Appendix I1

OKANAGAN WATER DEMAND MODEL SUMMARY

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This document summarizes the development of the Okanagan Water Demand Model used in the Phase 2 Project.

1.0 INTRODUCTION

The objective of developing the Okanagan Water Demand Model was to provide a scientifically-based tool to estimate water demands by land use throughout the Okanagan Basin, under both current and future conditions.

Development of the Okanagan Water Demand Model was initiated by the Ministry of Agriculture and Lands (MAL) and Agriculture and Agri-Foods Canada (AAFC) following completion of the Phase 1 work program in 2005. With assistance from Environment Canada (EC), MAL and AAFC developed a model that estimated irrigation water demands on the agricultural land base within the Okanagan Basin (both within and outside of the Agricultural Land Reserve).

During Phase 2, this model was refined to incorporate all remaining forms of water use within the Okanagan Basin, including:

- Irrigation of domestic properties (e.g. lawns and gardens),
- Irrigation of municipal land (e.g. parks, boulevards, and schools),
- Irrigation of golf courses, and
- Indoor water use for domestic, industrial, commercial, and institutional purposes.

Using information collected during the water use and management investigations (Appendix C), the Okanagan Water Demand Model was calibrated and further refined so that volumes of water extracted from specific water sources could ultimately be identified. This information was a key input parameter to the Okanagan Water Accounting Model (Appendix J).

2.0 METHODS

This section summarizes the model initially developed to estimate water demands on the agricultural land base (i.e. the Agricultural Water Demand Model), which accounts for the majority of the water used in the Okanagan Basin (Appendix C). This is followed by a description of the refinements made to incorporate all other water uses, and the steps taken to establish the linkage between water demands by users and the volumes extracted from specific sources. The Okanagan Water Demand Model encompasses all of these components.

2.1 MODELING AGRICULTURAL WATER USE

The Agriculture (Irrigation) Water Demand Model (van der Gulik et al., 2010) is based on a GIS database that contains information on crop type, irrigation system type, soil texture and climatic data. This information was collected using a Geographic Information System (GIS) and was ground truthed during a comprehensive field program undertaken by various teams using resources from local government, water purveyors and locals with knowledge of agriculture in the Okanagan Valley.

2.1.1 Cadastre

Cadastre information, which shows the boundaries of land ownership, was provided by the Regional Districts and other local governments in the Basin. A consultant was hired to unify all of the cadastral information into one seamless cover for the entire Basin. This process allows the model to calculate water demand for each parcel and allows the model to report out on sub-basins, local governments, water purveyors or groundwater aquifers by summing the data for those areas. A GIS technician used aerial photographs to conduct an initial review of agricultural crop information by cadastre and divided the cadastre into polygons that separated farmstead and driveways from crops. This data was entered into a database that was used by the field teams to conduct and complete the land use survey.

2.1.2 Land Use Survey

The survey maps and database were created by Agriculture and Agri-food Canada and MAL for the survey crew to enter data about each property. The Okanagan Basin was divided into a number of regions and four survey crews were used to conduct the systematic land use survey. Surveys were done through the summers of 2006 and 2007. The survey crew drove to each property where they checked the database for accuracy using visual observation and the aerial photography as provided on the survey maps. A technician verified the information in the database using a laptop computer and altered the appropriate codes if necessary. Corrections on the maps were made by hand. The map sheets were then sent back to the GIS technician to have the hand drawn lines digitized into the GIS system and have any additional polygons entered into the database.

Figure 2.1 provides an example of a typical map sheet. The Okanagan Basin was divided into 398 map sheets.

Polygons (outlined in blue on Figure 2.1) within each cadastre (outlined in yellow in Figure 2.1) represented the smallest unit for which water use was calculated. Each polygon represented a different land use or irrigation system within a cadastre. A total of 125,000 polygons were generated within the Okanagan Basin. Figure 2.2 provides an enhanced view of a cadastre containing six polygons. Each cadastre has a unique identifier as does each polygon. This allowed 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.

