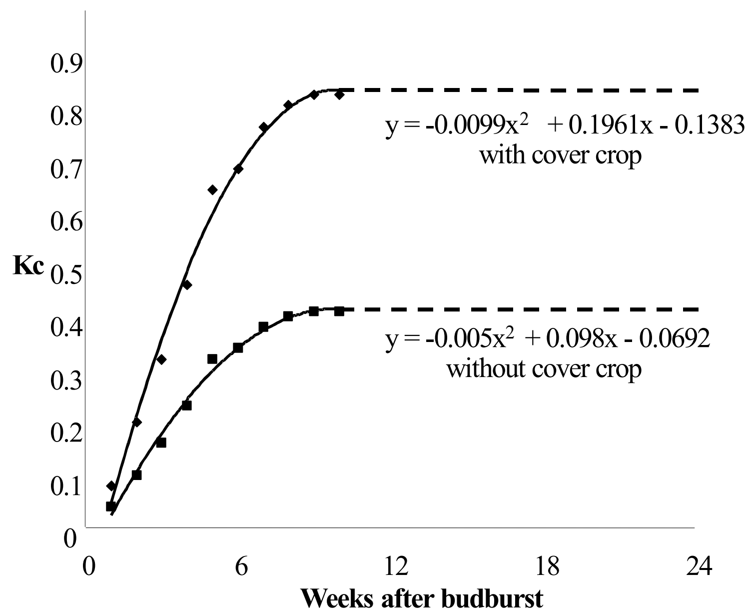


Figure 3. Seasonal crop coefficients (Kc) for grapevines in the Okanagan valley (mm water use/mm potential evapotranspiration) with and without cover crop. Earliest date of budburst May 1st.

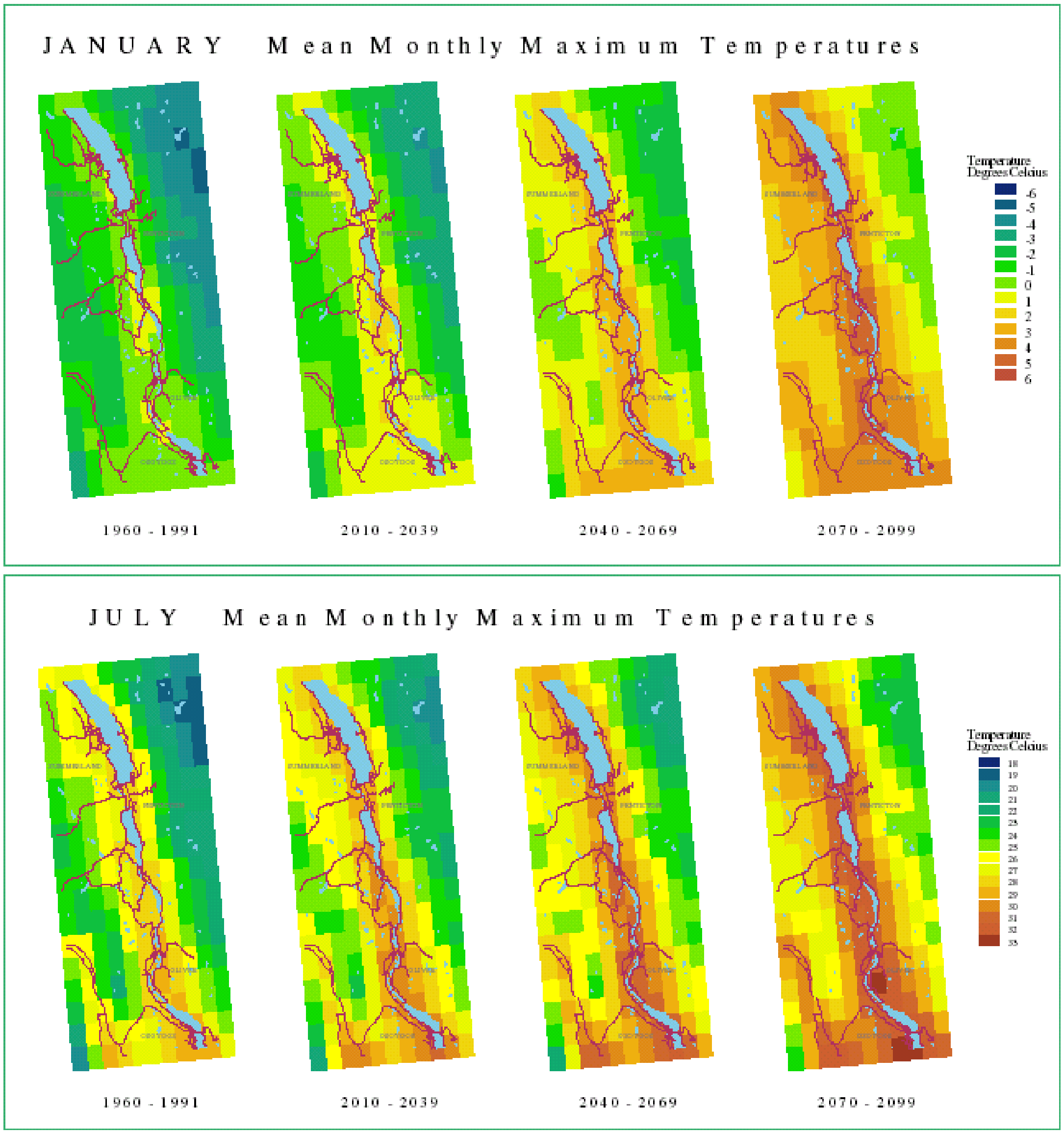


Figure 4. Estimated mean monthly maximum temperatures using PRISM for January and July in the south Okanagan valley during four time periods

Downscaling and Transformations of Climate Data

Climate data were transformed (downscaled) through two levels. The Canadian Global Circulation Model (CGCM1) climate parameters were spatially downscaled from a 3.75° latitude x 3.75° longitude grid cell output through the PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate interpolation program to an approximate 4 km x 4 km grid cell. PRISM is an expert system that uses point data and a digital elevation model (DEM) to generate gridded estimates of climate parameters (Daly et al., 1994). PRISM climate data for Southern BC were made available by

Environment Canada via Oregon State University's Spatial Analysis Climate Service (http://www.ocs.orst.edu/prism/). Mean monthly maximum and minimum temperature grids of the 30-year temperature normals for 1961-1990 and scenario periods 2010-2039, 2040-2069 and 2070-2099 were downloaded from this site, imported into the GIS and superimposed upon a map of the southern Okanagan. An example of the PRISM output is given in Figure 4, which depicts mean monthly minimum temperatures for January and July, by period.

