Impact of Climate Change on Crop Water Demand in the Okanagan Valley, B.C., Canada

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Abstract

Horticulture in the semi-arid, Okanagan valley is dependent on irrigation. Our objectives were to determine crop water requirements under climate change scenarios and to compare potential demand with current water use and supply. Methods were developed to integrate crop water demand data with spatial climate and land use data. Equations for seasonal crop coefficients were developed. Equations to predict daily solar radiation and daily maximum and minimum temperatures from monthly data were also derived as a basis for estimating PET. Future climate data (Canadian Global Coupled Model -CGMC1) were compared with 1961-1990 normals. 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 cells to create unique polygons. Calculations of crop water demand were performed for each polygon. Crop water demand was totaled on a region and Irrigation District basis. Overall average predicted water use data for present day conditions were compared with values of expected water use to test the crop water demand model. Predicted values were slightly lower than expected values (745 mm/year vs 820-1000 mm/year). This was attributed to the coarseness of the PRISM grid, which resulted in large elevation changes within cells and underestimation of temperatures. Total annual water consumption for the period 1996-1999 reported by the major Irrigation Districts 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. Some Irrigation Districts may not be able to meet the increased demand.

INTRODUCTION

Agricultural viability in the semi-arid, interior valleys of S. British Columbia is determined by the availability of irrigation water to meet crop requirements. In the Okanagan Valley, a sub-basin of the Columbia River, irrigation water is provided mainly by snow melt from adjacent mountains either as runoff or through ground water recharge. Potential 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. Such climate responses may result in 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. Analysis of historic climate and hydrologic data collected between 1976 and 1995 for unregulated streams in the Okanagan Basin, indicated significant increase in temperature and decreases in precipitation in spring and fall with resultant changes in stream hydrographs (Leith and Whitfield, 1998). In response to climate change models, Cohen and Kulkhani, (2001) reported earlier onset of spring peak flows (up to six weeks by 2080), lower peak flow and increased winter flow for similar un-regulated streams in the study area.

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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 the watershed crosses the international boundary, basin trans-border flows are governed by Canada-US agreements.

The objectives of this study were to determine potential crop water requirements under conditions of climate change, which may increase water demand, and to compare these spatial changes in demand with licensed water supply in the southern portion of the Okanagan Basin.

MATERIALS AND METHODS

In order to analyze regional crop water demand, methods were developed which integrated estimates of crop water use with spatial land use data and climate. Data were compiled in a GIS on the spatial distribution of crops, which were linked to estimates of water requirements utilizing crop coefficients developed for each crop type in response to current climate, and to climate change scenarios produced by the Canadian Global Coupled Model (GCM1) (Canadian Centre for Climate Modeling and Analysis, 2001)

Agricultural Land Use and Irrigation District Mapping

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 were obtained from the 2000 Sterile Insect Release Program, Osoyoos BC, from digitizing paper maps provided by the B.C. Wine Institute, some of which were verified using GPS (Global Positioning System). Data gaps were filled using BC Terrestrial Ecosystem Maps (BC Ministry of Water, Land and Air). To match crop water demand against licensed irrigation supply, the boundaries for 27 local government and irrigation jurisdictions were incorporated into the GIS. ARC Macro Language programming within ARC/INFO was used to assemble climate scenarios and land use coverage.

Estimating Crop Water Requirements

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

Seasonal Crop Coefficients

The crop coefficient is the ratio of crop water use to estimated evapotranspiration and varies with canopy size. Water balance data from the Summerland lysimeter, have indicated that a maximum crop coefficient (K_c) 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 to all tree fruits under the following assumptions:

1. Crop coefficients reported in the literature for different tree fruit crops are similar.
2. To determine maximum demand, all orchards were considered mature.
3. All tree fruits were considered to be under sprinkler irrigation and an 'efficiency

factor' was built into the equation (75%)

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. These crop coefficient data were linked to phenological stage and could thus be adapted to growing seasons of different length. Generalized crop coefficient curves for grapes and tree fruits are shown in Fig. 1.

Downscaling and Transformations of Climate Data

The Canadian Global Coupled 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). 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 imported into the GIS and superimposed upon a map of the southern Okanagan.

Daily mean and maximum temperatures estimated from PRISM monthly data were required to calculate growing degree day accumulations and evapotranspiration respectively. 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.

Estimating Potential Evapotranspiration ET

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:

$\phi = 0.01721*JD$

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

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

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

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

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

Modeling 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 to create unique climate/land units (polygon). Centroids of latitude and longitude for each polygon were added to the database. 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.