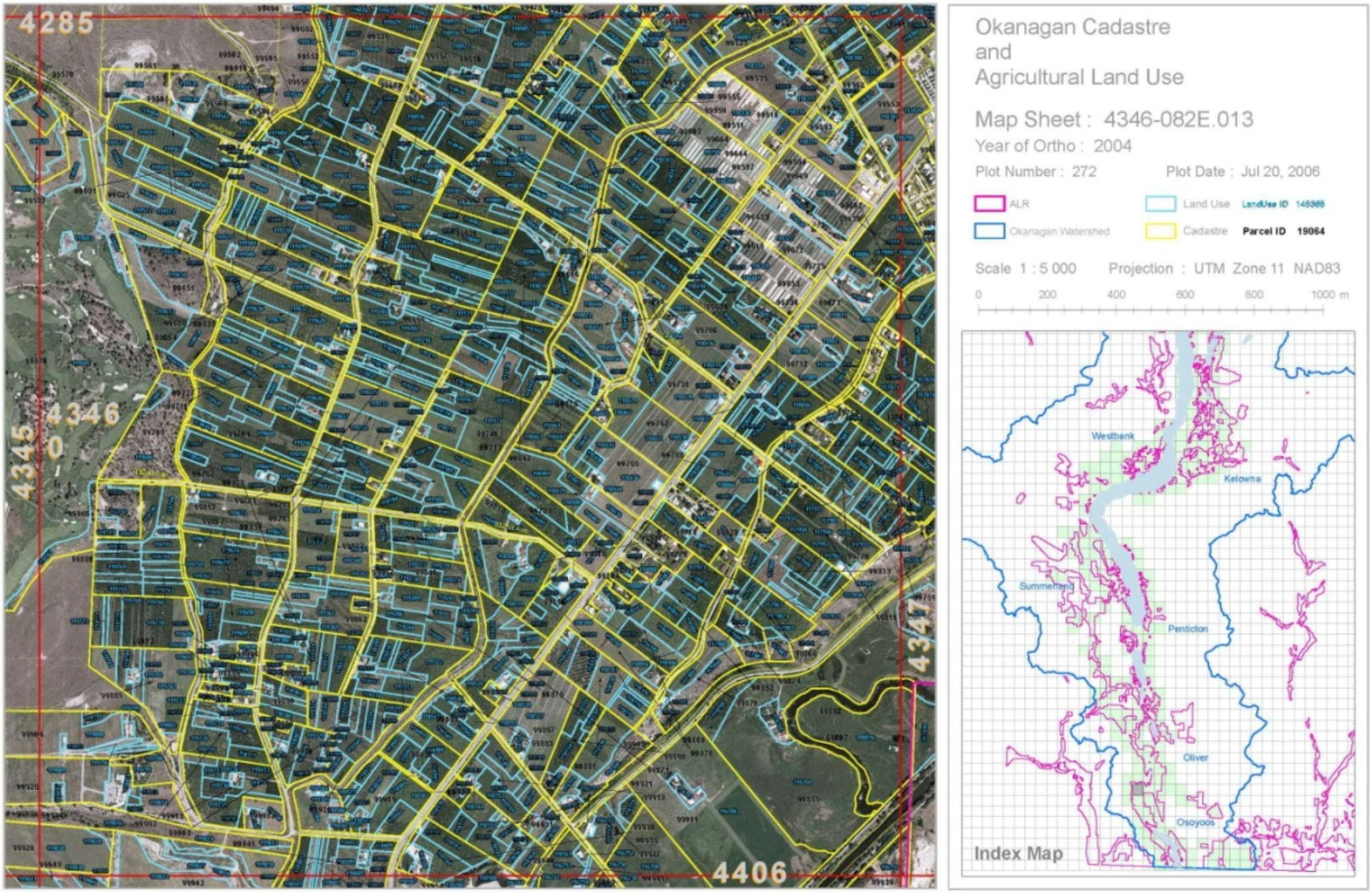

Figure 2.1 Example GIS map sheet.

