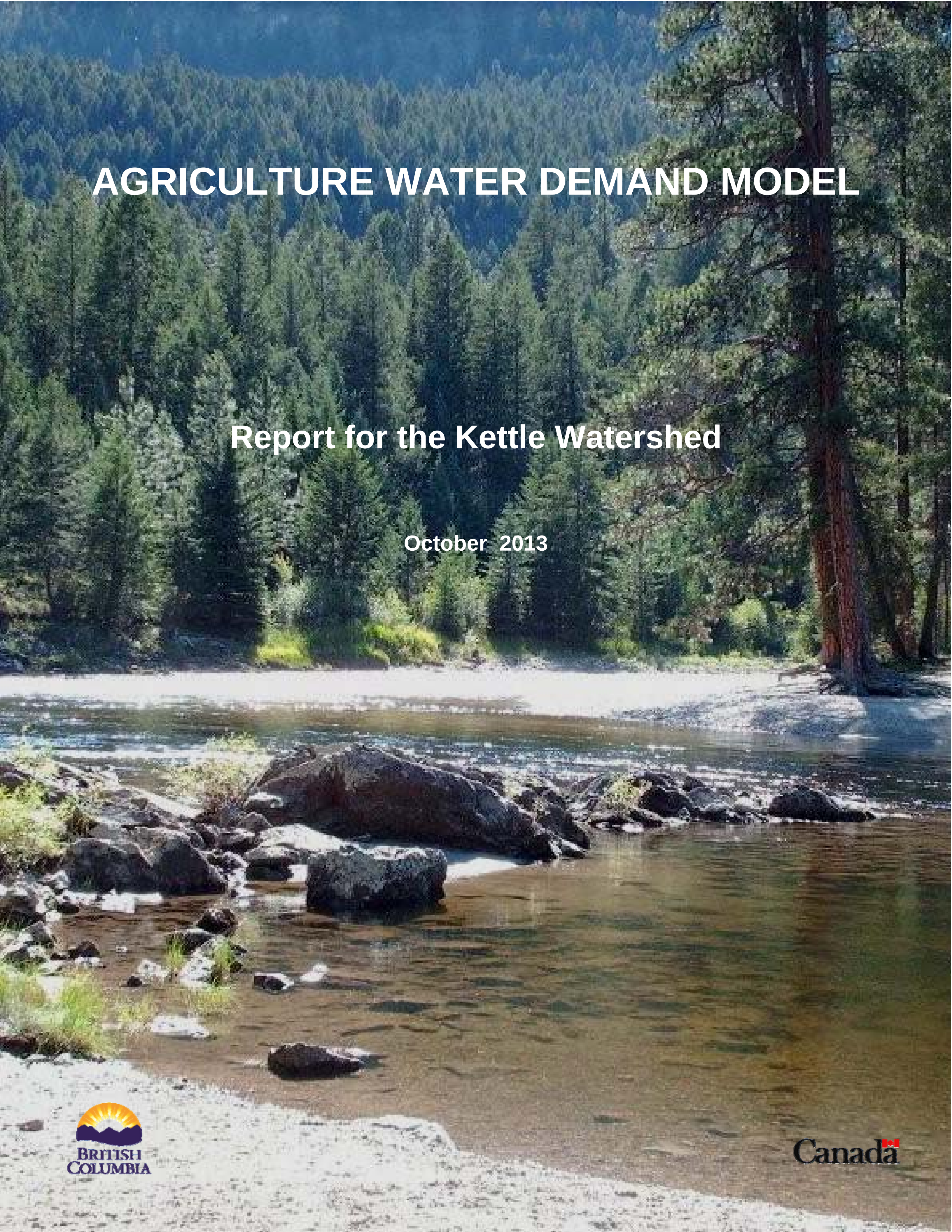

AGRICULTURE WATER DEMAND MODEL

Report for the Kettle Watershed

October 2013

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Tammy Steen	Contractor	Land Use Inventory

Background

The Agriculture Water Demand Model (AWDM) was originally developed in the Okanagan Watershed. It was developed in response to rapid population growth, drought conditions from climate change, and the overall increased demand for water. Many of the watersheds in British Columbia (BC) are fully allocated or will be in the next 15 to 20 years. The AWDM helps to understand current agricultural water use and helps to fulfil the Province's commitment under the "*Living Water Smart – BC Water Plan*" to reserve water for agricultural lands. The Model can be used to establish agricultural water reserves throughout the various watersheds in BC by providing current and future agriculture water use data.

Climate change scenarios developed by the University of British Columbia (UBC) and the Pacific Agri-Food Research Centre (PARC) in Summerland predict an increase in agricultural water demand due to warmer and longer summers and lower precipitation during summer months in the future.

The Agriculture Water Demand Model was developed to provide current and future agricultural water demands. The Model calculates water use on a property-by-property basis, and sums each property to obtain a total water demand for the entire basin or each sub-basin. Crop, irrigation system type, soil texture and climate data are used to calculate the water demand. Climate data from 2003 was used to present information on one of the hottest and driest years on record and 1997 data was used to represent a wet year. Lands within the Agriculture Land Reserve (ALR), depicted in green in Figure 1 were included in the project.

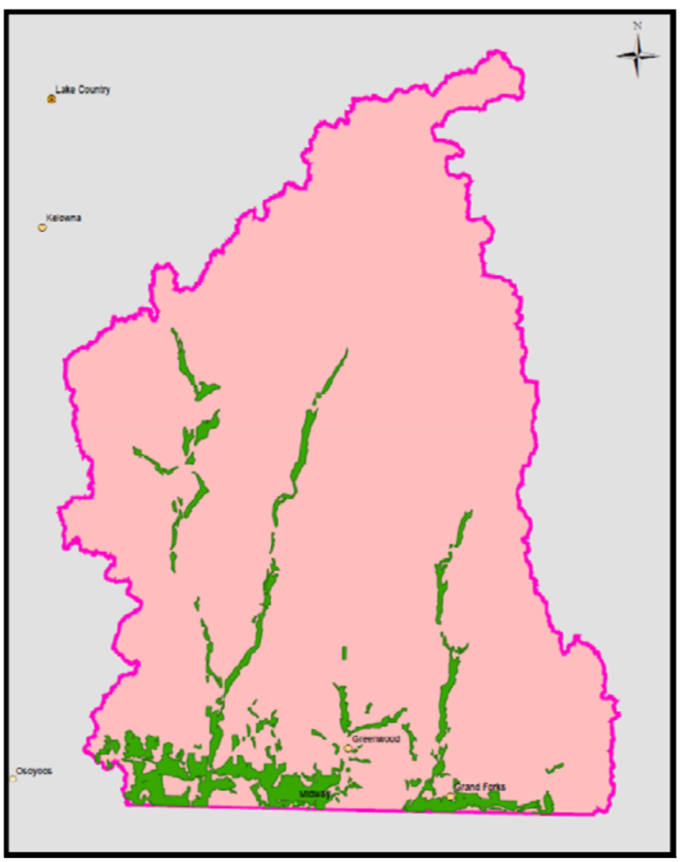

Figure 1 Map of ALR in the Kettle Valley

Methodology

The Model is based on a Geographic Information System (GIS) database that contains information on cropping, irrigation system type, soil texture and climate data. An explanation of how information was compiled for each is given below. The survey area included all properties within the ALR and areas that were zoned for agriculture by the local government. The inventory was undertaken by Ministry of Agriculture (AGRI) staff, hired professional contractors and summer students. Figure 2 provides a schematic of the map sheets that were generated to conduct the survey.

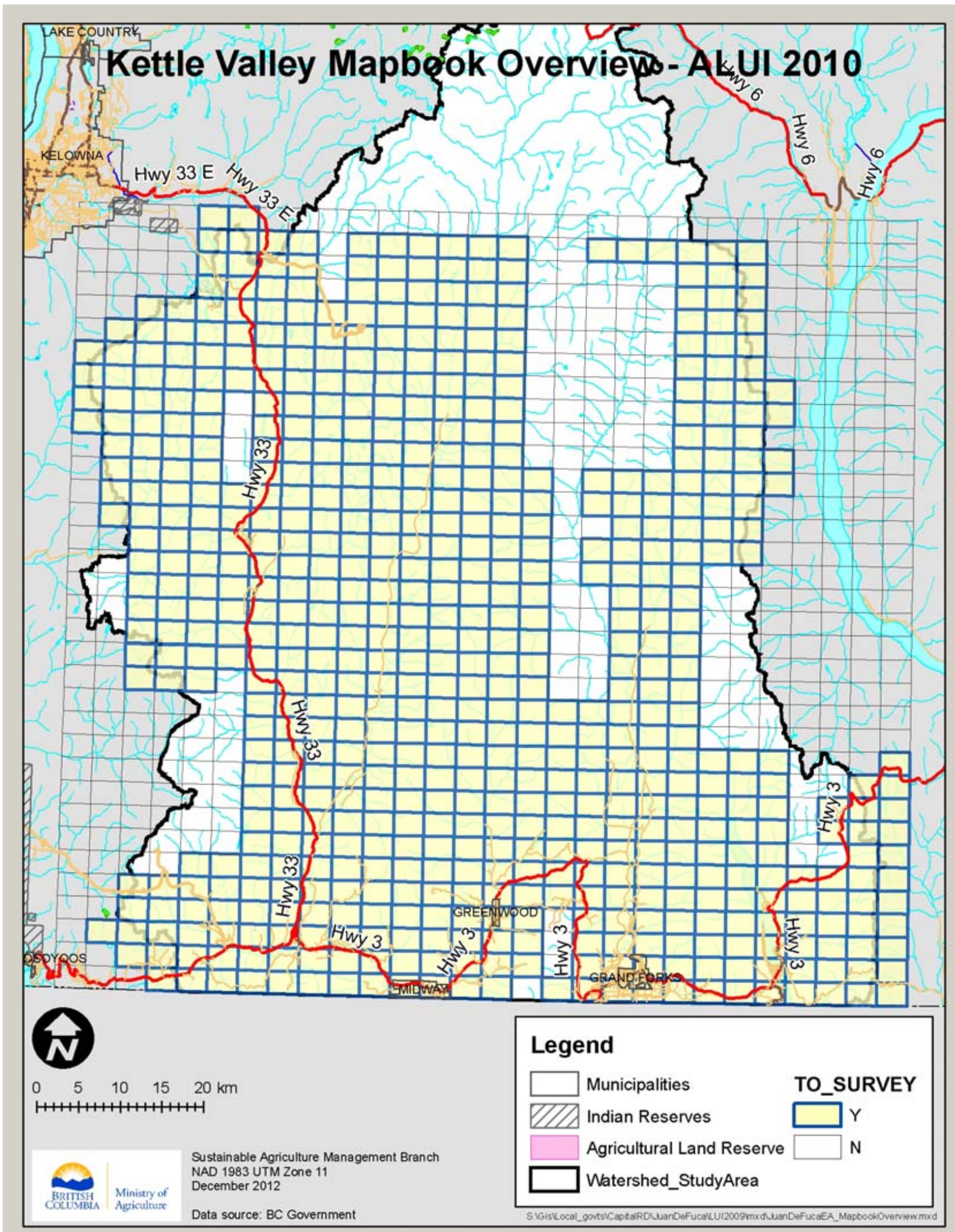

Figure 2 Overlaid Survey Map Sheets, Kettle Valley

Cadastre

Cadastre information was provided by the local governments in the Kettle Valley. The entire regional district is covered in one dataset which allows the Model to report out on each sub-basin, local government, water purveyor or groundwater aquifer. A GIS technician used aerial photographs to conduct an initial review of cropping information by cadastre, and divided the cadastre into polygons that separated farmstead and driveways from cropping areas. Different crops were also separated into different polygons if the difference could be identified on the aerial photographs. This data was entered into the database that was used by the field teams to conduct and complete the land use survey.

Land Use Survey

The survey maps and database were created by AGRI for the survey crew to enter data about each property. Surveys were done during the summer of 2012. The survey crew drove by each property where the team checked the database for accuracy using visual observation and the aerial photographs on the survey maps. A Professional Agrologist verified what was on the site and a GIS technician altered the codes in the database as necessary (Figure 3). Corrections were handwritten on the maps. The map sheets were then brought back to the office to have the hand- drawn lines digitized into the GIS system and have the additional polygons entered into the database.

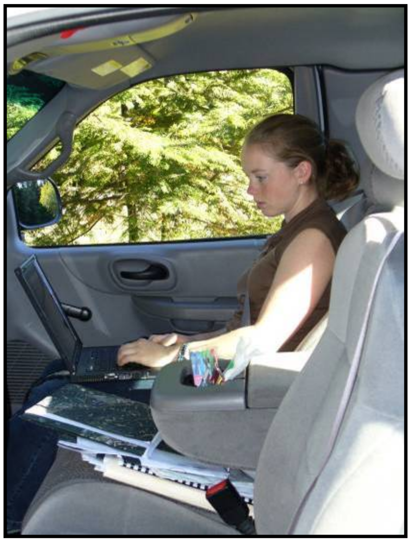

Figure 3 Land Use Survey

Once acquired through the survey, the land use data was brought into the GIS to facilitate analysis and produce maps. Digital data, in the form of a database and GIS shape files (for maps), is available upon request through a data sharing agreement with the Ministry of Agriculture.