A second transformation of scenario data involved the derivation of daily minimum and maximum temperature values during the growing season from PRISM monthly climate data (Tmax, Tmin). Daily mean temperature estimates were required to calculate growing degree day accumulations and daily maximum temperature was required to calculate evapotranspiration. The methodology was based on the observation that there is an approximate straight line relationship between temperature and Julian day (JD) from Jan 1- July 31(JD 1-212) and a separate straight line relationship between August 1 and Dec 31 (JD 213-365). Each monthly average was assigned to the middle of the month and the value for most other days was then estimated by linear interpolation. Estimates for days between mid July and the end of July (JD 198-212) were extrapolated from June and July monthly means. Estimates for the days between August 1st and mid August (JD 213-228) were extrapolated from August and September monthly means. Derivation of temperatures for a given Julian day was based on the algorithm:

$T(JDx) = T(JD1) + ((JDx-JD1)/JD2-JD1))*(T(JD2)-T(JD1))$ where

$T(JD1)$ = monthly average temperature associated with Julian day 1

$T(JD2)$ = monthly average temperature (for the next month) associated with Julian day 2

$T(JDx)$ = monthly average temperature associated with Julian day x

for interpolation $JD1<JDx<JD2$

for extrapolation $JD2<JDx(198<x<212)$

$JDx<JD1(213<x<228)$

Estimating potential evapotranspiration ET_o

Algorithms to estimate daily potential evapotranspiration during the growing season (JD92 - JD306) were developed from daily maximum temperature (Tmax), day of the year (JD) and the latitude (LAT) of the site. A potential evapotranspiration (ET_o) value was calculated for each PRISM cell as:

$$ET_o = -3.26 + 0.210\ Tmax + 0.058Qo$$

Calculating ET_o requires derivation of Qo, the solar energy (MJ m^{-2}) reaching the top of the atmosphere based on JD and LAT, and a set of intermediate variables ϕ, Δ, R, H1 and H2 where:

$$\phi = 0.01721*JD$$

$$\Delta = 0.4093*SIN(\phi - 1.405)$$

$$R = 1 + 0.033*COS(\phi)$$

$$H1 = -ARCOS(-TAN(LAT)*TAN(\Delta))$$

$$H2 = ARCOS(-TAN(LAT)*TAN(\Delta)) \text{ and}$$

$$Qo = (18.838868*R)*[\{COS(LAT)*COS(\Delta)*(SIN(H2)-SIN(H1))\} + \{SIN(LAT) * SIN(\Delta) * (H2-H1)\}]$$

Agricultural Land Use and Irrigation District Mapping for Assessment of Water Demand

Land use data were acquired from a variety of sources to generate a map describing the extent and distribution of agricultural crops in the study area. Base data were obtained from the 1992 land use coverage for tree fruit orchard types compiled by the Okanagan Valley Tree Fruit Authority (OVTFA 1995). Supplemental data, primarily for apple and pear orchards were obtained from the 2000 Sterile Insect Release Program, Osoyoos BC. These current data were used to update the older coverage where crop type was absent. Vineyard locations were obtained by digitizing boundaries from paper maps provided by the B.C. Wine Institute. Digital files for a few of the larger vineyards that had field boundaries verified with GPS (Global Positioning Systems) were obtained from Dr. P. Bowen, PARC (pers. Comm.), and incorporated into the base map. In order to complete the agricultural land use base map, location and extent of other agricultural activities, primarily cultivated vegetable fields, pastures and forage crops were obtained from the BC Terrestrial Ecosystem Mapping produced by BCMLWAP.

To match crop water demand against licensed irrigation supply, the boundaries for 27 local government and irrigation jurisdictions were incorporated into the GIS. For cities, towns and regional districts, digital maps were acquired. For other jurisdictions, paper maps were obtained from the B.C. Ministry of Municipal Affairs and boundaries created by digitizing.

Modelling Regional Crop Water Demand

1. Using historical weather data (1969-1990 normals) and PRISM

ARC Macro Language programming within ARC/INFO was used to assemble climate scenarios and land use coverage. PRISM grid data for the twelve mean monthly maximum and minimum temperatures were overlain with the agricultural land use coverage. This procedure created a database that described climatic conditions, over the year, for each unique land unit (polygon). The centroids of latitude and longitude for each polygon were added to the database and the values converted to radians, a necessary input for the calculation of ET. Visual Basic programming was used with MS Access™ to perform daily time-step calculations of crop water demand. The final coverage was then exported to a GIS viewer (ESRI ARC View™) for query and summary at the grid, local authority or regional scale of yearly values by land unit for: PE, growing degree days base 5 ºC and 10°C and volume of water demand. Two additional queries were also developed to summarize weighted mean values for these attributes by crop type.

2. Using data derived from a global circulation model (CGCM1 and PRISM)

To model scenarios 2010-2039, 2040-2069 and 2070-2099 database procedures were re-run utilizing future climate as input data. The beginning of the growing season was determined by the start of accumulation of growing degree days, base 10 °C. Because of the difficulty in projecting future land use patterns in the valley, the current land use base was used in all scenario calculations. For determination of spatial relationships, the resultant database records were imported into the GIS.