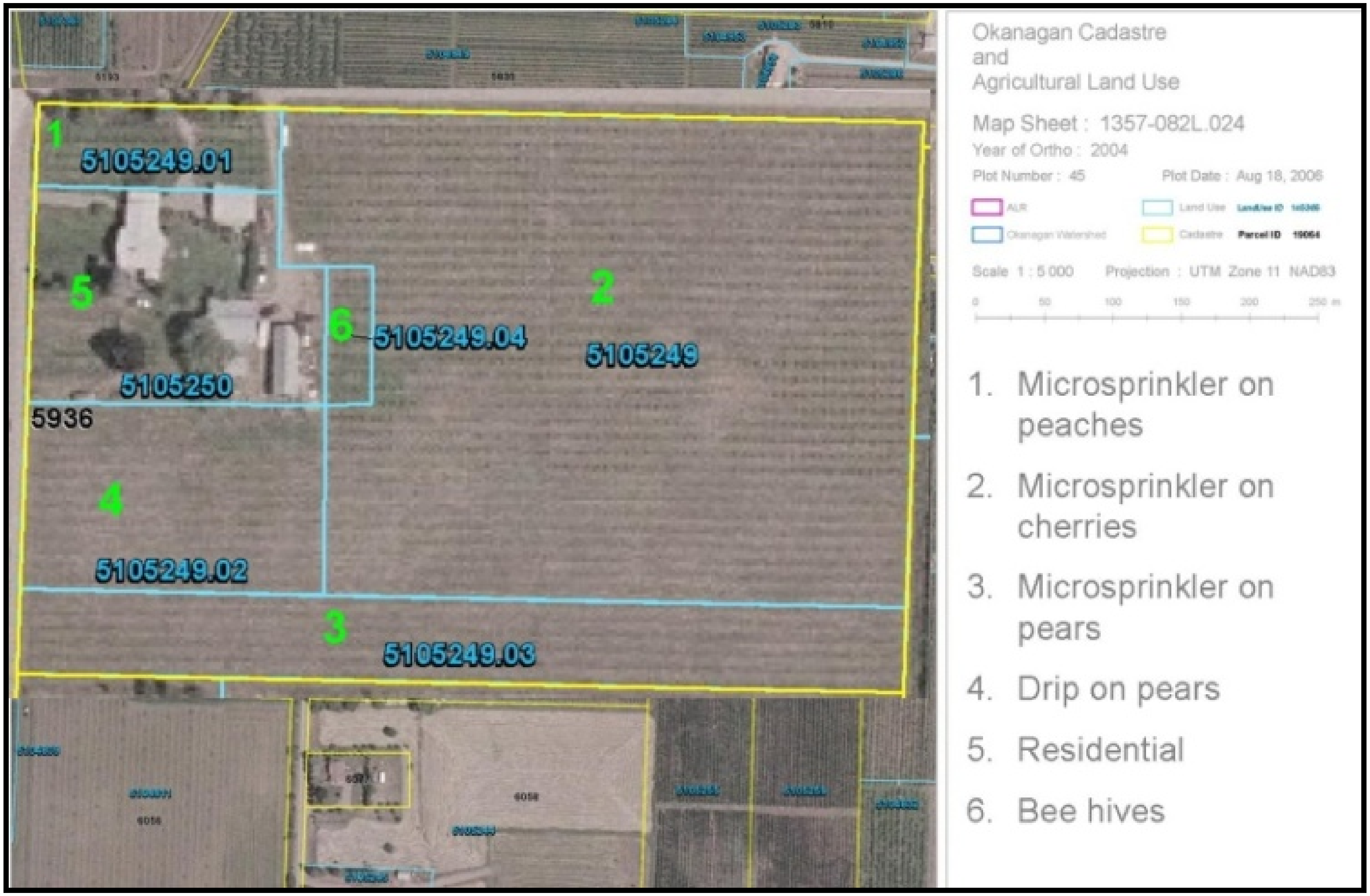

Figure 2.2 Example of designated land uses within each polygon of a specific cadastre.

2.1.3 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 (CAPAMP) database provided detailed (1:20,000 scale) soils surveys that were conducted in the Okanagan-Similkameen areas during the early 1980s. Products developed include soil survey reports, maps, agriculture capability and other related themes. Soils information required for this project included soil texture, available water storage capacity, and 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 2.3 shows how the land use information is divided into additional polygons using the soil boundaries. As discussed in Section 2.1.5, the climate grid does not develop additional polygons. Each cadastre is assigned to a climate grid.