Figure 4 provides an example of a map sheet from the Kettle Valley. The region was divided into 631 map sheets. Each map sheet also had a key map to indicate where it was located in the region.

The smallest unit for which water use is calculated are the polygons within each cadastre. A polygon is determined by a change in land use or irrigation system within a cadastre. Polygons are designated as blue lines within each cadastre as shown in Figures 4 and 5. The dataset for the Kettle Valley encompasses 3,429 inventoried land parcels that are in or partially in the ALR. There are a total of 7,451 polygons generated within these land parcels. Figure 5 provides an enhanced view of a cadastre containing three polygons. Each cadastre has a unique identifier as does each polygon. The polygon identifier is acknowledged by PolygonID. This allows the survey team to call up the cadastre in the database, review the number of polygons within the cadastre and ensure the land use is coded accurately for each polygon.

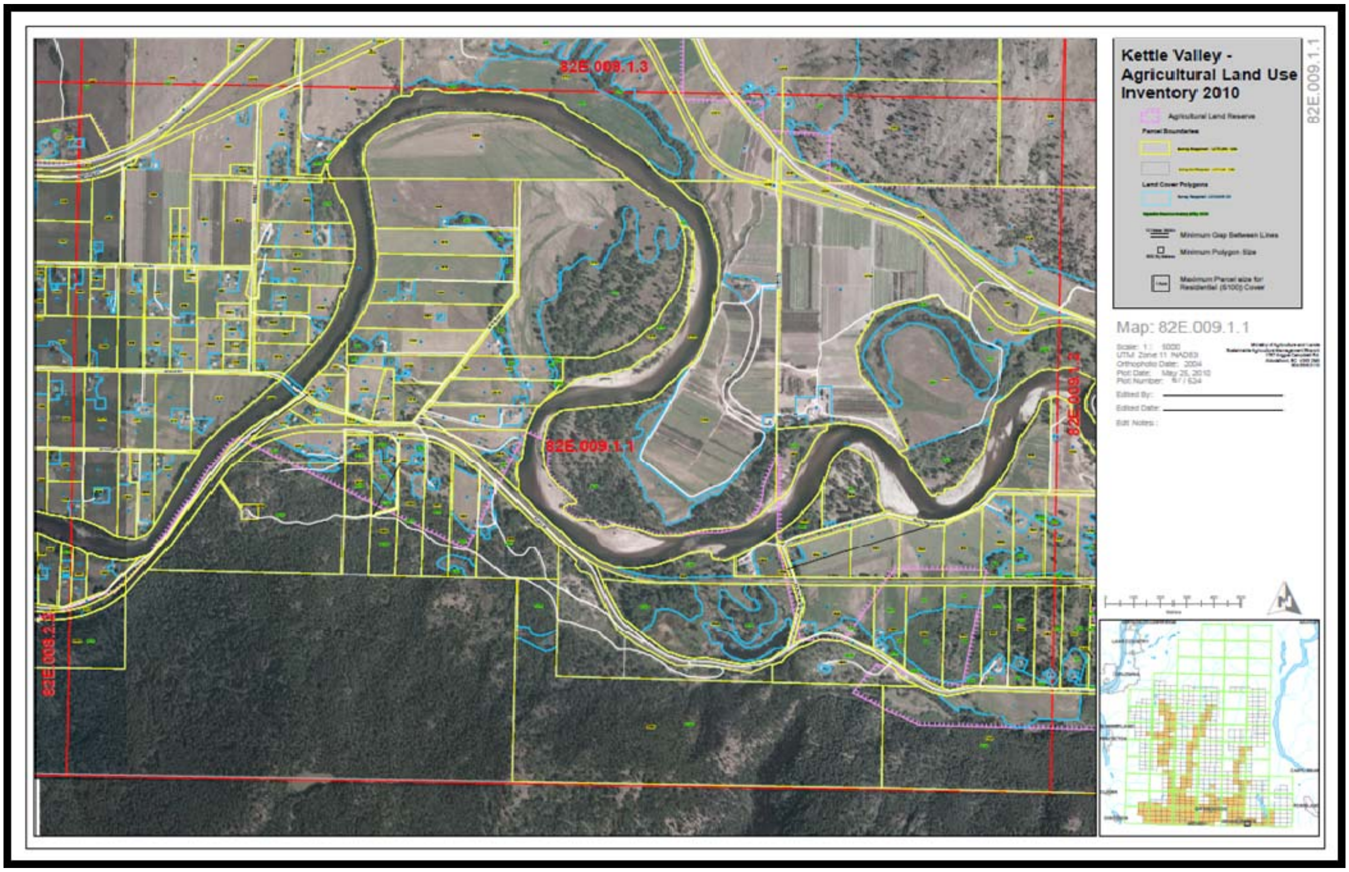

Figure 4 GIS Map Sheet

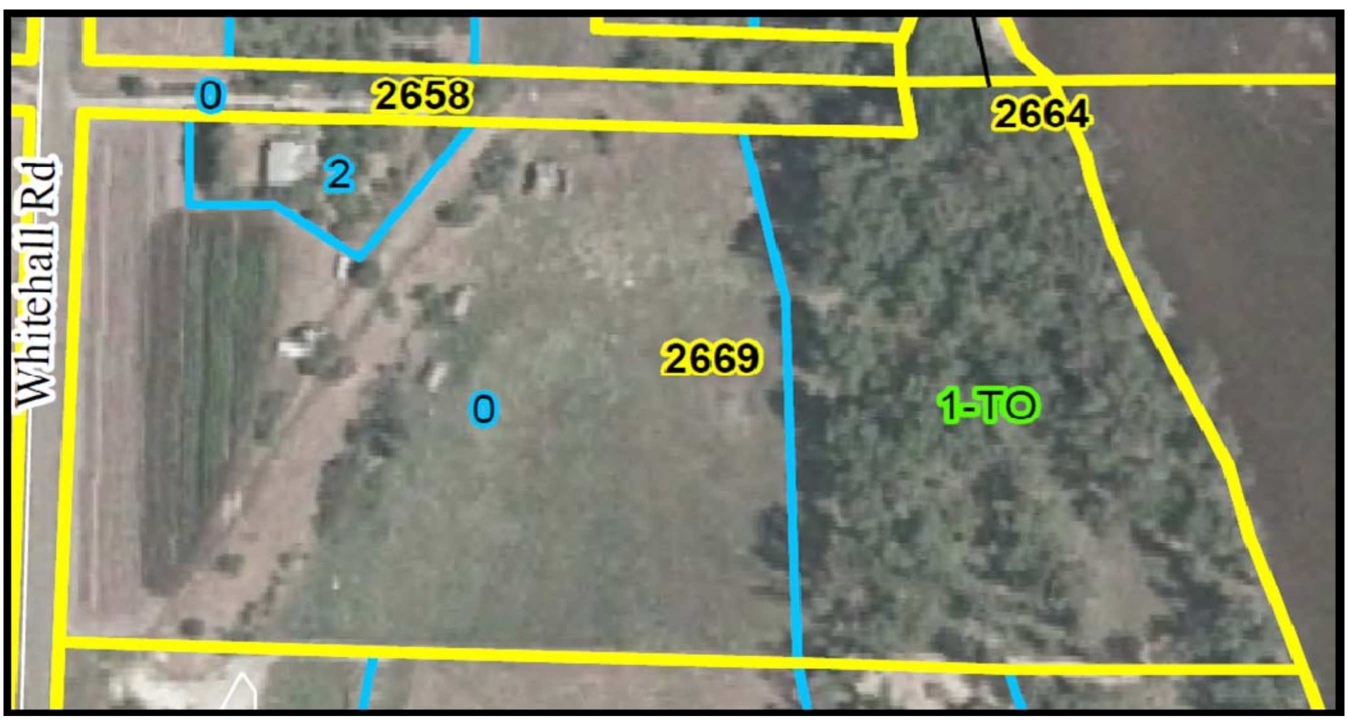

Figure 5 Cadastre with Polygon

Soil Information

Soil information was obtained digitally from the Ministry of Environment's Terrain and Soils Information System. The Computer Assisted Planning and Map Production application (CAPAMP) provided detailed (1:20,000 scale) soil surveys that were conducted in the Lower Mainland, on Southeast Vancouver Island, and in the Okanagan-Similkameen areas during the early 1980s. Products developed include soil survey reports, maps, agriculture capability and other related themes. Soil information required for this project was the soil texture (loam, etc.), the available water storage capacity and the peak infiltration rate for each texture type.

The intersection of soil boundaries with the cadastre and land use polygons creates additional polygons that the Model uses to calculate water demand. Figure 6 shows how the land use information is divided into additional polygons using the soil boundaries. The Model calculates water demand using every different combination of crop, soil and irrigation system as identified by each polygon.

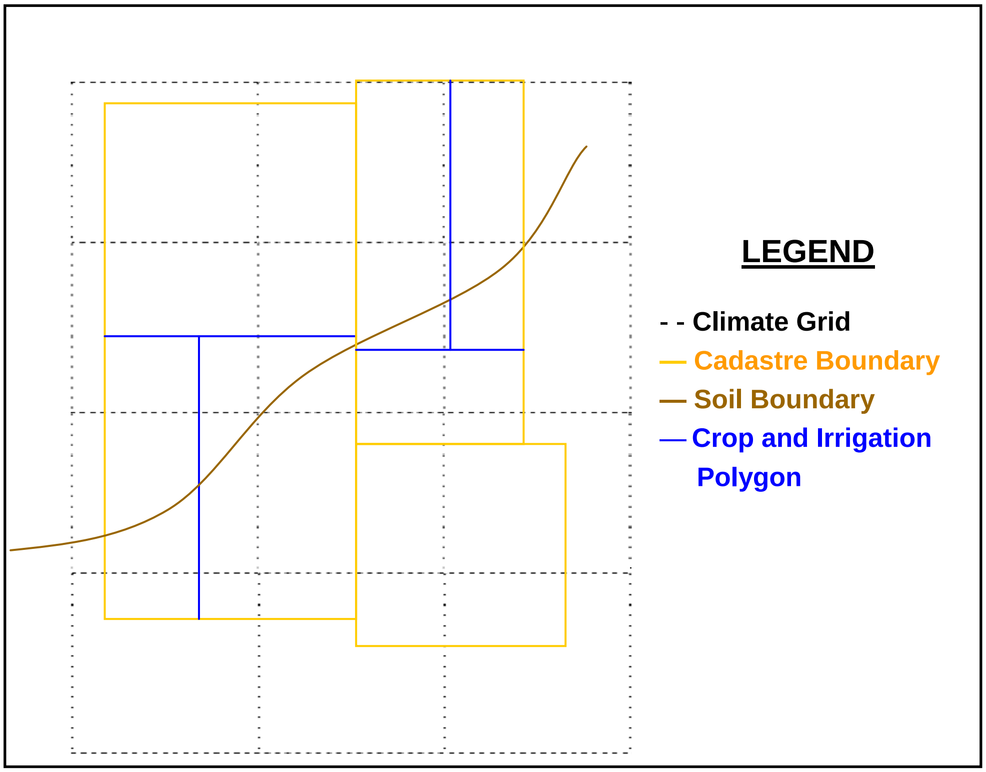

Figure 6 GIS Model Graphic

The next section will discuss about climate information where the climate grid does not develop additional polygons. Each polygon has the climate grid cell which is prominent for that polygon assigned to it.

Climate Information

The agricultural water demand is calculated using climate, crop, irrigation system and soil information data. To incorporate the climatic diversity, climate layers were developed for the entire region on a 500 m x 500 m grid. Each grid cell contains daily climate data, minimum and maximum temperature (T_{min} and T_{max}), and precipitation which allows the Model to calculate a daily reference evapotranspiration rate (ET_o) value. A range of agro-climatic indices such as growing degree days (GDD), corn heat units (CHU), frost free days and temperature sum (Tsum) can also be calculated for each grid cell based on temperature data. These values are used to determine seeding dates and the length of the growing season in the Model.

The climate dataset is generated using existing data from climate stations in and around the Kettle Watershed from 1961 to 2003, and other station data close to the region. This climate data set was then downscaled to provide a climate data layer for the entire watershed on the 500 m x 500 m grid. Since the Kettle Watershed is a little over 8,165 square km, there are a total of 33,364 grid cells populated with daily data. A detailed description of the climate modeling can be obtained by contacting the authors.