3.2 Impact Assessments

Available water supply

To assess the potential impact of increased crop water demand on available water supply, a review of licensed irrigation allocations and present day irrigation water use by "local authorities," (irrigation districts, improvement districts, cities and towns) was conducted. An online "Water Rights" database at http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input maintained by BCMWLA was accessed for licensed water allocations. Consumptive use was compiled from 1995 to 1999 "Annual Water Use Reports" for local authorities received from the Water Rights Administrator. Data were clarified and confirmed by follow up telephone enquiries and field visits.

Crop suitability

Potential changes in suitability for tree fruit and grape growing were assessed in response to changes in regional climatic parameters in the Okanagan Valley (OVTFA Tech. Ref. Man. 1995; Assoc. of BC Grape Growers 1984). Soils, topography and management factors were assumed to remain constant under future scenarios. Suitability was based on the following key climate criteria:

1. Extreme winter minimum temperatures - critical low temperatures for early, mid and late winter.
2. Winter damage to rootstocks - conditions contributing to soil temperatures of -8ºC or more.
3. Spring freeze risk – damage to blossoms occurring in all phenological stages from green tip (for apples, and the equivalent for other fruits) to post-bloom. Scenario bloom dates were adjusted as constants relative to the start of accumulation of growing degree days, base 10 °C.
4. Autumn fruit damage – damage when temperatures fall below –4 °C (start of damage) or –8 °C (severe damage), on or before the start, mid-point, or end of harvest, or at late harvest. Days from full bloom to harvest was assumed by algorithm: DFFB = 190.85 - .16(FB) – 1.08(MT30) (see OVTFA, Tech. Ref. Man.,

1995). However, it should be noted that within fruit types, the length of the growing season can vary by up to eight weeks, dependent on variety.

5. Apple colouring – one autumn event when minimum temperatures fall below critical threshold of 8 °C before harvest. As in 4, impact may depend on variety.
6. Sunscald – baking, burning, or blemishing of apple surfaces when temperature thresholds exceed 37 °C.
7. Growing degree days – the accumulation of daily mean temperatures above 5 °C (apples and soft fruits) and 10 °C (grapes).

4.0 Results

4.1 Changes in Crop Water Demand

Figure 5 shows agricultural land use surrounding Oliver. A total of 5,581 land unit polygons, each acting as a spatial unit for crop water demand calculations, resulted from the overlay of the land use and PRISM grid coverages for the entire study area.

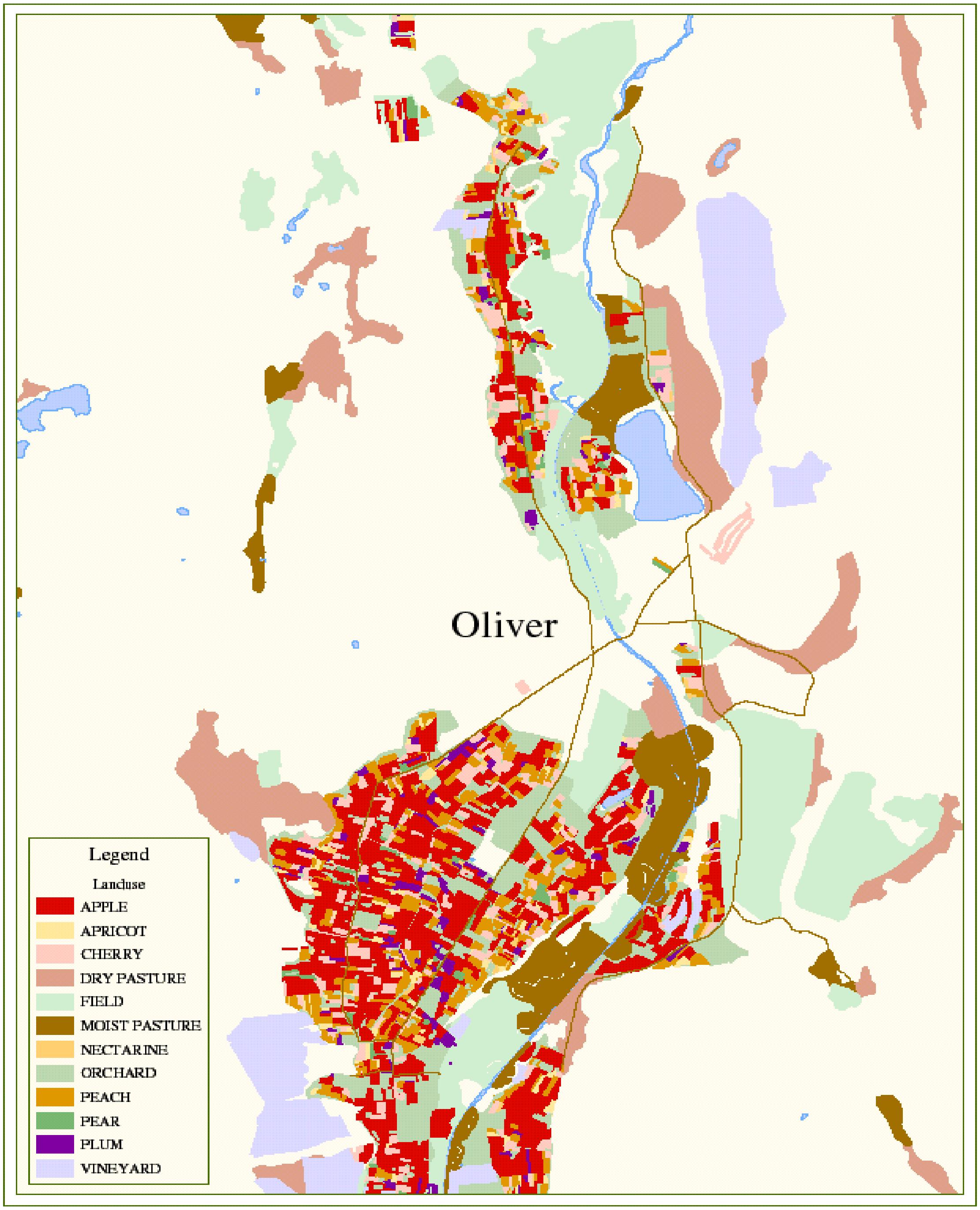
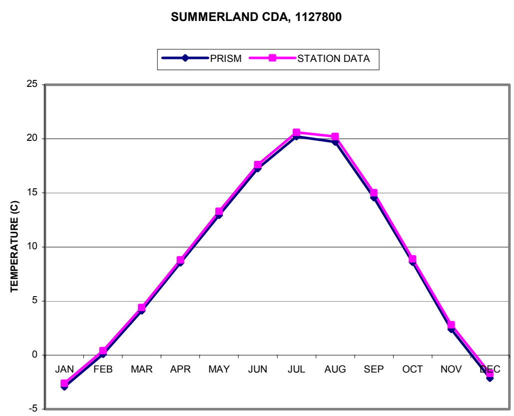