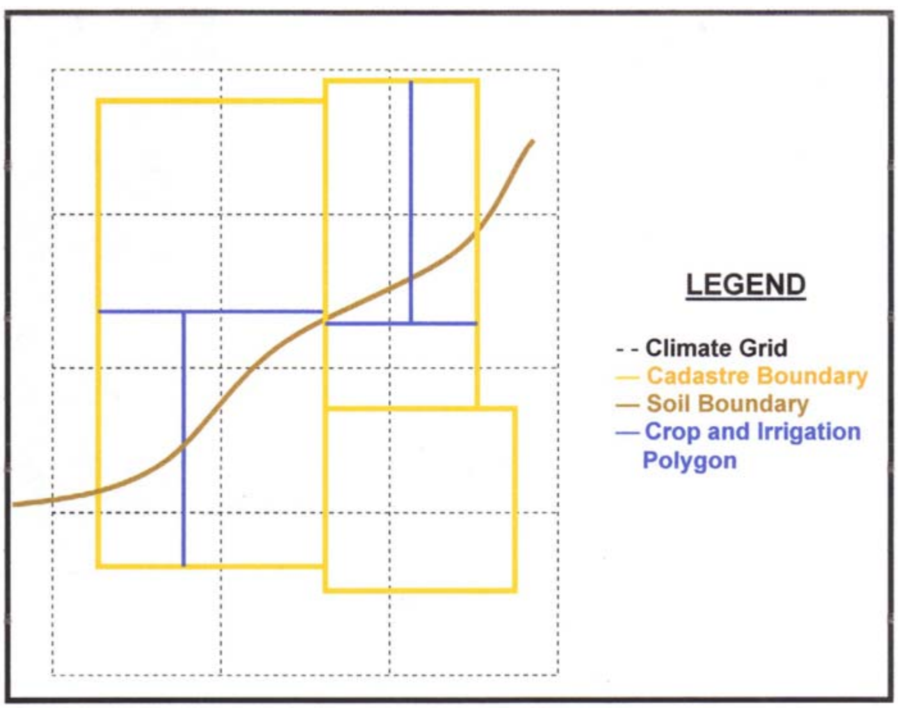

Figure 2.3 GIS model graphic.

2.1.4 Climate Information

Agricultural water demand is calculated using climate, crop, irrigation system, and soil information data. To incorporate the range in climates throughout the Basin, the gridded climate data sets described in Section 5.0 and Appendix N were used. Each grid cell contains daily climate data which permits the Okanagan Water Demand Model to calculate the following parameters:

- daily reference evapotranspiration rate (ETo),
- effective precipitation (EP),
- frost free days,
- growing degree days (base 5 and base 10),
- corn heat units, and
- first frost date.

This information is used to determine the growing season length as well as the beginning and end of the growing season. The model calculates the length of the growing season using the climate and crop information. The beginning and end of the growing season is also calculated and stored by Julian day.

2.1.5 Model Calculations

Irrigation Water Demand (IWD) is calculated for each polygon. The polygons are then summed to determine the IWD for each cadastre. The cadastre water demand values are summed to determine IWD for the basin, sub-basin, water purveyor or local government. The following steps summarize the process used by the model to calculate Irrigation Water Demand.

1. *Annual Soil Moisture Deficit*

The annual Soil Moisture Deficit (SMD) represents the amount of water that has to be added to the soil at the beginning of the growing season in order to start off with a full soil water reservoir. The following steps are required:

- For each crop type, the start of the growing season is determined.
- Start with the initial stored moisture depth on January 1 at the soil's maximum evaporation depth,
- For each day between the beginning of the calendar year and the crop's growing season start, calculate a new stored moisture from:
  - the evapotranspiration (ETo),
  - the effective precipitation (EP), where:

    EP = (actual precipitation - 5 mm) x 0.75
  - daily Climate Moisture Deficit (CMD) = ETo – EP
  - stored Moisture = previous day's stored Moisture – CMD

A negative daily CMD (precipitation in excess of the day's evapotranspiration) adds to the stored moisture level, while a positive climate moisture deficit reduces the amount in the stored moisture reservoir. The stored moisture balance is capped at 0 on the low end and the maximum evaporation depth (maxEvaporation) at the other end on a daily basis; if there is enough precipitation to fill the reservoir beyond the maximum evaporation level, that extra moisture is ignored.