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 current land use base was used in all scenario calculations. For determination of spatial relationships, the resultant database records were imported into the GIS.

RESULTS AND DISCUSSION

For the region as a whole, simulations of maximum monthly temperatures for July using CGCM1 and PRISM indicated an increase of 3-5°C between current day (1961-1990) temperature normals and those for 2070-2099. Crop water demand calculations were made for a total of 5,581 land unit polygons, which resulted from the overlay of the land use and PRISM grid coverages for the entire study area. The database model calculated key climate variables for each land unit on a daily basis. Average recorded dates of bloom 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 calculated evaporative demand ceased in the fall. Average growing season length for the study area during the four scenarios and the change from present day to 2099 are given in Table 1. Changes in crop water demand calculated for the four scenarios were thus a function of both temperature and the length of the growing season.

Overall average estimated water use for present day conditions (1961-1990) was compared with values of expected water use (BCMAFF, 1989;Van der Gulik, 1999) for sites within the region in order to test the crop water use model. Estimated values were slightly lower than BCMAFF values (745 mm/year vs 820-1000mm/year), which was possibly the result of under-estimation of temperatures by the PRISM procedure. This was attributed to the coarseness of the PRISM grid (4km x4km), which resulted in large elevation changes within individual cells. Licensed allocations, reported consumption and the estimated crop water demand for major local irrigation authorities in the study area are given in Table 2. Total annual water consumption for the period 1996-1999 reported by the major Irrigation Districts within the region was similar to that predicted by the model (46.9 m^3 x 10^6 vs 51.8 m^3 x 10^6). These results, plus the similarities between simulated and expected values of crop water use noted above, indicated that the model was likely adequate for making estimates of the impact of climate change on crop water demand.

For the region as a whole, estimated crop water demand increased by 37% from 745 to 1021 mm/year, on average, by scenario 2070-2099 (Table 2) although this varied from north to south and by crop type. The requirement for irrigation water increased from 80.1 to 109.8 m^3 x 10^6 over the same time period. There were considerable discrepancies between licensed allocations of irrigation water and estimated demand, both for current and for future use (Table 3). 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, where licensed allotments come from tributary streams, shortages are likely inevitable and in many instances supply will not be able to meet demand under future climate scenarios.

A second factor, which may affect future irrigation water requirement 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 mid-February to mid-November by 2070-2099. Currently, the Okanagan River system is managed primarily for flood control, with trade offs being made to protect fish habitat and to 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.

ACKNOWLEDGEMENTS

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Tables

Table 1. 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
GDD5 °C	JD 85-303	JD 72-307	JD 63-311	JD 52-317	+47 days
GDD10 °C	JD119-278	JD104-283	JD 95-288	JD 85- 296	+51 days
Total GDD 5 °C	1909	2225	2509	2860	50% increase
Total GDD10 °C	960	1183	1398	1666	74% increase

Table 2. 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%

Table 3. Annual volume of diversion allocations, reported mean consumption and estimated crop water demand for specified periods for major irrigation authorities in the study area.

Licensee	Allocation	Consumption	Crop Water Demand		Source[1]
	Annual	1996-1999	1961-1990	2070-2090	
	m^3x10^6				
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

Figures

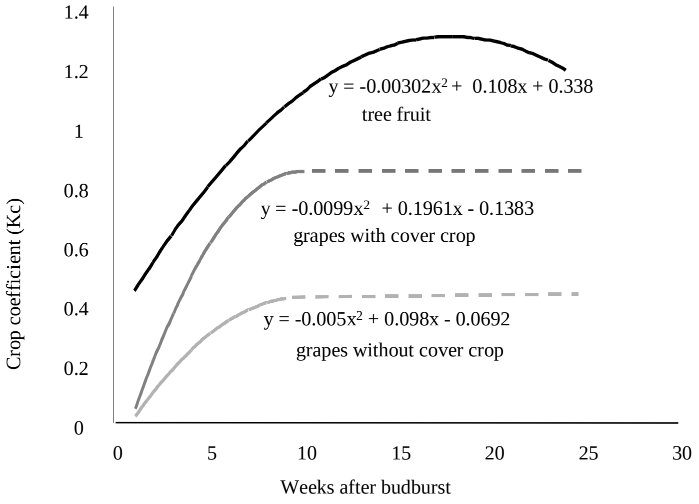

Fig. 1. Seasonal crop coefficient (Kc) curves for mature deciduous fruit trees and grapes in the Okanagan valley (mm water use/mm evaporation).