Figure 5. Land use in the Oliver area, south Okanagan valley, B.C.

The PRISM grid temperature values represent a mean for the elevation range represented by each cell. These cells seldom occupy only valley bottom locations where agriculture is practiced. Thus the PRISM output values used in our crop water demand model generally underestimated the temperature for the elevations where agricultural crops are grown. A comparison between mean monthly temperature estimates derived from PRISM and four climate stations for 1961-1990 period for is shown in Figure 6. The observed differences have significant influence on the demand estimates for crops in the narrow Okanagan Valley, where the grid elevation range along the valley walls may be 1000 m or more. This likely resulted in a reduction of modeled growing degree day values by as much as 30%, compared to those estimated from sites on the valley floor as illustrated for the Osoyoos West climate station (Figure 6). For sites off the valley floor, such as Summerland CDA station, the effect was minimal. However, this station is located close to the upper elevation limit of most horticultural crops due to valley wall topography.

The database model calculated key climate variables for each land unit on a daily basis. Growing degree-day calculations were used to estimate potential lengths of the growing season for various crops. The start, end and length of the growing season varied under each of the scenarios used (Table 2). Temperatures ranged from a T_{min} of –6.7 °C (JD60, 1961-1990 normals) to a T_{max} of 33.8 °C (JD212, 2070-2099 scenario). For crop water demand estimates, the database model calculated the length of the potential irrigation season based on the start of accumulation of growing degree days (base 10 °C) and ending with the last day of calculated evaporative demand > 0 mm.

A



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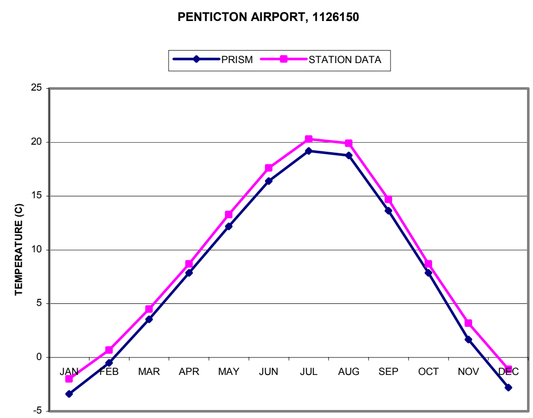
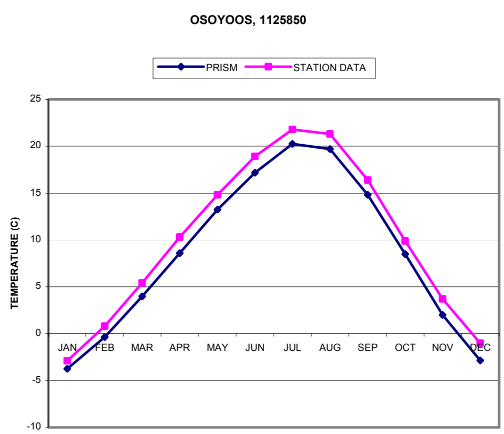


Prism elevation range: 480m (360–840m)
Station elevation: 454m

Prism elevation range: 340m (340–680m
Station elevation: 344m

C



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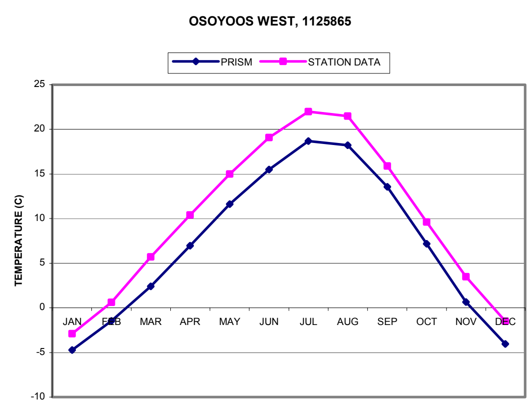

Prism elevation range: 620m (280–900m)
Station elevation: 297m

Prism elevation range: 1180m (280–1460m)
Station elevation: 297m

Source: Environment Canada/Oregon State Univ., Prism data, Southern BC, October 24

Environment Canada, Canadian Climate Normals (1961-90), http://www.cmc.ec.gc.ca/climate/normals/

Figure 6. Comparison of PRISM grid to Climate Station data - mean monthly temperature normals, 1961-1990

Table 2. Length of the growing season estimated by accumulation of growing degree days base 5 °C (GDD 5 °C) and base 10 °C (GDD 10 °C) under climate change scenarios for the south Okanagan study area.