Some of the existing climate stations that were used to determine the climate coverage are shown in Figure 7. The attributes attached to each climate grid cell include:

- Latitude
- Longitude
- Elevation
- Aspect
- Slope
- Daily Precipitation
- Daily T_{max} and T_{min}

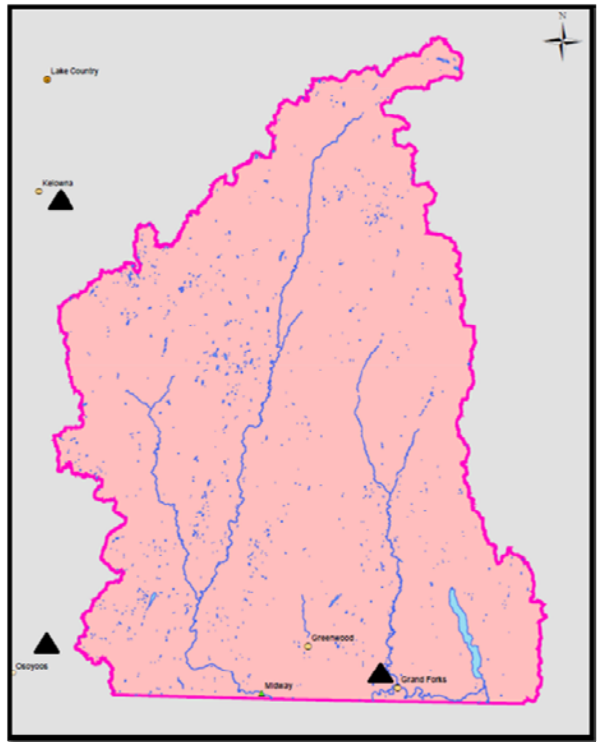

Figure 7 Kettle Valley Area Climate Stations

The climate database generated contains T_{min}, T_{max}, T_{mean} and Precipitation for each day of the year from 1961 to 2003. The parameters that need to be selected, calculated and stored within the Model are evapotranspiration (ET_o), Tsum of 1,000 (for the Island), effective precipitation (EP), frost free days, GDD with base temperatures of 5 ^oC and 10 ^oC, CHU, and first frost date. These climate and crop parameters are used to determine the growing season length as well as the beginning and end of the growing season in Julian day.

Model Calculations

The Model calculates the water demand for each polygon by using crop, irrigation, soil and climate parameters as explained below. Each polygon has been assigned an ID number as mentioned previously.

Crop

The CropID is an attribute of the PolygonID as each polygon will contain a single crop. The crop information (observed during the land use survey) 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 along with the climate data will also be 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, crop coefficient and a drip factor.

Rooting depth is the rooting depth for a mature crop in a deep soil.

An availability coefficient is assigned to each crop. The availability coefficient is used with the IrrigID to determine the soil moisture available to the crop for each PolygonID.

The crop coefficient adjusts the calculated ET_o for the stages of crop growth during the growing season. Crop coefficient curves have been developed for every crop. The crop coefficient curve allows the Model to calculate water demand with an adjusted daily ET_o value throughout the growing season.

The drip factor is used in the water use calculation for polygons where drip irrigation systems are used. Since the Model calculates water use by area, the drip factor adjusts the percentage of area irrigated by the drip system for that crop.

Irrigation

The IrrigID is an attribute of the PolygonID as each polygon will have a single irrigation system type operating. The irrigation information has been collected and stored (as observed during the land use survey) with the land use data. The land use survey determined if a polygon had an irrigation system operating, what the system type was, and if the system was being used. The IrrigID has an irrigation efficiency listed as an attribute.

Two of the IrrigID's, Overtreedrip and Overtreemicro are polygons that have two systems in place. Two irrigation ID's occur when an overhead irrigation system has been retained to provide crop cooling or frost protection. In this case, the efficiencies used in the Model are the drip and microsprinkler efficiencies.

Soil

The soil layer came from CAPAMP at the Ministry of Environment. In addition, soil data provided by Agriculture and Agri-Food Canada (AAFC) was also used to generate multiple soil layers within each polygon. Each parcel was assigned the most predominant soil polygon, and then for each crop field within that soil polygon, the most predominant texture within the crop's rooting depth was determined and assigned to the crop field.

Note that textures could repeat at different depths – the combined total of the thicknesses determined the most predominant texture. For example, a layer of 20 cm sand, followed by 40 cm clay and then 30 cm of sand would have sand be designated at the predominant soil texture.

The attributes attached to the SoilID is the Available Water Storage Capacity (AWSC) which is calculated using the soil texture and crop rooting depth.

The Maximum Soil Water Deficit (MSWD) is calculated to determine the parameters for the algorithm that is used to determine the Irrigation Requirement (IR). The Soil Moisture Deficit at the beginning of the season is calculated using the same terms as the MSWD.

Climate

The climate data in the Model is used to calculate a daily reference evapotranspiration rate (ET_o) for each climate grid cell. The data that is required to calculate this value are:

- Elevation, metres (m)
- Latitude, degrees (^{o})
- Minimum Temperature, degree Celsius (^{o}C)
- Maximum Temperature, degree Celsius (^{o}C)
- Classification as Coastal or Interior
- Classification as Arid or Humid
- Julian Day

Data that is assumed or are constants in this calculation are:

• Wind speed	2 m/s
• Albedo or canopy reflection coefficient,	0.23
• Solar constant, G_{sc}	0.082 $MJ^{-2}min^{-1}$
• Interior and Coastal coefficients, K_{Rs}	0.16 for interior locations 0.19 for coastal locations
• Humid and arid region coefficients, K_o	0 °C for humid/sub-humid climates 2 °C for arid/semi-arid climates

Agricultural Water Demand Equation

The Model calculates the Agriculture Water Demand (AWD) for each polygon, as a unique crop, irrigation system, soil and climate data is recorded on a polygon basis. The polygons are then summed to determine the AWD for each cadastre. The cadastre water demand values are then summed to determine AWD for the basin, sub-basin, water purveyor or local government. The following steps provide the process used by the Model to calculate Agricultural Water Demand. The entire process is outline although not all of the steps may be used for the Kettle Valley, e.g., flood harvesting. Detailed information is available on request.

1. Pre-Season Soil Moisture Content

Prior to the start of each crop's growing season, the soil's stored moisture content is modelled using the soil and crop evaporation and transpiration characteristics and the daily precipitation values. Precipitation increases the soil moisture content and evaporation (modelled using the reference potential evapotranspiration) depletes it. In general, during the pre-season, the soil moisture depth cannot be reduced beyond the maximum evaporation depth; grass crops in wet climates, however, can also remove moisture through crop transpiration.

The process used to model the pre-season soil moisture content is:

1. Determine whether the modelling area is considered to be in a *wet* or *dry* climate (see *Wet/Dry Climate Assessment*), and retrieve the early season evaporation factor in the modelling area
2. For each crop type, determine the start of the growing season (see *Growing Season Boundaries*)
3. For each crop and soil combination, determine the *maximum soil water deficit* (MSWD) and *maximum evaporation factor* (maxEvaporation)
4. Start the initial storedMoisture depth on January 1 at the MSWD level
5. For each day between the beginning of the calendar year and the crop's growing season start, calculate a new stored moisture from:

    a. the potential evapotranspiration (ET_o)
    b. the early season evaporation factor (earlyEvaporationFactor)
    c. the effective precipitation (EP) = actual precipitation x earlyEvaporationFactor
    d. daily Climate Moisture Deficit (CMD) = ET_o – EP
    e. storedMoisture = previous day's storedMoisture – CMD

A negative daily CMD (precipitation in excess of the day's potential evapotranspiration) adds to the stored moisture level while a positive climate moisture deficit reduces the amount in the stored moisture reservoir. The stored moisture cannot exceed the maximum soil moisture deficit; any precipitation that would take the stored moisture level above the MSWD gets ignored.

For all crops and conditions except for grass in wet climates, the stored moisture content cannot drop below the maximum soil water deficit minus the maximum evaporation depth; without any crop transpiration in play, only a certain amount of water can be removed from the soil through evaporative processes alone. Grass in wet climates does grow and remove moisture from the soil prior to the start of the irrigation season, however. In those cases, the stored moisture level can drop beyond the maximum evaporation depth, theoretically to 0.

Greenhouses and mushroom barns have no stored soil moisture content.

2. In-Season Precipitation

During the growing season, the amount of precipitation considered effective (EP) depends on the overall wetness of the modelling area's climate (see *Wet/Dry Climate Assessment*). In dry climates, the first 5 mm of precipitation is ignored, and the EP is calculated as 75% of remainder:

$$EP = (Precip - 5) \times 0.75$$

In wet climates, the first 5 mm is included in the EP. The EP is 75% of the actual precipitation:

$$EP = Precip \times 0.75$$

Greenhouses and mushroom barns automatically have an EP value of 0.

3. *Crop Cover Coefficient (K_c)*

As the crops grow, the amount of water they lose due to transpiration changes. Each crop has a pair of polynomial equations that provide the crop coefficient for any day during the crop's growing season. It was found that two curves, one for modelling time periods up to the present and one for extending the modelling into the future, provided a better sequence of crop coefficients than using a single curve for all years (currently 1961 to 2100). The application automatically selects the current or future curve as modelling moves across the c*rop Curve Changeover Year*.

For alfalfa crops, there are different sets of equations corresponding to different cuttings throughout the growing season.

4. *Crop Evapotranspiration (ET_c)*

The evapotranspiration for each crop is calculated as the general ET_o multiplied by the crop coefficient (K_c):

$$ET_c = ET_o \times K_c$$

5. *Climate Moisture Deficit (CMD)*

During the growing season, the daily Climate Moisture Deficit (CMD) is calculated as the crop evapotranspiration (ET_c) less the Effective Precipitation (EP):

$$CMD = ET_c - EP$$

During each crop's growing season, a stored moisture reservoir methodology is used that is similar to the soil moisture content calculation in the pre-season. On a daily basis, the stored moisture level is used towards satisfying the climate moisture deficit to produce an *adjusted Climate Moisture Deficit* (CMD_a):

$$CMD_a = CMD - storedMoisture$$

If the storedMoisture level exceeds the day's CMD, then the CMD_a is 0 and the stored moisture level is reduced by the CMD amount. If the CMD is greater than the stored moisture, then all of the stored moisture is used (storedMoisture is set to 0) and the adjusted CMD creates an irrigation requirement.

The upper limit for the storedMoisture level during the growing season is the maximum soil water deficit (MSWD) setting.

6. *Crop Water Requirement (CWR)*

The Crop Water Requirement is calculated as the adjusted Climate Moisture Deficit (CMD_a) multiplied by the soil water factor (swFactor) and any stress factor (used primarily for grass crops):

$$CWR = CMD_a \times swFactor \times stressFactor$$

7. *Irrigation Requirement (IR)*

The Irrigation Requirement is the Crop Water Requirement (CWR) after taking into account the irrigation efficiency (I_e) and, for drip systems, the drip factor (D_f):

$$IR = CWR \times \frac{D_f}{I_e}$$

For irrigation systems other than drip, the drip factor is 1.

8. *Irrigation Water Demand (IWDperc and IWD)*

The portion of the Irrigation Water Demand lost to deep percolation is the Irrigation Requirement (IR) multiplied by the percolation factor (soilPercFactor):

$$IWD_{perc} = IR \times soilPercFactor$$

The final Irrigation Water Demand (IWD) is then the Irrigation Requirement (IR) plus the loss to percolation (IWD_{perc}):

$$IWD = IR + IWD_{perc}$$

9. *Frost Protection*

For some crops (e.g. cranberries), an application of water is often used under certain climatic conditions to provide protection against frost damage. For cranberries, the rule is: when the temperature drops to 0 ^{o}C or below between March 16 and May 20 or between October 1 and November 15, a frost event will be calculated. The calculated value is an application of 2.5 mm per hour for 10 hours. In addition, 60% of the water is recirculated and reused, accounting for evaporation and seepage losses.

This amounts to a modelled water demand of 10 mm over the cranberry crop's area for each day that a frost event occurs between the specified dates.

10. *Annual Soil Moisture Deficit*

Prior to each crop's growing season, the Model calculates the soil's moisture content by starting it at full (maximum soil water deficit level) on January 1, and adjusting it daily according to precipitation and evaporation. During the growing season, simple evaporation is replaced by the crop's evapotranspiration as it progresses through its growth stages. At the completion of each crop's growing season, an annual soil moisture deficit (SMD) is calculated as the difference between the soil moisture content at that point and the maximum soil water deficit (MSWD):

$$SMD = MSWD - storedMoisture$$

In dry/cold climates, this amount represents water that the farmer would add to the soil in order to prevent it from freezing. Wet climates are assumed to have sufficient precipitation and warm enough temperatures to avoid the risk of freezing without this extra application of water; the SMD demand is therefore recorded only for dry areas.

There is no fixed date associated with irrigation to compensate for the annual soil moisture deficit. The farmer may choose to do it any time after the end of the growing season and before the freeze up. In the Model's summary reports, the water demand associated with the annual soil moisture deficit shows as occurring at time 0 (week 0, month 0, etc.) simply to differentiate it from other demands that do have a date of occurrence during the crop's growing season.

Greenhouses and mushroom barns do not have an annual soil moisture deficit.

11. Flood Harvesting

Cranberry crops are generally harvested using flood techniques. The Model calculates the flood harvesting demand as 250 mm of depth for 10% of the cranberry farmed area. For modelling purposes, it is assumed that 250 mm of water gets applied to the total cranberry crop area, 10% at a time. The water is reused for subsequent portions, but by the time the entire crop is harvested, all of the water is assumed to have been used and either depleted through losses or released from the farm.

The water demand is therefore calculated as a fixed 25 mm over the entire cranberry crop area. The harvesting generally takes place between mid-October and mid-November where the Model treats it as occurring on the fixed date of November 16.