On the day before the start of each crop's growing season, the annual SMD value is finalized as the difference between the stored moisture at that time and the maximum evaporation:

SMD = maxEvaporation – storedMoisture

2. *Crop Evapotranspiration Rate (ETc)*

The reference evapotranspiration rate (ETo) is calculated for each climate grid cell for the years selected by the model using a modified Penman-Montieth equation that uses daily Tmin and Tmax. The evapotranspiration for each crop (ETc) is calculated as the reference evapotranspiration (ETo) multiplied by the crop coefficient Kc:

$$ETc = ETo \times Kc$$

The crop coefficients are based on crop-specific polynomial equations accounting for the plant growth and ground coverage stages. For alfalfa crops there is a set of equations corresponding to different cuttings throughout the growing season.

3. *Climatic Moisture Deficit (CMD)*

The CMD is stored with the Polygon identifier. The CMD is calculated daily but summarized for the length of the growing season (or a specified time period as selected for the case study) that has been determined for the crop that is resident on the polygon.

During the growing season, the daily Climate Moisture Deficit is calculated as the crop evapotranspiration (ETc) less the Effective Precipitation (EP); the effective precipitation is 75% of (actual precipitation minus 5 mm) (anything less than 5 mm of rainfall is considered to evaporate without providing any irrigation benefit):

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

$$CMD = ETc - EP$$

If the precipitation is 5 mm or less, then the effective precipitation (EP) is 0.

During each crop's growing season, a stored moisture reservoir methodology is used that's similar to the calculation of the annual Soil Moisture Deficit. At the beginning of the growing season, the starting point for the stored moisture is the maximum stored moisture depth under the assumption that any soil moisture deficit has been satisfied. Then, on a daily basis, the stored moisture level is used towards satisfying the climate moisture deficit to produce an *adjusted Climate Moisture Deficit* (CMDa):

$$CMDa = CMD - storedMoisture$$

If the storedMoisture level exceeds the day's CMD, then the CMDa = 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 stored moisture setting (maxStoredMoisture).

4. *Crop Water Requirement (CWR)*

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

$$CWR = CMDa * swFactor * stressFactor$$

5. *Irrigation Requirement (IR)*

The irrigation requirement (IR) is stored with the Polygon identifier. The irrigation requirement is determined from the crop water requirement CWR, a factor that adjusts for the area irrigated by a drip system (Drip Irrigation Factor (Df)) and the Irrigation System Efficiency (Ie). The Drip Factor (Df) is only used when a drip irrigation system is used in the polygon. The Df defaults to 1.0 if a drip irrigation system is not used.

The Irrigation Requirement is therefore calculated as:

$$IR = CWR \times (Df / Ie)$$

Additional technical details on the (Agricultural) Irrigation Water Demand Model are provided by Fretwell (2009) in Appendix I2.

2.2 MODELING NON-AGRICULTURAL OUTDOOR WATER USE

As described in Section 2.1, agricultural water demands were calculated on a polygon basis throughout the Basin using information on climate, soil texture, crop type, irrigation method, and other factors that drive water demand requirements. In Phase 2 of the Okanagan Water Supply and Demand Project, the Agricultural Water Demand Model was refined to include non-agricultural outdoor water uses, including:

- Irrigation of residential properties (e.g. domestic outdoor water use for lawns and gardens),
- Irrigation of municipal land (e.g. parks, boulevards, and schools), and
- Irrigation of golf courses.

Since non-agricultural outdoor water demands respond to the same climate drivers as water demand for agriculture, the same methodology was used to estimate non-agricultural water demands as was used for agricultural water demands. However, for all non-agricultural areas, “turf grass” was the assumed crop.