Parameter	1961-1990	2010-2039	2040-2069	2070-2099	Change
Start GDD5 °C	March 26th (JD85)	March 13th (JD72)	March 4th (JD63)	February 21st (JD52)	33 days
Start GDD10 °C	April 29th (JD119)	April 14th (JD104)	April 5th (JD95)	March 26th (JD85)	34 days
End GDD5 °C	October 30th (JD303)	November 3rd (JD307)	November 7th (JD311)	November 13th (JD317)	14 days
End GDD10 °C	October 5th (JD278)	October 10th (JD283)	October 15th (JD288)	October 22nd (JD295)	17 days
Total GDD5 °C	1909	2225	2509	2860	50% increase
Total GDD10 °C	960	1183	1398	1666	74% increase

Once the growing season was defined for each scenario, and PE calculated for each land unit polygon, crop water demand for the region was calculated (Table 3). For the south Okanagan study area as a whole, annual crop water demand was increased 37% by scenario 2079-2099 from 745 mm to 1021 mm on average, although this varied from north to south and by crop type.

Table 3. Annual crop water demand under climate change scenarios for the south Okanagan study area.

Parameter	1961-1990	2010-2039	2040-2069	2070-2099	Increase
ET (mm)	642	724	796	879	37%
Water Demand (mm)	745	840	896	1021	37%
Irrigation Requirement (cubic metres x 10^6)	80.1	90.4	99.5	109.8	37%

A spatial representation of the change in crop water demand is given for the Oliver area (Figure 7). Commonly, crop water demand for the present climatic scenario based on 1961 to 1990 normals was in the range of 610-914 mm of water. By the 2070-2099 scenario, maximum crop water demand was in the range of 1220 mm of water. Water demand varied by crop with the pasture blocks remaining relatively lower through all scenarios than fruit producing blocks.

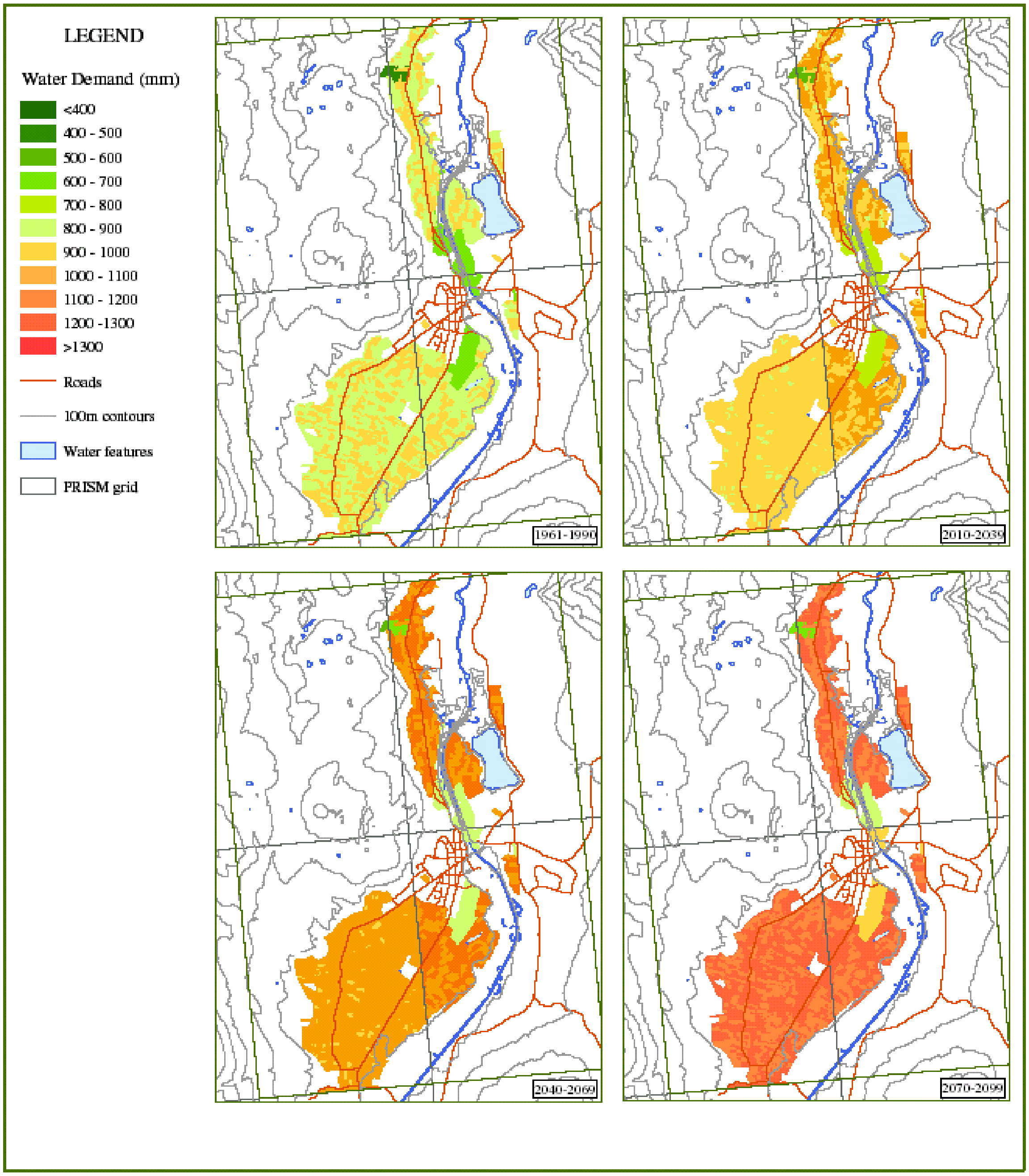

Figure 7. Climate scenario impacts on crop water demand at Oliver, south Okanagan valley, B.C.