Livestock Water Use

The Model calculates an estimated livestock water demand using agricultural census data and an estimate of the water use per animal. Water use for each animal type is calculated a bit differently depending on requirements. For example, for a dairy milking cow, the water demand for each animal includes, drinking, preparation for milking, pen and barn cleaning, milking system washout, bulk tank washout and milking parlor washing. However, for a dry dairy cow, the demand only includes drinking and pen and barn cleaning.

The water use is estimated on a daily basis per animal even though the facility is not cleaned daily. For example, for a broiler operation, the water use for cleaning a barn is calculated as 4 hours of pressure washing per cycle at a 10 gpm flow rate, multiplied by 6 cycles per barn with each barn holding 50,000 birds. On a daily basis, this is quite small with a value of 0.01 litres per day per bird applied.

For all cases, the daily livestock demand is applied to the farm location. However, in the case of beef, the livestock spend quite a bit of the year on the range. Since the actual location of the animals cannot be ascertained, the water demand is applied to the home farm location, even though most of the demand will not be from this location. Therefore, the animal water demand on a watershed scale will work fine but not when the demand is segregated into sub-watersheds or groundwater areas.

The estimates used for each livestock are shown in Table 1.

Table 1 Livestock Water Demand (Litres/day)

Animal Type	Drinking	Milking Preparation	Barn Component	Total
Milking Dairy Cow	65	5	15	85
Dry Cow	45		5	50
Swine	12		0.5	12.5
Poultry – Broiler	0.16		0.01	0.17
Poultry – Layer	0.08		0.01	0.09
Turkeys	0.35		0.01	0.36
Goats	8			8
Sheep	8			8
Beef – range, steer, bull, heifer	50			50
Horses	50			50

Definition and Calculation of Individual Terms used in the Irrigation Water Demand Equation

Growing Season Boundaries

There are three sets of considerations used in calculating the start and end of the irrigation season for each crop:

- temperature-based growing season derivations, generally using Temperature Sum (Tsum) or Growing Degree Day (GDD) accumulations
- the growing season overrides table
- the irrigation season overrides table

These form an order of precedence with later considerations potentially overriding the dates established for the previous rules. For example, the temperature-based rules might yield a growing season start date of day 90 for a given crop in a mild year. To avoid unrealistic irrigation starts, the season overrides table might enforce a minimum start day of 100 for that crop; at that point, the season start would be set to day 100. At the same time, a Water Purveyor might not turn on the water supply until day 105; specifying that as the minimum start day in the irrigation season overrides table would prevent any irrigation water demands until day 105.

This section describes the rules used to establish growing season boundaries based on the internal calculations of the Model. The GDD and Tsum Day calculations are described in separate sections. The *standard end of season* specified for several crops is the earlier of the end date of Growing Degree Day with base temperature of 5 ^{o}C (GDD_5) or the first frost.

1. Corn (silage corn)

- uses the corn_start date for the season start
- season end: earlier of the killing frost or the day that the CHU2700 (2700 Corn Heat Units) threshold is reached

2. Sweetcorn, Potato, Tomato, Pepper, Strawberry, Vegetable, Pea

- corn_start date for the season start
- corn start plus 110 days for the season end

3. Cereal

- GDD5 start for the season start
- GDD5 start plus 130 days for the season end

4. AppleHD, AppleMD, AppleLD, Asparagus, Berry, Blueberry, Ginseng, Nuts, Raspberry, Sourcherry, Treefruit, Vineberry

- season start: (0.8447 x tsum600_day) + 18.877
- standard end of season

5. Pumpkin

- corn_start date
- standard end of season

6. Apricot

- season start: (0.9153 x tsum400_day) + 5.5809
- standard end of season

7. CherryHD, CherryMD, CherryLD

- season start: (0.7992 x tsum450_day) + 24.878
- standard end of season

8. Grape, Kiwi

- season start: (0.7992 x tsum450_day) + 24.878
- standard end of season

9. Peach, Nectarine

- season start: (0.8438 x tsum450_day) + 19.68
- standard end of season

10. Plum

- season start: (0.7982 x tsum500_day) + 25.417
- standard end of season

11. Pear

- season start: (0.8249 x tsum600_day) + 17.14
- standard end of season

12. Golf, TurfFarm

- season start: later of the GDD_5 start and the tsum300_day
- standard end of season

13. Domestic, Yard, TurfPark

- season start: later of the GDD_5 start and the tsum400_day
- standard end of season

14. Greenhouse (interior greenhouses)

- fixed season of April 1 – October 30

15. GH Tomato, GH Pepper, GH Cucumber

- fixed season of January 15 – November 30

16. GH Flower

- fixed season of March 1 – October 30

17. GH Nursery

- fixed season of April 1 – October 30

18. Mushroom

- all year: January 1 – December 31

19. Shrubs/Trees, Fstock, NurseryPOT

- season start: tsum500_day
- end: julian day 275

20. Floriculture

- season start: tsum500_day
- end: julian day 225

21. Cranberry

- season start: tsum500_day
- end: julian day 275

22. Grass, Forage, Alfalfa, Pasture

- season start: later of the GDD_5 and the tsum600_day
- standard end of season

23. Nursery

- season start: tsum400_day
- standard end of season

Evapotranspiration (ET_o)

The ET_o calculation follows the FAO Penman-Montieth equation. Two modifications were made to the equation:

- Step 6 – Inverse Relative Distance Earth-Sun (d_r)
  Instead of a fixed 365 days as a divisor, the actual number of days for each year (365 or 366) was used.

- Step 19 – Evapotranspiration (ET_o)
  For consistency, a temperature conversion factor of 273.16 was used instead of the rounded 273 listed.

Availability Coefficient (AC)

The availability coefficient is a factor representing the percentage of the soil's total water storage that the crop can readily extract. The factor is taken directly from the crop factors table (*crop_factors*) based on the cropId value.

Rooting Depth (RD)

The rooting depth represents the crop's maximum rooting depth and thus the depth of soil over which the plant interacts with the soil in terms of moisture extraction. The value is read directly from the crop factors table.

Stress Factor (stressFactor)

Some crops, such as *grasses*, are often irrigated to a less degree than their full theoretical requirement for optimal growth. The *stress factor* (*crop_groups_and_factors*) reduces the calculated demand for these crops.

Available Water Storage Capacity (AWSC)

The available water storage capacity is a factor representing the amount of water that a particular soil texture can hold without the water dropping through and being lost to deep percolation. The factor is taken directly from the soil factors table (*soil_factors*).

Maximum Soil Water Deficit (MSWD)

The maximum soil water deficit is the product of the crop's availability coefficient, rooting depth, and the available water storage capacity of the soil:

$$MSWD = RD \times AWSC \times AC$$

Deep Percolation Factor (soilPercFactor)

The soil percolation factor is used to calculate the amount of water lost to deep percolation under different management practices.

For greenhouse crops, the *greenhouse leaching factor* is used as the basic soil percolation factor. This is then multiplied by a greenhouse recirculation factor, if present, to reflect the percentage of water re-captured and re-used in greenhouse operations.

$$soilPercFactor = soilPercFactor \times (1 - recirculationFactor)$$

For Nursery Pot (Nursery POT) and Forestry Stock (Fstock) crops, the soil percolation factor is fixed at 35%. For other crops, the factor depends on the soil texture, the MSWD, the irrigation system, and the Irrigation Management Practices code. The percolation factors table (*soil_percolation_factors*) is read to find the first row with the correct management practices, soil texture and irrigation system, and a MSWD value that matches or exceeds the value calculated for the current land use polygon.

If the calculated MSWD value is greater than the index value for all rows in the percolation factors table, then the highest MSWD factor is used. If there is no match based on the passed parameters, then a default value of 0.25 is applied.

For example, a calculated MSWD value of 82.5 mm, a soil texture of sandy loam (SL) and an irrigation system of solid set overtree (Ssovertree) would retrieve the percolation factor associated with the MSWD index value of 75 mm in the current table (presently, there are rows for MSWD 50 mm and 75 mm for SL and Ssovertree).

Maximum Evaporation Factor (maxEvaporation)

Just as different soil textures can hold different amounts of water, they also have different depths that can be affected by evaporation. The factor is taken directly from the soil factors table.

Irrigation Efficiency (I_e)

Each irrigation system type has an associated efficiency factor (inefficient systems require the application of more water in order to satisfy the same crop water demand). The factor is read directly from the irrigation factors table (*irrigation_factors*).

Soil Water Factor (swFactor)

For the greenhouse "crop", the soil water factor is set to 1. For other crops, it is interpolated from a table (*soil_water_factors*) based on the MSWD. For Nurseries, the highest soil water factor (lowest MSWD index) in the table is used; otherwise, the two rows whose MSWD values bound the calculated MSWD are located and a soil water factor interpolated according to where the passed MSDW value lies between those bounds.

For example, using the current table with rows giving soil water factors of 0.95 and 0.9 for MSWD index values of 75 mm and 100 mm respectively, a calculated MSWD value of 82.5 mm would return a soil water factor of:

$$
\begin{aligned}
& 0.95 + \left[\frac{82.5 - 75}{100 - 75} \times (0.9 - 0.95) \right] \\
&= 0.935
\end{aligned}
$$

If the calculated MSWD value is higher or lower than the index values for all of the rows in the table, then the factor associated with the highest or lowest MSWD index is used.

Early Season Evaporation Factor (earlyEvaporationFactor)

The effective precipitation (precipitation that adds to the stored soil moisture content) can be different in the cooler pre-season than in the growing season. The early season evaporation factor is used to determine what percentage of the precipitation is considered effective prior to the growing season.

Crop Coefficient (K_c)

The crop coefficient is calculated from a set of fourth degree polynomial equations representing the crop's ground coverage throughout its growing season. The coefficients for each term are read from the crop factors table based on the crop type, with the variable equalling the number of days since the start of the crop's growing season. For example, the crop coefficient for Grape on day 35 of the growing season would be calculated as:

$$
\begin{aligned}
K_c &= [0.0000000031 \times (35)^4] + [-0.0000013775 \times (35)^3] + (0.0001634536 \times (35)^2] + (-0.0011179845 \times 35) + 0.2399004137 \\
&= 0.346593241
\end{aligned}
$$

Alfalfa crops have an additional consideration. More than one cutting of alfalfa can be harvested over the course of the growing season, and the terms used for the crop coefficient equation changes for the different cuttings. For alfalfa, the alfalfa cuttings table is first used to determine which cutting period the day belongs to (first, intermediate or last), and after that the associated record in the crop factors table is accessed to determine the terms.

There are two sets of polynomial coefficients used to calculate the crop coefficient; the first set is used for modelling time periods up to the year specified as the *crop curve changeover year*; and the second for modelling into the future. The changeover year will be modified as time goes on and new historical climate observations become available.

Growing Degree Days (GDD)

The Growing Degree Day calculations generate the start and end of GDD accumulation.

1. ***Start of GDD Accumulation***

   For each base temperature (bases 5 and 10 are always calculated, other base temperature can be derived), the start of the accumulation is defined as occurring after 5 consecutive days of T_{mean} matching or exceeding the base temperature (BaseT). The search for the start day gets reset if a killing frost ($< -2\ ^oC$) occurs, even after the accumulation has started. The search also restarts if there are 2 or more consecutive days of $T_{min} \leq 0\ ^oC$. The GDD start is limited to Julian days 1 to 210; if the accumulation has not started by that point, then it is unlikely to produce a reasonable starting point for any crop.

2. ***End of GDD accumulation***

   The search for the end of the GDD accumulation begins 50 days after its start. The accumulation ends on the earlier of 5 consecutive days where T_{mean} fails to reach BaseT (strictly *less than*) or the first killing frost ($-2\ ^oC$).

During the GDD accumulation period, the daily contribution is the difference between T_{mean} and BaseT, as long as T_{mean} is not less than BaseT:

$$GDD = T_{mean} - BaseT;\ 0 \text{ if negative}$$

Frost Indices

Three frost indices are tracked for each year:

- the last spring frost is the latest day in the first 180 days of the year with a $T_{min} \leq 0\ ^oC$
- the first fall frost is the first day between days 240 and the end of the year where $T_{min} \leq 0\ ^oC$
- the killing frost is the first day on or after the first fall frost where $T_{min} \leq -2\ ^oC$

Corn Heat Units (CHU)

The Corn Heat Unit is the average of two terms using T_{min} and T_{max}. Prior to averaging, each term is set to 0 individually if it is negative.

$$\begin{aligned}
\text{term1} &= [3.33 \times (T_{max} - 10)] - [0.084 \times (T_{max} - 10) \times (T_{max} - 10)];\ 0 \text{ if negative} \\
\text{term2} &= 1.8 \times (T_{min} - 4.44);\ 0 \text{ if negative} \\
\text{CHU} &= \frac{(\text{term1} + \text{term2})}{2}
\end{aligned}$$

Corn Season Start and End

The corn season boundary derivations are similar to the GDD determinations. The start day is established by 3 consecutive days where $T_{mean} \geq 11.2\ ^oC$. As in the case of the GDD calculations, the search for the corn season start day gets reset if $T_{min} \leq -2\ ^oC$, or if there are 2 or more consecutive days of $-2\ ^oC \leq T_{min} \leq 0\ ^oC$.

The search for the silage corn season end begins 50 days after the start. The season ends on the earlier of a mean temperature dropping below 10.1 or a killing frost.

The end of the sweet corn season is defined as 110 days after the season start.