In order to identify the non-agricultural areas under irrigation in the Basin, a combination of image/aerial photo analysis, local government and BC Assessment data was used to identify "green spaces" within residential, industrial, commercial, and institutional properties, which are likely under irrigation.

The process used to identify the irrigated areas within the non-agricultural land base involved analysis of high resolution (0.5 m to 1.0 m) orthophotos collected in 2004 and 2007. Land cover was initially classified into two broad categories, "pervious" and "non-pervious" and then sub-divided further as outlined in Table 2.1 using visual evidence.

Table 2.1 Land cover classification used to identify areas of irrigated non-agricultural land.

Pervious surfaces	**Impervious surfaces**	**Irrigated**
Turf grass (green)		Yes
Turf grass (brown)		No
Trees		Yes
Natural vegetation		No
Bare soil		No
	Pool	No
	Roofs (white, red, grey, tan)	No
	Driveways	No

Using GIS techniques, several steps (e.g. Figure 2.4) were followed in order to identify all non-agricultural areas that are likely to be irrigated. These areas were then added to the database and used in the Okanagan Water Demand Model.

Figure 2.4. Example of a residential area showing the GIS-based land classification. Note: The green shading represents assumed non-agricultural areas under irrigation.

2.3 Modeling Indoor Water Use

Indoor water use by residential, industrial, commercial, and institutional users was incorporated into the Okanagan Water Demand Model by obtaining the BC Assessment Authority Actual Use codes for all land parcels in the Okanagan Basin, and assigning average daily water use values by parcel based on an analysis of water meter records from key municipalities (Miles 2009, Appendix I3). The average daily water use per water use category is presented in Table 2.2 and was entered into the Okanagan Water Demand Model source database, from which it is multiplied by the number of days in a reporting period to arrive at an indoor water use estimate. A detailed description of how the average water use values for each category were derived is presented in Appendix I3.

Table 2.2 Average water use by water use category (based on Miles 2009).

Water Use Category	Average Water Use (m^3/day/ parcel)	Water Use Category	Average Water Use (m^3/day/ parcel)	Water Use Category	Average Water Use (m^3/day/ parcel)
Residential-Vacant	**0.020**	Commercial-Storage High Water User	**1.97**	Hospitality-Food Service or Entertainment Low Water Use - restaurants	**10.2**
Residential Seasonal Dwelling or Residential Outbuilding	**0.029**	Industrial-Low Water Use	**0.395**	Hospitality-Food Service or Entertainment Low Water Use - other	**0.233**
Residential-Manufactured Home Park*	**17.1**	Industrial-Medium Water Use	**4.91**	Hospitality – Food Service or Entertainment Medium Water Use	**3.08**
Residential-Low Density	**0.457**	Industrial-High Water Use	**29.2**	Commercial-Assisted Living Facilities Low Water Use	**1.54**
Residential-Medium Density	**1.60**	Infrastructure-Low Water Use	**0.709**	Commercial-Assisted Living Facilities Medium Water Use	**12.9**
Residential-High Density	**9.28**	Infrastructure-Medium Water Use	**4.98**	Commercial-Assisted Living Facilities High Water Use	**24.9**
Commercial-Retail Low Water User	**0.689**	Infrastructure-High Water Use	**33.5**	Industrial-Food Production Low Water Use	**4.67**
Commercial-Retail Medium Water User	**1.17**	Commercial-Automobile Oriented Low Water Use	**0.846**	Industrial-Food Production High Water Use	**537**
Commercial-Retail High Water User	**3.51**	Commercial-Automobile Oriented Medium Water Use	**5.77**	Institutional-Low Water Users	**0.413**
Commercial-Retail Large Format Low Water User	**10.0**	Commercial-Automobile Oriented High Water Use	**18.0**	Institutional-Medium Water Users	**10.2**
Commercial-Retail Large Format Medium Water User	**28.7**	Hospitality-Accomodation Low Water Use	**1.73**	Institutional-High Water Users	**16.4**
Commercial-Retail Large Format High Water User	**94.9**	Hospitality-Accomodation Medium Water Use	**10.9**	Institutional-Hospitals	**427**
Commercial-Storage Low Water User	**0.309**	Hospitality-Accomodation High Water Use	**38.2**		