4.2 Water Supply

Licensed water allocations to local authorities and consumption patterns for the Okanagan basin are shown in Table 4. Water licensing data are from the Water Rights database (http://www.elp.gov.bc.ca/wat/wrs/surface.html), as of February 2001. Consumption data are based on the BCMWLA database of Annual Water Use Reports, for the period 1995-1999. In those cases where information was not readily available, estimates were derived from telephone interviews or previously published data. Individual and corporate licensees, as well as water use for all other purposes are not included. Licensed quantity is normally based on estimated water use in a 1 in 5 year drought (pers. comm., D. McKee, MLWA). This study focused only on licences to "local authorities" for purposes of "irrigation" or "irrigation-local authority". Quantities, (expressed in m^3x10^6 per annum) indicate the licensed allotments and not the actual amount used. Water licences do not have an expiry term, as long as the licence holder complies with the terms of the licence. Some problems exist with over-allocations on many of the smaller tributaries. In these situations, as licences are canceled, they are usually re-allocated to fish and fish habitat purposes (pers. comm., B. Symonds, MLWA).

Licensed allocations, reported consumption and the estimated crop water demand for local irrigation authorities in the study area are given in Table 5. The annual irrigation requirement, modeled from land use/climate data for the major irrigation districts in the southern Okanagan, was similar to the consumptive reporting by local authorities (1994-1999). However, both reported consumption and estimated water requirements for these irrigation districts, differed from estimates of demand for the whole of the southern Okanagan (Table 3). Some of this difference is attributable to individual and corporate licensees (there is no requirement to report consumptive use), and potential agricultural land included in the modeling calculation but not included within irrigation district boundaries.

Table 4. Listing of annual volumes of allotments and consumption of water by local authorities for the entire Okanagan Basin

Licensee	Date of Incorporation	Diversion Allotment (m^3x10^6)	Total Consumption (Incl. Groundwater) (m^3x10^6)
Black Mountain Irr.D.	1920	22.8	9.9
Boundary Line Irr. D.	1950	0.5	0.3
Glenmore-Ellison I.D.	1990	13.2	4.8
Kaleden Irr.D.	1922	2.47	1.2
Kelowna, City of	1905	0.4	0
Lake Country I.D.[1]		14.8	6.9
Lakeview Irr. D.	1951	4.4	2.3
Meadow Valley Irr.D.	1964	1.66	1.5
Naramata Irr. D.[2]	1920	13.6	1.9
North Okanagan Regional District[3]	1965	37.1	21.9
Okanagan Falls Irr. D. (all wells)[4]	1934		0.5
Oliver, Town of	1908	75.4	17.2
Osoyoos Irr. D.	1948	1.84	1.2
Osoyoos, Town of[5]	1949		8.8
Peachland, Township of	1916	4.4	2.0
Rolling Hills W.W.D. (1 well)[6]			0.2
Penticton, Corp. of	1908	7.97	7.41
Shuttleworth Creek Irr. D.		0.1	0
South East Kelowna Irr. D.	1920	30.7	10.4
Skaha Estates I.D.	1978	0.2	0.02
South Okanagan-Mission I.D.	1984	0.2	0.6
Summerland, Corp. of	1907	20.9	9.7
Sun Valley I.D. (well)	1983		0.6
Vernon, City of	1892	1.3	0.3
West Bench Irr. D.	1953	1.1	0.8
Westbank Irr. D.	1922	6.3	3.0
Sub total:		261.2	112.9

[1] Includes the former Oyama Irr.D., Wood Lake I.D. and Winfield & OK Centre Irr.D.
[2] Licences held by Okanagan-Similkameen Regional District.
[3] Includes licensing and re-diversion from Sushwap/Fraser watershed (pers. comm., regional district water manager).
[4] Groundwater, unlicensed, estimated.
[5] Estimated consumption, 1994-2000 Water Statistics, Town of Osoyoos.

Table 5. Annual volume of diversion allotments, reported mean consumption and estimated crop water demand for specified periods for major irrigation authorities in the study area.

Licensee	Allotment Annual	Consumption 1996-1999	Crop Water Demand 1961-1990	Crop Water Demand 2070-2090	Source[1]
	$m^3 x 10^6$				
Boundary Line Irr. D	0.5	0.3	0.3	0.5	Main
Kaleden Irr.D.	2.5	1.2	2.8	3.8	Main
Meadow Valley Irr.D	1.7	1.5	0.3	0.4	Tributary
Naramata Irr. D	13.6	1.9	3.7	4.9	Tributary
Oliver, Town of	75.4	17.2	14.3	19.4	Main
Osoyoos Irr. D	1.84	1.2	1.4	1.9	Main
Osoyoos, Town of		8.9	7.3	10.0	Main
Penticton, Corp. of	8.0	7.4	6.6	9.1	Main+Tributary
Summerland, Corp. of	20.9	9.7	13.7	19.1	Tributary
West Bench Irr. D	1.11	0.8	1.4	1.9	Main
Total	125.4	46.9	51.8	71.0	

[1]Main = main channel, including major lakes; Tributary = Tributary stream

4.3 Impacts on Crop Suitability

Growing degree days base 5 °C is an index that relates well to certain physiological stages for both apples and soft fruits (OVTFA, Tech. Ref. Man., 1995). The accumulation of growing degree days base10 °C is an index that has also been utilized in the assessment of grape growing potential (Assoc. of B.C. Grape Growers, 1984).

The discrepancies illustrated between PRISM cell climate data and station climate data (Figure 6) also apply to growing degree day values. The mean value for growing degree days base 5 ºC of just over 1900 in Table 2 for the 1961-1990 reference period for the study area compares favorably to the range of 1750 to 2225 degree days reported for this same period for valley bottom climate stations (OVTFA, Tech. Ref.

Manual, 1995). However, a mean PRISM based value of just under 1000 growing degree days base 10 ºC rates the valley bottom of the study area as class 3 (fair) suitability for grape production in comparison to the predominantly class 2 (good) suitability determined for such areas in previous mapping analyses based on interpolated station data (Assoc. of B.C. Grape Growers, 1984). Given that the PRISM cell data seem to underestimate growing degree day accumulation, the predicted increases of 50% in growing degree days base 5 ºC, 75% in growing degree days base 10 ºC and ≥1.5 months for the growing season by 2070-2099 (Table 2) are likely conservative. It follows then that the interpretations of changes in crop suitability are also likely conservative in nature.