Tsum Indices

The Tsum day for a given number is defined as the day that the sum of the positive daily T_{mean} reaches that number. For example, the Tsum400 day is the day where the sum of the positive T_{mean} starting on January 1 sum to 400 units or greater.

Days where T_{mean} falls below 0 ^oC are simply not counted; therefore, the Model does not restart the accumulation sequence.

Wet/Dry Climate Assessment

Starting with the Lower Mainland, some of the modelling calculations depend on an assessment of the general climatic environment as *wet* or *dry*. For example, when modelling the soil moisture content prior to the start of the crop's growing season, the reservoir can only be drawn down by evaporation except for *grass* crops in *wet* climates which can pull additional moisture out of the soil.

The assessment of wet or dry uses the total precipitation between May 1 and September 30. If the total is more than 125 mm during that period, the climate is considered to be *wet* and otherwise *dry*.

Groundwater Use

The Model generates water sources for irrigation systems. This is done by first determining which farms are supplied by a water purveyor, and then coding those farms as such. Most water purveyors use surface water but where groundwater is used, the farms are coded as groundwater use. The second step is to check all water licences and assign the water licences to properties in the database. The remaining farms that are irrigating will therefore not have a water licence or be supplied by a water purveyor. The assumption is made that these farms are irrigated by groundwater sources.

Land Use Results

A summary of the land area and the inventoried area of the Kettle Valley is shown in Table 2. The primary agricultural use of the ARL area is shown in Table 3. Figure 8, 9 and 10 show the areas of water, ALR and land parcels in the Kettle Valley graphically.

Table 2 Overview of Land and Inventoried Area in the Kettle Valley

Area Type	Area (ha)	Number of Parcels
Kettle Valley		
Total Area	816,511	-
Area of Water Feature	6,226	-
Area of Land (excluding water features)	810,285	-
ALR Area	470,399	4,220
Area of First Nations Reserve	-	-
Inventoried Area		
Total Inventoried Area	470,538	3,429
Area of First Nations Reserve in ALR	-	-

Table 3 Summary of Primary Agricultural Activities within the ALR where Primary Land Use is Agriculture in the Kettle Valley

Primary Agriculture Activity	Total ALR Area (ha)	Number of Parcels
Poly greenhouse	2	5
Grains, cereals, oilseeds	74	19
Tree fruits	28	10
Vines and berries	7	4
Forage, pasture	10,723	1,007
Vegetables	43	15
Specialty, turf, nut trees	26	6
Nursery & tree plantation	353	28
Other	193	48
Total	**11,450**	**1,142**

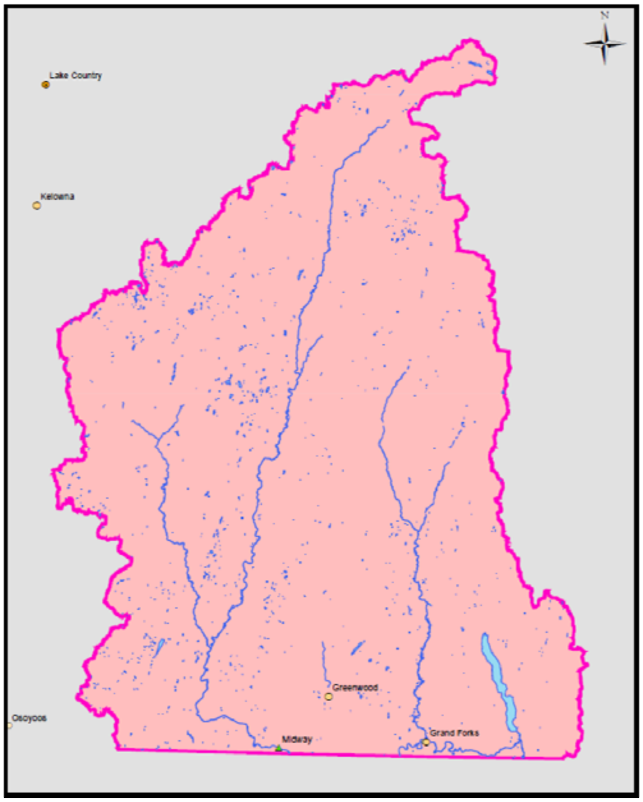

Figure 8 Water Areas in the Kettle Watershed

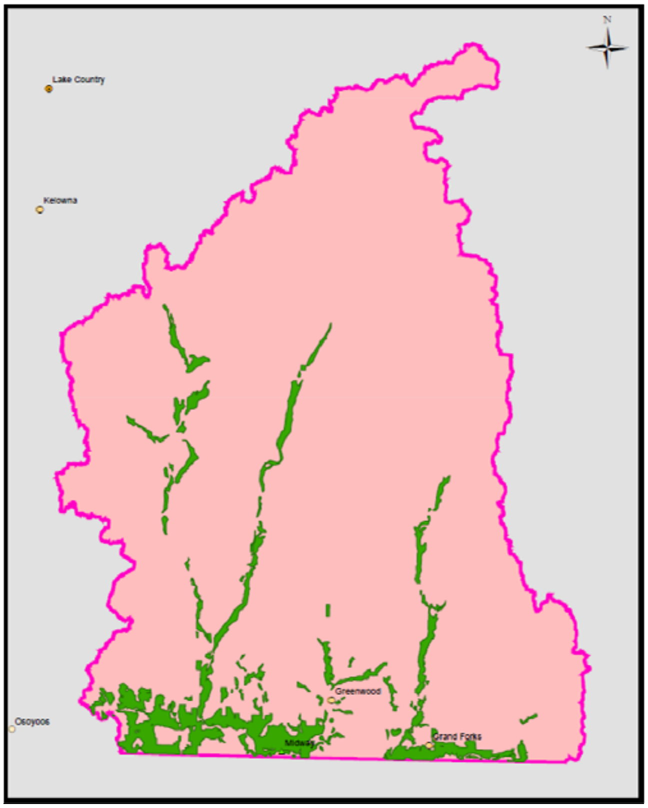

Figure 9 ALR Area in the Kettle Watershed

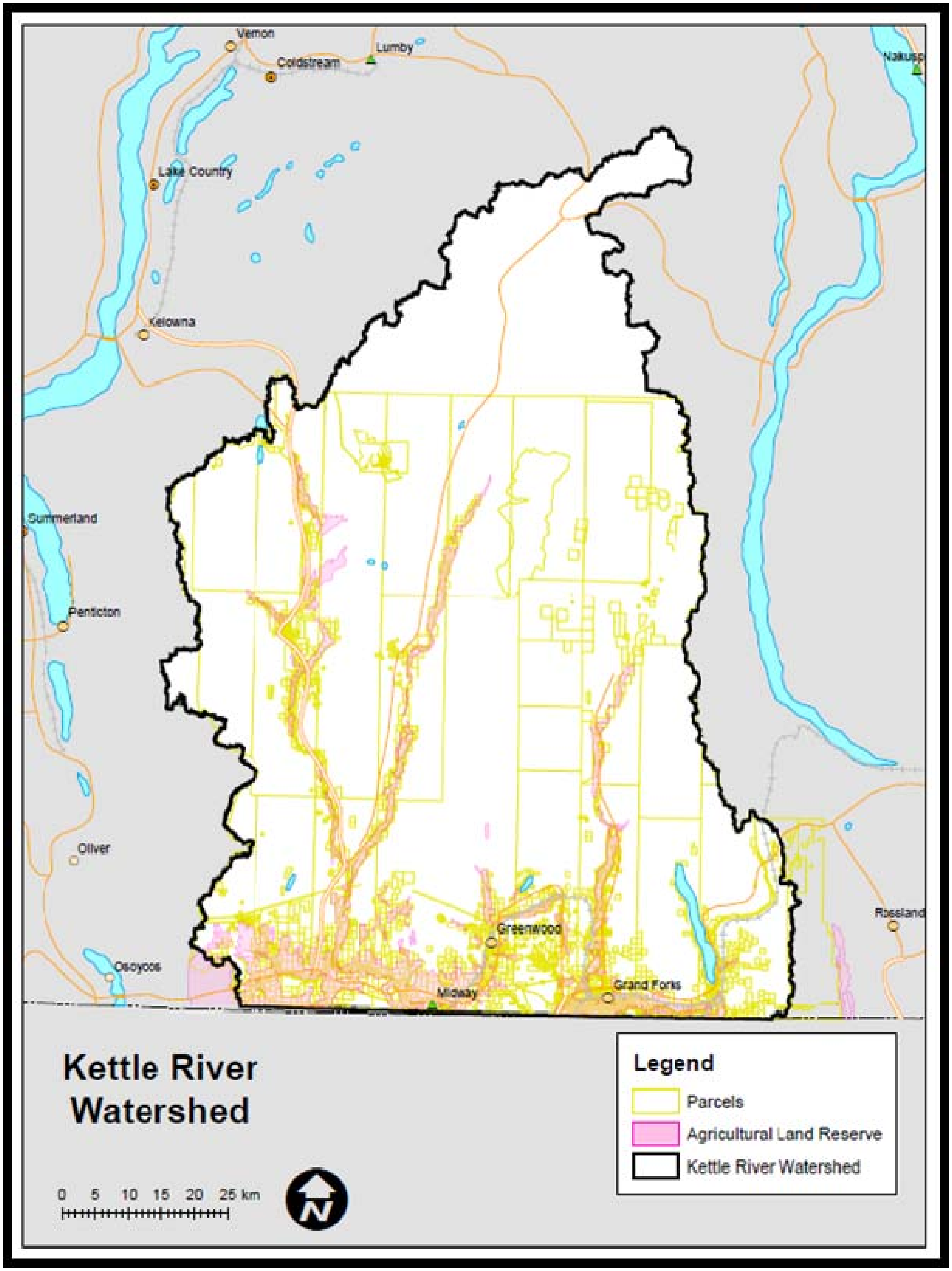

Figure 10 Land Parcels in the Kettle Watershed

Agricultural Water Demand Model Results

The Model has a reporting feature that can save and generate reports for many different scenarios that have been pre-developed. This report will provide a summary of the reported data in the Appendices. Climate data from 1997 and 2003 were chosen as they represent a relatively wet year and dry year respectively. Most reports are based on the 2003 data since the maximum current demand can then be presented.

Annual Crop Water Demand – Tables A and B

The Model can use three different irrigation management factors, good, average and poor. Unless otherwise noted, average management was used in the tables. Table A provides the annual irrigation water demand for current crop and irrigation systems for the year 2003 using average irrigation management, and Table B provides the same data for 1997.

The outdoor irrigated acreage in the ALR for the Kettle Valley is 3,988 hectares (ha). The total annual irrigation demand for this area was 43,106,392 m^3 in 2003 (a dry year), and dropped to 22,858,236 m^3 in 1997 (a wet year).

Of interest is that during a wet year like 1997, the demand was only 51% of a hot dry year like 2003. Another point to consider is that the actual water demand used by an irrigation system may be less or more than the numbers shown above. The model generates a demand based on crop, climate and soil but may not actually represent what is applied by a producer. For example, soil moisture studies have indicated that farmers usually under apply irrigation when using center pivot systems. The AWDM calculations determine irrigation demand based on relatively good practices. Actual use may actually be higher or lower than what is calculated by the Model.

The predominant irrigated agriculture crop in the Kettle Valley is forage.

Annual Water Demand Reported by Irrigation System – Table C

The crop irrigation demand can also be reported by irrigation system type as shown in Table C. The total area that is currently irrigated by efficient systems such as drip, microsprinkler or microspray is relatively small as forage is the predominant crop type. Sprinkler and travelling gun systems used on forage and pasture crops account for 85% of the irrigation system types.

Annual Water Demand by Soil Texture – Table D

Table D provides the annual water demand by soil texture. Where soil texture data is missing, the soil texture has been defaulted to sandy loam. The defaults are shown in the Table D.

Annual Water Demand by Sub-Basin – Table E

Table E provides a breakdown of the water demand by sub-basin within the Kettle River watershed. Six sub-basins have been identified.

Annual Water Demand by Water Purveyor – Table F

There are three water purveyors in the Kettle Watershed that are significant suppliers to agriculture. Table F provides a breakdown of water supplied. All three purveyors rely primarily on groundwater sources.

Irrigation Management Factors – Table G

The Model can estimate water demand based on poor, average and good irrigation management factors. This is accomplished by developing an irrigation management factor for each crop, soil and irrigation system combination. The Maximum Soil Water Deficit (MSWD) is the maximum amount of water that can be stored in the soil within the crop rooting zone. An irrigation system applying more water than what can be stored will result in percolation beyond the crop's rooting depth. Irrigation systems with high application rates will have a probability of higher percolation rates, a stationary gun for instance.

For each soil class, ranges of four MSWD are provided, which reflect a range of crop rooting depths. An irrigation management factor, which determines the amount of leaching, is established for each of the MSWD values for the soil types (Table 4). The management factor is based on irrigation expertise as to how the various irrigation systems are able to operate. For example, Table 4 indicates that for a loam soil and a MSWD of 38 mm, a solid set overtree system has a management factor of 0.1 for good management while the drip system has a management factor of 0.05. This indicates that it is easier to prevent percolation with a drip system than it is with a solid set sprinkler system. For poor management, the factors are higher.