2.4 MODELING WATER EXTRACTION FROM STREAMS, LAKES AND GROUNDWATER

To support the Okanagan Basin Water Accounting Model, it was necessary for the Okanagan Water Demand Model to link water demands on the land base to extractions from specific water sources (e.g. streams, lakes and aquifers). In order to define this linkage, two steps were required:

1. A GIS-based coverage of "water use areas" was developed that covers all areas in the Okanagan Basin where water use occurs (Map 3, Attachment 3). Water use areas are defined as areas on the land surface that receive or are likely to receive water from the same source or number of sources. These areas are consistent with water systems operated by the main water suppliers in the Basin.
2. The specific source(s) of water supplying each of the delineated water use areas was determined. In many cases, a single source was associated with an area, but in cases where water is blended or provided from a combination of sources at different times of the year, multiple sources were identified and the average annual distribution of water obtained from each of the sources was estimated based on the information available.

The "water use area" GIS coverage along with identified water sources were incorporated into the Okanagan Water Demand Model. Therefore, in addition to estimating water demands in the Okanagan Basin, the model provides estimates of water extraction from each surface source or groundwater source[1].

In order to identify the water use areas, the study team conducted a detailed review of the water supply and demand investigations and all the responses to water supplier questionnaires listed in the Okanagan Water Information Reference Library (Appendix L). Some information gaps were filled by consulting with Bob Hrasko, P.Eng., Senior Water Supply Engineer, who has a wealth of experience and knowledge of the water supply systems in the Okanagan Basin.

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

Other information gaps were filled and missing spatial information (e.g. maps or GIS data) on the boundaries of water systems operated by the main water suppliers were obtained by directly contacting several of the main water suppliers, including:

- Black Mountain Irrigation District,
- City of Penticton,
- District of Summerland,
- Greater Vernon Services,
- District of Lake Country,
- Town of Oliver, and
- Town of Osoyoos.

Within the Okanagan Basin, roughly 100 water suppliers were identified, who distribute water to approximately 200 water use areas defined in this study (Map 3, Attachment 3). These areas represent the vast majority of water use in the Okanagan Basin (Hrasko, B. pers comm. 2009). The remaining water use in the Basin is accounted for by individual water users who may hold water licences to divert water from surface sources and/or operate groundwater well(s). To account for these other users, 72 water use areas were classified as "other"[2], according to the sub-basins or residual areas they fell within.

In order to determine the distribution of water sources within each of the "other" water use areas, an analysis of well locations and licensed points of diversion (PODs) was performed using GIS. In order to complete the work within a reasonable level of effort, it was necessary to make a simplifying assumption that the volume of water extracted from an individual well or POD was equivalent on an annual basis. As a result of this assumption, the number of wells and PODs provides an indication of the distribution of use among the two water sources (surface and groundwater). For the portions of the "other" water use areas that are sourced by groundwater, GIS coverages of well and

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[2] In the Okanagan Water Demand Model, the term "excluded" was used to designate areas generally outside of the known water supplier distribution areas. Since the areas may not be entirely consistent, the term "other" was used to avoid confusion.

aquifer locations were subsequently used to identify the distribution of water use by specific aquifer.

In order to incorporate this information into the Okanagan Water Demand Model, the coverage of water use areas was overlaid with the land use/cadastre coverage and each land parcel that uses water was tagged with the water source(s) it is supported by.

3.0 RESULTS

The results of the Okanagan Water Demand Model for the 1996-2006 period are provided in Appendix C and are summarized in Section 6.0 of the Summary Report. Results from running the Okanagan Water Demand Model under future scenarios are summarized in Section 18.0 of the Summary Report.

4.0 REFERENCES

Fretwell, R. 2009. Irrigation Water Demand Model Technical Description, July 7, 2009. Prepared by RHF Systems Ltd for Ministry of Agriculture and Lands and Agriculture and Agri-Food Canada.

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