Table 6. Predicted apple bloom and harvest dates for early varieties under climate change scenarios.

Scenario	Bloom Date	Mean Temp(°C) 30 days after bloom	DFFB[1] (days)	Harvest Date
1961-1990	Apr 27	14.0	134	Sept 7
2010-2039	Apr 13	13.8	132	Aug 23
2040-2069	Apr 4	13.8	131	Aug 13
2070-2099	Mar 25	13.9	129	Aug 1

[1]DFFB – days from full bloom to harvest

While growing degree day indices indicate changes in overall growing season intensity and duration, other suitability factors such as spring freeze risk during first 30 days after bloom remain unchanged although the period of risk moves to earlier dates in the year and harvest dates for some early varieties would arrive in mid summer rather than the fall (Table 6). However, opportunities would arise to grow varieties requiring longer growing seasons than are currently available.

Changes in crop suitability based on growing degree indices, winter and summer threshold temperatures and changes in the length and timing of the growing season are summarized in Table 7.

Table 7. Inferred crop suitability changes based on climate change scenarios through to the 2070-2099 period for the study area.

Parameter	Impact	Adaptation
Extreme winter minimum temperatures	Inferred. Less frequency of severe Artic events that result in significant crop damage. Increased survival of less winter hardy varieties.	Increased range of crop options including less winter hardy varieties, soft fruits and vines.
Winter damage to rootstocks	Inferred. Less frequency of root damaging winter events that result in significant damage to rootstocks. Greater survival of tree fruits and vines.	Less dependency on winter hardy rootstocks.
Spring freeze risk	Inferred. Neutral. Blossom date (blossom damage) remains constant relative to critical damaging temperatures. Scenario blossom dates were adjusted (held constant) relative to the start of accumulation of growing degree days, base 10ºC.	None. Average number of days elapsing between each phenological stage remains relatively constant in all scenarios.
Autumn fruit damage	Inferred. Less frequency of freezes occurring at either damage level (-4 or –8C), on or before the start, mid-point, or end of harvest, or at late harvest. Days from full bloom to harvest expected to diminish from 1.5 to 2 days per scenario period (see Table 6). Predicted harvest dates (apples) expected 16 days (2010-2039) to 49 days (2070-2099) earlier, where still suited to being grown.	In near term, increasing ability to shift to later maturing apple varieties prone to autumn frost damage. In long term apple production limited by other parameters. More plantings of soft fruits and vines.
(Grape) Autumn Freeze Risk and Vine Hardiness	Increasingly less frequency of damaging autumn freezes in many low lying areas resulting in an early loss of foliage. Increasing suitability of vines reaching full dormancy (vine hardiness) through manufacture and translocation of carbohydrates.	More plantings of vines.

Table 7 cont'd		
Apple colouring	Increasingly less frequency to achieve minimum temperatures below 8 °C by harvest date. Non-colouring of early maturing apples varieties.	In near term, increasing ability to shift to later maturing apple varieties (Jonagold, Spartan/Empire, Red Delicious, Red Rome) where colouring is important. In long term apple production limited by other parameters. Crop shift from apples to soft fruits and vines.
Sunscald	Increasingly significant damage to apples, especially south and west facing aspects near valley bottoms. By 2010-2039, general unsuitability for apples at lower elevations due to temperature thresholds (37ºC) and other limiting parameters.	Conversion of apple crops to soft fruits and vineyards. Conversion of upslope pastures and fields to apple varieties, some soft fruits and grapes.
Growing degree days	Expansion of growing season in heat units and duration (see Table 2) For apples, decreasing fruit size and lowering of yields due to too much heat accumulation in low valley areas. By late 2010-2039, general unsuitability for most early variety apple production in lower valley areas. For grapes, general improvement in suitability throughout, advancing by 2 suitability classes by 2070-2099. In comparison to other viticulture areas of world, similar heating units as Chalons-sur Marne, France by 2010-2039, (Winkler Region I), Bordeau by 2040-2069 (Winkler Region II), and Barossa Valley, Australia by 2070-2099, (Winkler Region III).	Conversion of apple crops to soft fruits and vineyards. Conversion of upslope pastures and fields to apple varieties, some soft fruits and grapes, where other factors not limiting. Adaptation to varietal vines used in other important viticulture areas of world.

5.0 Discussion

Model calculations of present day values of crop water demand (Table 3) fall within the range of licensed allocations and reported consumption in most regions of the study area (Table 5). These predicted annual values, around 745mm on average, are slightly lower than average demand (820-1000) reported previously for specific sites within the study area (Van der Gulik, 1999), but sufficiently close to allow confidence to be placed in the modeling procedure and thus on predictions of increases in demand of around 40% by the 2070-2099.

There are a number of limitations to the model, imposed by the assumptions used in the calculations. The use of fixed regional bloom dates for the study area for the 1961-1990 period and variable bloom dates for future scenarios suggests that the magnitude of the change in demand may have been underestimated in the southern Oliver-Osoyoos area and overestimated in the more northern localities. In calculating evapotranspiration, assumptions were made that could also have affected the crop water demand values. Commercial orchards and vineyards in the Okanagan consist of tree or vine rows interspersed with grass covered alleyways, although in some cases clean cultivation between rows may be practiced. Orchards with cover crops can use 20-30% more water than orchards without (Doorenbos and Pruitt, 1977) and it was assumed in the model that all orchards and vineyards had cover crops. The effect of cover crop is, to some extent, dependent on irrigation method as there is no direct application of water to the cover crop with trickle irrigation. However, high-density trickle irrigated orchards may also be considered to have full cover (BC Trickle Irrigation Manual, 1999). In the current study, all orchards and vineyards were considered to have sprinkler irrigation, which with it's built in inefficiency factor of 75%, may have resulted in an over-estimation of demand. However, possible over-estimation of demand resulting from assumptions associated with predicting evapotranspiration was likely more than offset by the underestimation associated with the use of PRISM to estimate temperature data. As noted earlier, the size of PRISM cells (4km x 4km) was sufficiently large, that many growing areas, which are concentrated at lower elevations in the valley, were included in PRISM cells with a wide range of elevation likely resulting in a lower average temperature for the whole cell (Figure 6).