There are a total of 1,344 irrigation management factors established for the 16 different soil textures, MSWD and 21 different irrigation system combinations used in the Model.

Table 4 Irrigation Management Factors

Soil Texture	MSWD	Solid Set Overtree			Drip		
		Good	Average	Poor	Good	Average	Poor
Loam	38	0.10	0.15	0.20	0.05	0.10	0.15
	50	0.05	0.10	0.15	0.05	0.075	0.10
	75	0.05	0.10	0.15	0.05	0.075	0.10
	100	0.05	0.075	0.10	0.05	0.075	0.10
Sandy loam	25	0.20	0.225	0.25	0.10	0.15	0.20
	38	0.10	0.15	0.20	0.10	0.125	0.15
	50	0.05	0.10	0.15	0.05	0.10	0.10
	75	0.05	0.10	0.15	0.05	0.075	0.10

The management factors increase as the MSWD decreases because there is less soil storage potential in the crop rooting depth. For irrigation systems such as guns, operating on a pasture which has a shallow rooting depth, on a sandy soil which cannot store much water, the poor irrigation management factor may be as high as 0.5.

The management factor used in the Model assumes all losses are deep percolation while it is likely that some losses will occur as runoff as well.

Table G provides an overview of the impacts on the management factor and irrigation systems used. Management improvements could be more significant if irrigation systems were converted to more efficient systems.

Table G also provides percolation rates based on good, average and poor management using 2003 climate data. In summary, there is 5,851,695 m^3 of water lost to percolation on good management, 6,988,873 m^3 on average management, and 8,116,051 m^3 on poor management. Percolation rates for poor management are 38% higher than for good management.

Deep Percolation – Table H

The percolation rates vary by crop, irrigation system type, soil and the management factor used. Table H shows the deep percolation amounts by irrigation system type for average management. The last column provides a good indication of the average percolation per hectare for the various irrigation system types. Stationary gun systems have a high percolation rate as the high system application rate fills the soil profile very quickly, requiring the system to be moved in four to six hours. The short system set time is not often accomplished by the manager which results in higher percolation losses. Landscape systems have a high percolation rate predominantly because application rates are high and the grass rooting depth is quite shallow.

Improved Irrigation Efficiency and good Management – Table I

There is an opportunity to reduce water use by converting irrigation systems to a higher efficiency for some crops. For example, drip systems could be used for all berry crops, vegetable crops and some of the other horticultural crops. Forage crops could use low pressure center pivot systems for all field sizes larger than 10 ha. In addition, using better management such as irrigation scheduling techniques will also reduce water use. Table I provides a scenario of water demand if all sprinkler systems are converted to drip systems for horticultural crops and forage fields larger than 10 ha are converted to pivot systems, using good irrigation management. The water demand for 2003 would then reduce from 43,106,392 m^3 to 38,507,279 m^3. This is about an 11% reduction in water demand.

Livestock Water Use – Table J

The Model provides an estimate of water use for livestock. The estimate is based on the number of animals in the Kettle Valley as determined by the latest census, the drinking water required for each animal per day and the barn or milking parlour wash water. Values used are shown in Table J. For the Kettle Valley, the amount of livestock water is estimated at 261,039 m^3.

Climate Change Water Demand for 2050 – Table K

The Model also has access to climate change information until the year 2100. While data can be run for each year, the three driest years in the 2050's were selected to give a representation of climate change. Figure 11 shows the climate data results which indicate that 2053, 2056, and 2059 generate the highest annual ET_o and lowest annual precipitation. These three years were used in this report.

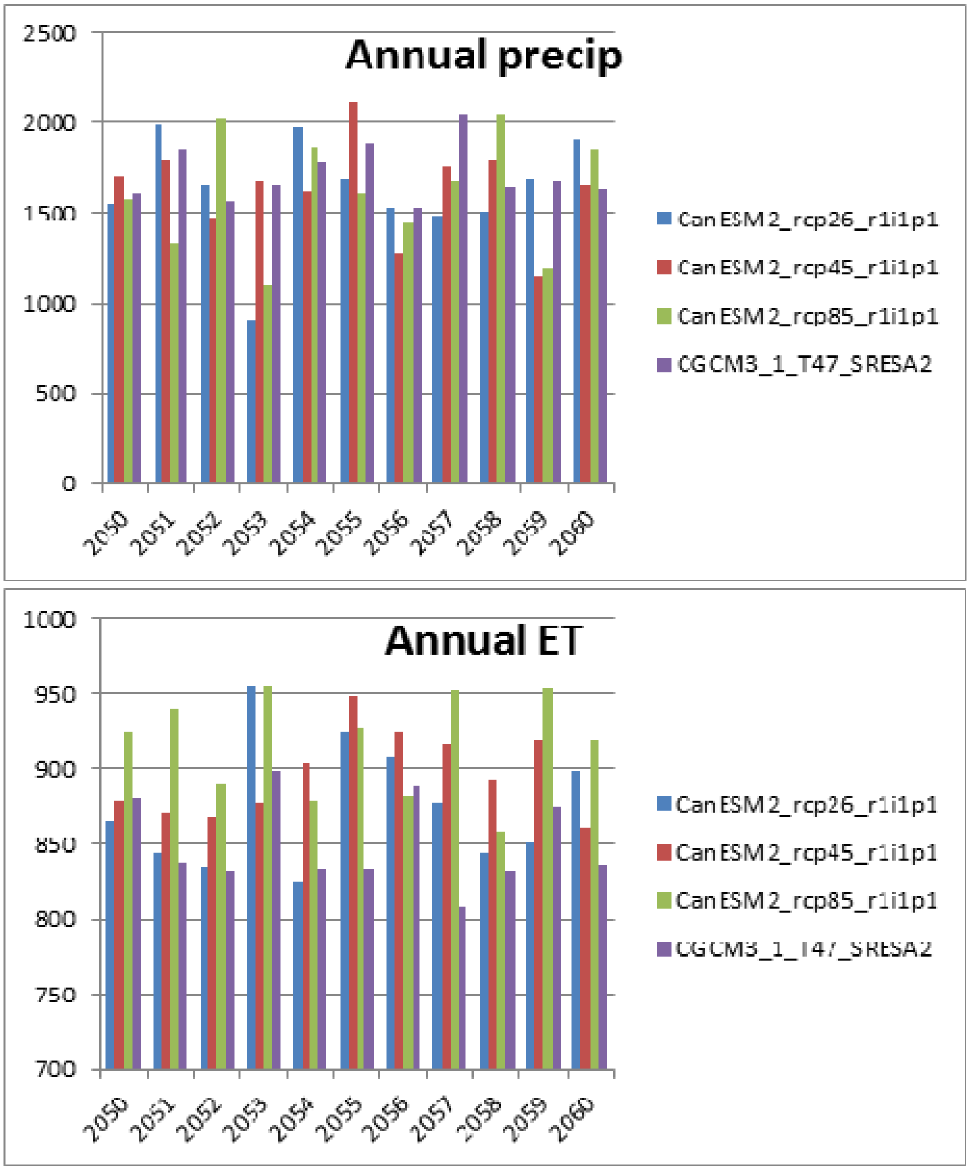

Figure 11 Annual ET and Effective Precipitation in 2050's

Table K provides the results of climate change on irrigation demand for the three years selected using current crops and irrigation systems. Current crops and irrigation systems are used to show the increase due to climate change only, with no other changes taking place.

Figure 12 shows all of the climate change scenario runs for the Okanagan using 12 climate models from 1960 to 2100. This work was compiled by Denise Neilsen at the Agriculture and Agri-Food Canada – Summerland Research Station. There is a lot of scatter in this figure, but it is obvious that there is a trend of increasing water demand.

The three climate change models used in this report are RCP26, RCP45 and RCP85. Running only three climate change models on three selected future years in the Kettle Valley is not sufficient to provide a trend like in Figure 12. What the results do show is that in an extreme climate scenario, using rcp85 in 2059, it is possible to have an annual water demand that is 25% higher than what was experienced in 2003. Averaging the data between the three climate change models shows that if the data for just the year 2053 is examined, the increase in demand is 7.5% higher than 2003. More runs of the climate change models will be required to better estimate a climate change trend for the Kettle Watershed.

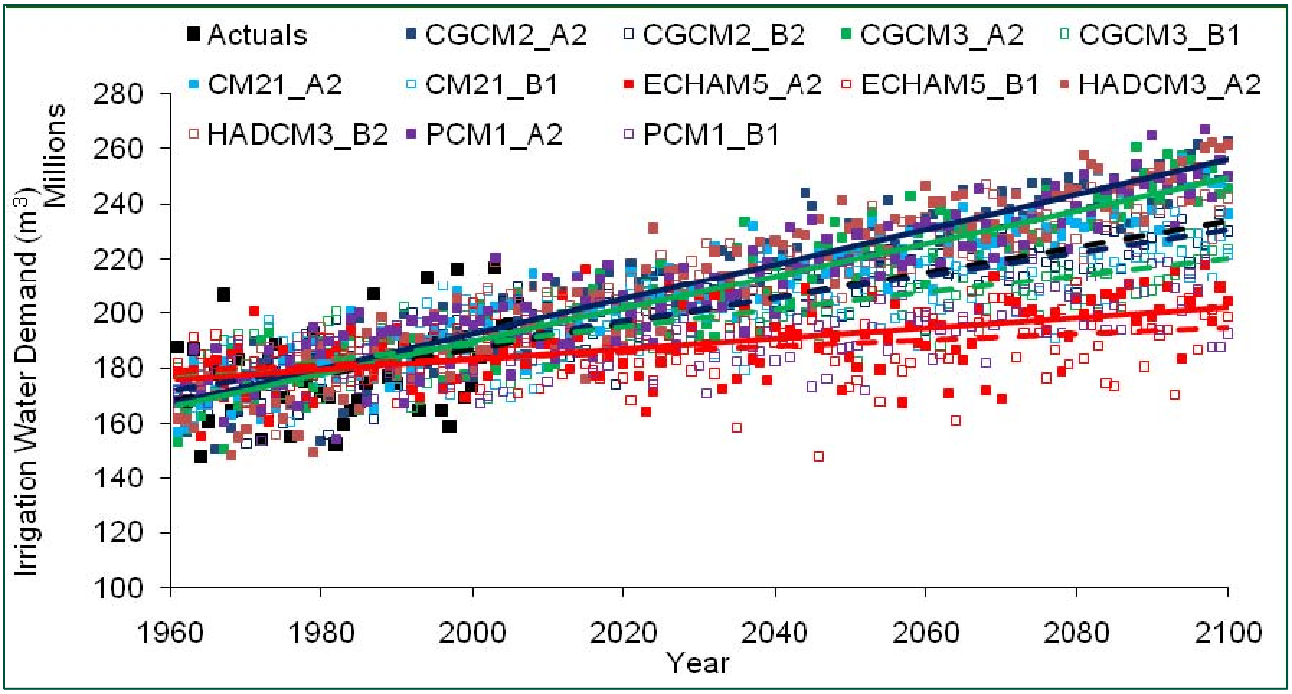

Figure 12 Future Irrigation Demand for All Outdoor Uses in the Okanagan in Response to Observed Climate Data (Actuals) and Future Climate Data Projected from a Range of Global Climate Models

Agricultural Buildout Crop Water Demand Using 2003 Climate Data – Table L

An agricultural buildout scenario was developed that looked at the total potential agricultural lands that could be irrigated in the future. The rules used to establish where potential additional agricultural lands were located in the Kettle Valley are as follows:

- within 1,000 m of water supply (lake)
- within 1,000 m of water supply (water course)
- within 1,000 m of water supply (wetland)
- within 1,000 m of high productivity aquifer
- within 1,000 m of water purveyor
- with Ag Capability class 1-4 only where available
- must be within the ALR
- below 750 m average elevation

For the areas that are determined to be eligible for future buildout, a crop and irrigation system need to be applied. Where a crop already existed in the land use inventory, that crop would remain and an irrigation system assigned. If no crop existed, then a crop and an irrigation system are assigned as per the criteria below.

- **Forage crops**: 50% of buildout area with sprinkler irrigation or low pressure pivot
- **Grass**: 25% of buildout area with sprinkler irrigation or low pressure pivot
- **Pasture**: 20% of buildout area with sprinkler irrigation or low pressure pivot
- **Vegetable**: 5% of buildout area with drip irrigation

For forage or grass irrigated areas equal to or over 10 ha, and if the crop type is not ginseng, golf, nursery, turf park or blank, then the irrigation system type will be changed from sprinkler to low-pressure pivot (if not already using a low-pressure pivot). It is anticipated that current irrigation systems will be replaced by more efficient systems like low-pressure pivots in the future to reduce water demand when water resources are more stretched.

Figure 13 indicates the location of agricultural land that is currently irrigated (dark green) and the land that can be potentially irrigated (red). Based on the scenario provided for the Kettle Watershed, the additional agricultural land that could be irrigated is 3,840 ha, bringing the total irrigated area to 7,829.1 ha. The water demand for a year like 2003 would be 72,375,055 m^3 assuming efficient irrigation systems and good management.

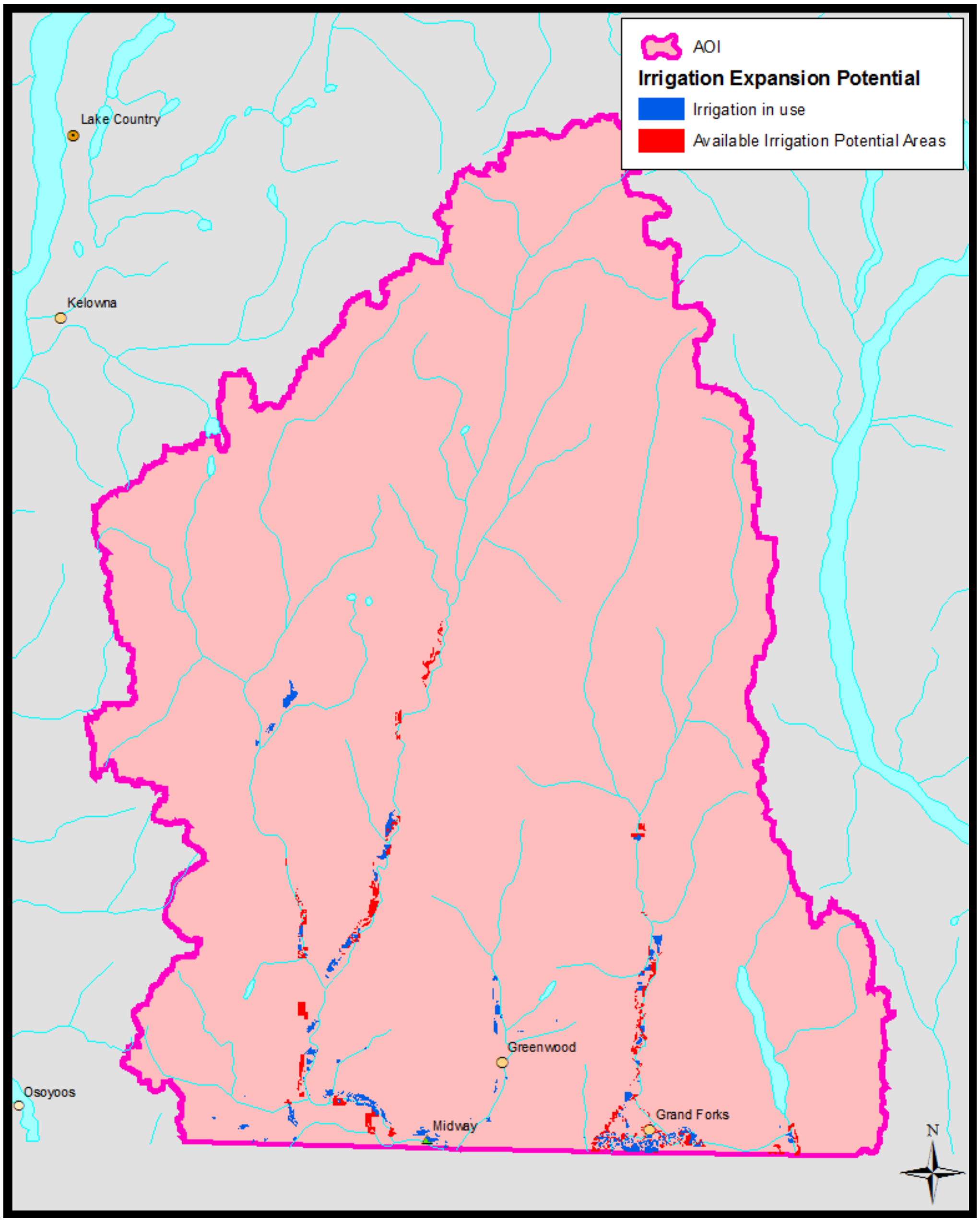

Figure 13 Kettle Valley Irrigation Expansion Potential

Agricultural Buildout Crop Water Demand for 2050 – Table M

The same irrigation expansion and cropping scenario used to generate the values in Table K were used to generate the climate change water demand shown in Table M. Three climate models were used and the results averaged. When climate change is added to the buildout scenario the water demand increases from 72.375 million m^3 using 2003 climate data to 80.264 million m^3 (10% increase) if averaging the three climate change models for the 2053 scenario. Again, more runs are required to develop a good trend with the climate change data. See discussion under Table K.

Irrigation Systems Used for the Buildout Scenario – Table N

Table N provides an account of the irrigation systems used by area for the buildout scenario in the previous two examples. Note that low pressure center pivots will be the most predominant irrigation system followed by sprinkler, as forage and grass will be the most prevalent crops under the scenarios run.

Water Demand by Sub-Basin for the Buildout Scenario – Table O

The results from Table O indicate that the largest potential for the buildout of irrigated agriculture will use surface water supplies when compared to the data generated in Table E. The increased acreage from surface water supplies is 3061 ha while increased irrigated acreage from groundwater is 780 ha. However surface water sources were given priority over groundwater in the model scenario which may not actually be the case in some of the reaches along the Kettle River.

Water Demand by Water Purveyor for the Buildout Scenario – Table P

Table P indicates that 547 ha of the potential groundwater buildout is outside the existing irrigation districts within the Kettle Watershed. This is logical as it is expected that buildout potential within the irrigation district boundaries would be limited.

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Appendix Tables

Appendix Table A 2003 Water Demand by Crop with Average Management												
Water Source	**Surface Water**			**Reclaimed Water**			**Groundwater**			**Total**		
Agriculture Crop Group	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Alfalfa	376.4	4,375,457	1,163	-	-	-	299.0	3,497,014	1,170	675.4	**7,872,471**	1,166
Apple	4.9	41,797	853	-	-	-	6.6	54,260	820	11.5	**96,057**	834
Berry	-	-	-	-	-	-	1.8	13,867	759	1.8	**13,867**	759
Cherry	13.7	124,177	909	-	-	-	1.7	17,804	1,074	15.3	**141,981**	927
Domestic Outdoor	1.1	10,919	979	-	-	-	16.3	162,088	997	17.4	**173,007**	995
Forage	1,768.9	18,273,606	1,033	-	-	-	940.4	9,885,801	1,051	2,709.3	**28,159,406**	1,039
Fruit	-	-	-	-	-	-	4.1	34,706	840	4.1	**34,706**	840
Golf	74.4	841,563	1,131	-	-	-	30.6	294,485	961	105.1	**1,136,048**	1,081
Grape	2.3	10,156	442	-	-	-	5.7	23,560	413	8.0	**33,716**	421
Greenhouse/Nursery	205.5	2,544,426	1,238	-	-	-	153.1	2,153,505	1,253	358.6	**4,697,930**	1,205
Recreational Turf	-	-	-	-	-	-	8.4	86,321	1,029	8.4	**86,321**	1,029
Vegetable	0.4	3,921	907	-	-	-	73.0	656,959	900	73.5	**660,880**	900
TOTALS	2,447.5	26,226,022	1,072	-	-	-	1,540.8	16,880,370	1,096	3,988.3	**43,106,392**	1,081

Appendix Table B 1997 Water Demand by Crop with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Crop Group	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Alfalfa	376.4	2,195,369	583	-	-	-	299.0	1,790,171	599	675.4	**3,985,540**	590
Apple	4.9	20,752	424	-	-	-	6.6	25,216	381	11.5	**45,967**	399
Berry	-	-	-	-	-	-	1.8	5,706	312	1.8	**5,706**	312
Cherry	13.7	55,581	407	-	-	-	1.7	8,302	501	15.3	**63,883**	417
Domestic Outdoor	1.1	6,870	616	-	-	-	16.3	102,476	630	17.4	**109,346**	629
Forage	1,768.9	9,912,690	560	-	-	-	940.4	5,368,928	571	2,709.3	**15,281,618**	564
Fruit	-	-	-	-	-	-	4.1	15,474	374	4.1	**15,474**	374
Golf	74.4	537,376	722	-	-	-	30.6	205,650	671	105.1	**743,025**	707
Grape	2.3	2,908	126	-	-	-	5.7	6,288	110	8.0	**9,195**	115
Greenhouse/Nursery	205.5	1,107,087	539	-	-	-	153.1	1,012,039	880	358.6	**2,119,126**	845
Recreational Turf	-	-	-	-	-	-	8.4	53,669	640	8.4	**53,669**	640
Vegetable	0.4	2,640	611	-	-	-	73.0	423,045	579	73.5	**425,685**	579
TOTALS	2,447.5	**13,841,272**	566	-	**-**	-	1,540.8	**9,016,963**	585	3,988.3	**22,858,236**	573

Appendix Table C 2003 Water Demand by Irrigation System with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Irrigation System	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Gun	77.0	1,132,302	1,470	-	-	-	92.8	1,506,569	1,624	169.8	**2,638,871**	1,554
Handline	290.7	2,988,030	1,028	-	-	-	421.5	4,756,984	1,128	712.2	**7,745,015**	1,087
Landscapesprinkler	-	-	-	-	-	-	1.0	11,007	1,078	1.0	**11,007**	1,078
Microsprinkler	18.1	161,505	892	-	-	-	-	-	-	18.1	**161,505**	892
Overtreedrip	2.3	10,156	442	-	-	-	8.4	41,778	499	10.7	**51,934**	486
Pivot	53.0	505,352	954	-	-	-	-	-	-	53.0	**505,352**	954
SDI	-	-	-	-	-	-	1.4	8,003	577	1.4	**8,003**	577
Sprinkler	285.4	3,077,135	1,078	-	-	-	277.5	2,649,583	955	563.0	**5,726,718**	1,017
Ssovertree	76.5	822,510	1,076	-	-	-	15.2	169,165	1,110	91.7	**991,675**	1,081
Sssprinkler	6.5	73,882	1,129	-	-	-	47.6	526,808	1,106	54.2	**600,690**	1,109
Ssundertree	-	-	-	-	-	-	5.6	54,966	989	5.6	**54,966**	989
Travgun	251.2	3,079,223	1,226	-	-	-	86.7	1,065,283	1,229	337.9	**4,144,506**	1,227
Wheelline	1,386.8	14,375,927	1,037	-	-	-	575.5	6,040,247	1,049	1,962.3	**20,416,173**	1,040
TOTALS	2,447.5	**26,226,022**	1,072	-	-	-	1,540.8	**16,880,370**	1,096	3,988.3	**43,106,392**	1,081

Appendix Table D 2003 Water Demand by Soil Texture with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Soil Texture	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
Loam	40.7	364,743	896	-	-	-	23.0	170,006	740	63.7	**534,749**	840
Loamy Sand	405.8	4,018,793	990	-	-	-	57.7	583,875	1,011	463.5	**4,602,668**	993
Organic	78.2	479,064	613	-	-	-	-	-	-	78.2	**479,064**	613
Sand	1,893.6	21,134,817	1,116	-	-	-	1,354.0	15,302,478	1,130	3,247.6	**36,437,295**	1,122
Sandy Loam	16.1	138,931	865	-	-	-	91.2	720,109	789	107.3	**859,040**	801
Sandy Loam (defaulted)	-	-	-	-	-	-	1.5	20,279	1,348	1.5	**20,279**	1,348
Silt	13.1	89,674	683	-	-	-	13.4	83,623	625	26.5	**173,297**	654
TOTALS	2,447.5	**26,226,022**	1,072	-	-	-	1,540.8	**16,880,370**	1,096	3,988.3	**43,106,392**	1,081

Appendix Table E 2003 Water Demand by Sub-Basin with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Soil Texture	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
Granby River	310.1	3,419,420	1,103	-	-	-	222.6	2,177,623	978	532.6	**5,597,043**	1,051
Kettle River Cascade	291.9	3,277,833	1,123	-	-	-	750.5	8,900,127	1,186	1,042.4	**12,177,960**	1,168
Kettle River Grand Forks	225.9	2,323,961	1,029	-	-	-	66.6	699,160	1,050	292.4	**3,023,121**	1,034
Kettle River Midway	721.9	8,059,291	1,116	-	-	-	413.9	4,157,838	1,004	1,135.8	**12,217,129**	1,076
Kettle River West Kettle	510.5	5,633,118	1,103	-	-	-	57.3	654,205	1,142	567.8	**6,287,322**	1,107
West Kettle River	387.2	3,512,399	907	-	-	-	29.9	291,417	973	417.2	**3,803,816**	912
TOTALS	2,447.5	**26,226,022**	1,072	-	-	-	1,540.8	**16,880,370**	1,096	3,988.3	**43,106,392**	1,081

Appendix Table F   2003 Water Demand by Water Purveyor with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Soil Texture	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
Covert Irrigation District	-	-	-	-	-	-	10.5	115,005	1,096	10.5	**115,005**	1,096
Grand Forks Irrigation District	5.4	68,541	1,275	-	-	-	469.9	5,755,852	1,225	475.3	**5,824,393**	1,225
Sion Improvement District	10.0	139,694	1,402	-	-	-	134.4	1,442,470	1,074	144.3	**1,582,164**	1,096
Private	2,432.2	26,017,787	1,070	-	-	-	926.0	9,567,043	1,081	3,358.2	**35,584,830**	1,094
TOTALS	2,447.5	**26,226,022**	1,072	-	-	-	1,540.8	**16,880,370**	1,096	3,988.3	**43,106,392**	1,081