Attempts to relate estimated present and future crop water demand to supply from local authority water purveyors were problematic. Local authority water purveyors are varied in legal stature, organization and management. A number of consolidations have occurred since earlier published work (Agrodev Canada Inc, 1994) making historical assessments of supply and demand on the basis of individual licence authorities difficult. For instance, water licences formerly held by the Southern Okanagan Lands Irrigation District (S.O.L.I.D.) which dissolved in 1990, are now registered to the Town of Oliver. Since then, the Town of Oliver and the Town of Osoyoos have operated their water systems independently but divert water under the same licences held by Oliver. Oliver provides water services to the northern 2/3rd of the former SOLID, Osoyoos to the southern 1/3rd. Reported values of consumption differed from calculated crop water demand values, in some cases being higher and in some cases lower (Table 5). However, overall, reported annual consumption in 1996-1999 (46.9 m^3 x 10^6) was reasonably close to predicted annual demand for 1961-1990 (51.8 m^3 x 10^6).

Much greater discrepancies occurred between licensed allocations of irrigation water and estimated demand, both for current and for future use. It is unclear whether future supply of irrigation water will be enough to satisfy future demand created by changed climate conditions. It is estimated that with the exception of a multi-year drought, there is sufficient water in the main stem of the Okanagan River and lakes system to fulfill demands even if consumption of the total licensed allocations occurs. (Pers comm. B. Symons BCMLWAP). However, it should be noted that the Town of Oliver, which has the largest allotment of all irrigation districts in the basin (Table 4), is the only water purveyor with a large margin of excess supply in the study area, and, because of its large allotment, is almost solely responsible for the overall imbalance between water demand and supply (Table 5). Where allotments come from small tributary streams, shortages are likely inevitable and in many instances supply will not be able to meet demand under future climate scenarios. There is also a possibility that water purveyors upstream of Oliver, who take their water from the main channel and lakes, may also exceed their allotted supply. Consequently, management of upstream shortages for main channel users may require a redistribution of water allocations.

A second factor, which may affect irrigation water requirements and supply, is the extension of the growing season. Licensed withdrawals are limited to a fixed time period between April and September, but our study has indicated that the growing season may extend from Feb 21st to November 13th by 2070-2099. Currently, the Okanagan

River system is managed primarily for flood control, with trade offs being made to protect fish habitat and store water. Changes in the hydrograph, which are predicted to occur in response to climate change, include earlier spring runoff and lower draw down in the fall (Leith and Whitfield, 1998). How these changes in the pattern of water supply will interact with the predicted changes in the pattern of demand and the management parameters of the Okanagan River/Lake system is beyond the scope of the present study, but clearly they will be an important factor in determining water availability.

Estimates of impacts from a climate change scenario on land use were restricted to a tabulation of potential changes in key climatic variables that determine the viability of crops (Table 7). As such, there would be potential changes in crop types as well as varietal adjustments for tree fruits and grapes. It is recognized that an upslope migration of climatic zones could occur in addition to a latitudinal shift. However, other factors including soil suitability and slope steepness may seriously limit an upslope expansion of agricultural production. Nevertheless, there are relatively large grassland benches, many of which belong to First Nations groups, that are currently undeveloped for agriculture, but which may, in the future, be available for agricultural production. The analysis of effects of potential agricultural land expansion on crop production and water demand was beyond the scope of this study.

6.0 Conclusions

- There will be significant change in climate variables important to agriculture. Growing season will lengthen by 1.5 to 1.7 months by 2070-2099. Growing degree days will increase by 50% (growing degree days base 5 ºC) and 74% (growing degree days base 10 ºC). From our estimates, this will result in an increase of around 40% in crop water demand.
- There will be significant change in key climate variables important to tree fruit and grape suitability:
    - Decreasing frequency of significantly damaging events from: extreme winter minimum temperatures, winter damage to rootstocks, and autumn fruit damage. Days from full bloom to harvest will diminish by 1.5 to 2 days per scenario period. Predicted harvest dates for apples will occur 16 days (2010-2039) to 49 days (2070-2099) earlier, where still suited to being grown.
    - In the near term, increasing suitability for later maturing apple varieties that are prone to autumn frost damage.
    - For apples, there is a potential for decreased fruit size and yield reduction due to too much heat accumulation in low valley areas. Increased frequency of damage from sunscald may be expected, especially on south and west facing slopes.
    - For grapes, general improvement in suitability throughout, advancing by 2 suitability classes (from Winkler Region I to III) by 2070-2099. Decreasing frequency of damaging autumn freezes and increasing suitability of vines reaching full dormancy (vine hardiness).
    - Crop shifts out of apples to other commodities of increasing suitability (soft fruits, vines, nuts, etc). Possible conversion of some upslope fields and pastures to tree fruits and other commodities where not limited by other climate, technological and economic considerations (i.e. pumping ability upslope).
- Predictions and calculations were limited by the PRISM grid resolution (4 km^2).

This resulted in an underestimation of impacts on agricultural lands where elevation range varies significantly over short distances.

- Local authority consumption currently averages 37% of licensed allotment. Most of the discrepancy between allotment and consumption occurs within the jurisdiction of one irrigation purveyor. For most other purveyors licensed allocation may be insufficient to accommodate climate change impacts through to 2080s. A water deficit is likely, particularly for authorities dependent on tributary stream water. Increased withdrawal from tributary streams may be prevented by issues related to water quality, timing, storage, and competition for the resource.
- Groundwater use continues to be unlicensed and poorly documented.

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