Appendix Table G   2003 Management Comparison on Irrigation Demand and Percolation Volumes

Water Source	Surface Water				Reclaimed Water				Groundwater				Total				
Agriculture Management	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Deep Percolation (m^3)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Deep Percolation (m^3)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Deep Percolation (m^3)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Deep Percolation (m^3)	Percolation (m^3/ha)
Poor	2,447.5	26,849,738	1097	4,627,506	-	-	-	-	1,540.8	17,383,832	1128	3,488,545	3,988.3	44,233,570	1109	8,116,051	2,035
Avg	2,447.5	26,226,022	1072	4,003,790	-	-	-	-	1,540.8	16,880,370	1096	2,985,083	3,988.3	43,106,392	1081	6,988,873	1,752
Good	2,447.5	25,602,306	1046	3,380,074	-	-	-	-	1,540.8	16,376,908	1063	2,481,622	3,988.3	41,979,214	1053	5,861,695	1,470

Appendix Table H 2003 Percolation Volumes by Irrigation System with Average Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total			
Agriculture Irrigation System	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Deep Percolation (m^3)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Deep Percolation (m^3)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Deep Percolation (m^3)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Deep Percolation (m^3)**	**Percolation (m^3/ha)**
Drip	-	-	-	-	-	-	7.5	49,976	5,241	7.5	**49,976**	**5,241**	699
Gun	77.0	1,132,302	296,651	-	-	-	92.8	1,506,569	400,339	169.8	**2,638,871**	**696,990**	4,105
Handline	290.7	2,988,030	493,851	-	-	-	421.5	4,756,984	826,430	712.2	**7,745,015**	**1,320,281**	1,854
Landscapesprinkler	-	-	-	-	-	-	1.0	11,007	2,356	1.0	**11,007**	**2,356**	2,356
Microsprinkler	18.1	161,505	17,344	-	-	-	-	-	-	18.1	**161,505**	**17,344**	958
Overtreedrip	2.3	10,156	1,027				8.4	41,778	3,341	10.7	**51,934**	**4,368**	408
Pivot	53.0	505,352	43,963				-	-	-	53.0	**505,352**	**43,963**	829
SDI	-	-	-				1.4	8,003	486	1.4	**8,003**	**486**	347
Sprinkler	285.4	3,077,135	513,452				277.5	2,649,583	426,940	563.0	**5,726,718**	**940,392**	1,670
Ssovertree	76.5	822,510	88,370				15.2	169,165	23,937	91.7	**991,675**	**112,307**	1,225
Sssprinkler	6.5	73,882	10,454	-	-	-	47.6	526,808	85,652	54.2	**600,690**	**96,106**	1,773
Ssundertree	-	-	-	-	-	-	5.6	54,966	7,595	5.6	**54,966**	**7,595**	1,356
Travgun	251.2	3,079,223	534,240	-	-	-	86.7	1,065,283	185,590	337.9	**4,144,506**	**719,829**	2,130
Wheelline	1,386.8	14,375,927	2,004,439	-	-	-	575.5	6,040,247	1,017,177	1,962.3	**20,416,173**	**3,021,615**	1,540
TOTALS	2,447.5	**26,226,022**	4,003,790	-	-	-	1,540.8	**16,880,370**	2,985,083	3,988.3	**43,106,392**	**6,988,873**	1,752

Appendix Table I 2003 Crop Water Demand for Improved Irrigation System Efficiency and Good Management												
Water Source	**Surface Water**			**Reclaimed Water**			**Groundwater**			**Total**		
Agriculture Crop Group	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Alfalfa	376.4	3,825,269	1,016	-	-	-	299.0	3,307,737	1,106	675.4	**7,133,007**	1,056
Apple	4.9	29,049	593	-	-	-	6.6	35,254	533	11.5	**64,304**	558
Berry	-	-	-	-	-	-	1.8	7,915	433	1.8	**7,915**	433
Cherry	13.7	87,811	643	-	-	-	1.7	10,705	646	15.3	**98,516**	643
Domestic Outdoor	1.1	10,691	959	-	-	-	16.3	159,014	978	17.4	**169,705**	976
Forage	1,768.9	15,864,989	897	-	-	-	940.4	9,105,904	968	2,709.3	**24,970,893**	922
Fruit	-	-	-	-	-	-	4.1	22,835	552	4.1	**22,835**	552
Golf	74.4	827,164	1,111	-	-	-	30.6	288,761	942	105.1	**1,115,925**	1,062
Grape	2.3	7,241	315	-	-	-	5.7	16,895	296	8.0	**24,136**	301
Greenhouse/Nursery	205.5	2,431,027	1,183	-	-	-	153.1	2,047,889	1,218	358.6	**4,478,916**	1,174
Recreational Turf	-	-	-	-	-	-	8.4	84,643	1,009	8.4	**84,643**	1,009
Vegetable	0.4	2,025	469	-	-	-	73.0	334,460	458	73.5	**336,486**	458
TOTALS	2,447.5	23,085,267	943	-	-	-	1,540.8	15,422,012	1,001	3,988.3	**38,507,279**	966

Appendix Table J 2003 Water Demand by Animal Type

Animal Type	Demand (m^3)
Beef	237,604
Dairy - dry	1,589
Dairy - milking	2,702
Goats	386
Horses	15,129
Poultry - broiler	200
Poultry - laying	106
Sheep	2,527
Swine	796
TOTALS	**261,039**

Appendix Table K Climate Change Water Demand Circa 2050 for High Demand Year with Good Management Using Current Crops and Irrigation Systems

Climate Change	rcp26			rcp45			rcp85			Average		
Year	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
2053	3,988.3	45,700,812	1,146	3,988.3	41,414,351	1,038	3,988.3	52,137,259	1,307	3,988.3	**46,417,474**	1,164
2056	3,988.3	45,688,128	1,146	3,988.3	41,157,055	1,032	3,988.3	35,464,936	889	3,988.3	**40,770,040**	1,022
2059	3,988.3	28,043,413	703	3,988.3	50,651,447	1,270	3,988.3	53,894,498	1,351	3,988.3	**44,196,453**	1,108
Average	3,988.3	39,810,784	998	3,988.3	44,407,618	1,113	3,988.3	47,165,564	1,182	3,988.3	**43,794,655**	1,098

Appendix Table L Buildout Crop Water Demand for 2003 Climate Data with Good Management												
Water Source	**Surface Water**			**Reclaimed Water**			**Groundwater**			**Total**		
Agriculture Crop Group	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Alfalfa	476.3	4,673,506	981	-	-	-	304.5	3,297,801	1,083	780.8	**7,971,307**	1,021
Apple	4.9	29,049	593	-	-	-	6.6	35,254	533	11.5	**64,304**	558
Berry	-	-	-	-	-	-	1.8	7,915	433	1.8	**7,915**	433
Cherry	13.7	87,811	643	-	-	-	1.7	10,705	646	15.3	**98,516**	643
Domestic Outdoor	1.1	10,691	959	-	-	-	16.4	160,903	979	17.6	**171,594**	977
Forage	4,629.8	41,047,770	887	-	-	-	1,685.4	16,393,152	973	6,315.2	**57,440,922**	910
Fruit	-	-	-	-	-	-	4.1	22,835	552	4.1	**22,835**	552
Golf	74.4	827,164	1,111	-	-	-	30.6	288,761	942	105.1	**1,115,925**	1,062
Grape	2.3	7,241	315	-	-	-	5.7	16,895	296	8.0	**24,136**	301
Greenhouse	-	-	-	-	-	-	0.2	5,554	2,801	0.2	**5,554**	2,801
Greenhouse	-	-	-	-	-	-	0.2	5,554	1,100	0.2	**5,554**	1,100
Nursery	205.5	2,431,027	1,183	-	-	-	152.9	2,042,335	1,336	358.4	**4,473,362**	1,248
Greenhouse/Nursery	205.5	2,431,027	1,183	-	-	-	153.1	2,047,889	1,218	358.6	**4,478,916**	1,174
Recreational Turf	-	-	-	-	-	-	8.4	84,643	1,009	8.4	**84,643**	1,009
Vegetable	100.8	428,573	425	-	-	-	101.9	465,471	457	202.7	**894,044**	441
TOTALS	5,508.8	**49,542,832**	899	-	-	-	2,320.2	**22,832,223**	984	7,829.1	**72,375,055**	924

Appendix Table M Buildout Crop Water Demand for Climate Change Data Circa 2050 and Good Management												
Climate Change Model	**rcp26**			**rcp45**			**rcp85**			**Average**		
Year	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
2053	7,829.1	78,908,335	1,008	7,829.1	71,626,483	915	7,829.1	90,258,394	1,153	7,829.1	**80,264,404**	1,025
2056	7,829.1	78,591,483	1,004	7,829.1	71,317,127	911	7,829.1	61,460,819	785	7,829.1	**70,456,476**	900
2059	7,829.1	48,591,758	621	7,829.1	86,800,933	1,109	7,829.1	92,953,219	1,187	7,829.1	**76,115,303**	972
Average	7,829.1	68,697,192	878	7,829.1	76,581,514	978	7,829.1	81,557,477	1,042	7,829.1	**75,612,061**	966

Appendix Table N Buildout Irrigation System Demand for 2003 Climate Data and Good Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Agriculture Irrigation System	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
Drip	121.7	552,674	454	-	-	-	129.3	608,003	470	251.0	**1,160,677**	462
Gun	77.0	1,069,241	1,388	-	-	-	92.8	1,426,969	1,538	169.8	**2,496,210**	1,470
Handline	144.6	1,483,453	1,026	-	-	-	335.2	3,696,900	1,103	479.7	**5,180,353**	1,080
Landscapesprinkler	-	-	-	-	-	-	1.0	10,793	1,057	1.0	**10,793**	1,057
PivotLP	3,144.3	26,438,238	841	-	-	-	711.4	5,917,415	832	3,855.7	**32,355,654**	839
Sprinkler	1,682.7	16,253,795	966	-	-	-	686.4	7,189,187	1,047	2,369.1	**23,442,982**	990
Ssovertree	76.5	804,717	1,052	-	-	-	15.2	163,504	1,073	91.7	**968,221**	1,056
Sssprinkler	6.5	71,242	1,089	-	-	-	48.5	514,607	1,061	55.1	**585,849**	1,064
Ssundertree	-	-	-	-	-	-	1.0	10,166	1,001	1.0	**10,166**	1,001
Travgun	111.8	1,334,737	1,194	-	-	-	61.6	746,600	1,212	173.4	**2,081,337**	1,200
Wheelline	143.8	1,534,734	1,067	-	-	-	237.8	2,548,079	1,072	381.6	**4,082,813**	1,070
TOTALS	5,508.8	**49,542,832**	899	-	-	-	2,320.2	**22,832,223**	984	7,829.1	**72,375,055**	924

Appendix Table O Buildout Demand by Sub-Basin for 2003 Climate Data and Good Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Sub-Basin	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)	Irrigated Area (ha)	Irrigation Demand (m^3)	Avg. Req. (mm)
Granby River	991.4	9,155,630	923	-	-	-	349.5	3,078,202	881	1,340.9	**12,233,832**	912
Kettle River Cascade	649.7	6,851,406	1,055	-	-	-	1,148.7	12,325,751	1,073	1,798.4	**19,177,158**	1,066
Kettle River Grand Forks	226.6	1,977,577	873	-	-	-	71.6	663,654	926	298.2	**2,641,231**	886
Kettle River Midway	1,480.6	13,230,271	894	-	-	-	558.0	4,884,022	875	2,038.6	**18,114,293**	889
Kettle River residual	17.5	184,886	1,057	-	-	-	85.7	839,504	979	103.2	**1,024,390**	992
Kettle River West Kettle	1,525.1	12,977,863	851	-	-	-	74.5	734,439	985	1,599.7	**13,712,302**	857
West Kettle River	616.8	5,152,608	835	-	-	-	31.3	298,190	953	648.1	**5,450,798**	841
TOTALS	5,508.8	**49,542,832**	899	-	-	-	2,320.2	**22,832,223**	984	7,829.1	**72,375,055**	924

Appendix Table P Buildout Demand by Water Purveyor for 2003 Climate Data and Good Management

Water Source	Surface Water			Reclaimed Water			Groundwater			Total		
Water Purveyor	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**	**Irrigated Area (ha)**	**Irrigation Demand (m^3)**	**Avg. Req. (mm)**
Christina Waterworks District	-	8	1,019	-	-	-	-	27	1,040	-	**35**	1,035
Covert Irrigation District	-	-	-	-	-	-	64.6	693,008	1,073	64.6	**693,008**	1,073
Grand Forks Irrigation District	9.6	109,737	1,148	-	-	-	526.2	5,846,232	1,111	535.8	**5,955,969**	1,112
Sion Improvement District	76.6	683,459	892	-	-	-	248.3	2,490,948	1,003	324.9	**3,174,407**	977
Sion Possible Future Service	-	-	-	-	-	-	8.1	83,673	1,039	8.1	**83,673**	1,039
Private	5,422.7	48,749,627	899	-	-	-	1,473.2	13,718,336	1,007	6,895.8	**62,467,963**	994
TOTALS	5,508.8	**49,542,832**	899	-	-	-	2,320.2	**22,832,223**	984	7,829.1	**72,375,055**	924