Blue, Green and Virtual Water: Comparing Irrigation Water Requirements for Different Crops in the Driest Watershed in Canada

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Disclaimer**: At the time of writing this report the "Crop Water Demand Model" developed by Van der Gulik (BCMAL) and Neilsen (AAFC) is a work in progress and is still being fine-tuned and calibrated. This calibration is expected to be completed later this year and as a result some of the detailed numbers might change.**

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1. Introduction

The aims of this research project are to discuss and employ the concepts of blue, green and virtual water, to summarize the role water resources play in global food trade, and to apply these concepts to a case study in Canada. The objectives of the case study are to show how much water is required to produce different food commodities in the Okanagan Basin in British Columbia and identify potential and emerging conflicting demands on the limited and vulnerable water resources of the basin. This watershed is unique since it is one of the few places in the country with favorable soil and climatic conditions to grow a variety of fruit trees and grapes. The Okanagan is also a headwaters region, the only water available for use is the precipitation that falls in the valley. It is also a very desirable place to live and as a result has experienced massive growth and urban land use intensification. Since this is one of the driest watersheds in Canada and since most readily available freshwater resources are being used, questions are being raised about the long term capacity to sustain food production and population growth. This is of particular concern because this watershed is highly vulnerable to increased climatic variability. Agriculture uses about 70% of the freshwater resources of the region thus the potential conflict between urban and agricultural water use is emerging. The results of this study allow a comparison of water demand differences between different crops and potential trade-off that could be made during years of drought. The agricultural water requirement study was done in collaboration with the B.C. Ministry of Agriculture and Lands and Agriculture and Agri-Food Canada, who supplied the GIS database and water balance model, and it is part of the overall water use and water balance study that is scheduled to be completed in late 2009 by the Okanagan Water Board.

1.1. The Blue, Green and Virtual Water Concept

Can we produce enough food to meet the food demand by a growing population that is expected to reach 9 billion by 2050? This question is emerging (Lal et al. 2005) because of concerns about increased climatic variability, the shrinking land base to produce food, the increase in land degradation, and the global shift in diets towards increased meat consumption. Water availability and efficiency of use are key factors that will determine future successes. In a “Comprehensive Assessment of Water Management in Agriculture” (Molden et al., 2007) the authors are cautiously optimistic that the food sufficiency targets can be met, but clearly state that a massive improvement in water management will be required. Since agriculture uses about 70% of all the consumed freshwater resources, and urban and industrial uses for water are increasing, it is evident that water conservation and efficiency of use are prime topics to be addressed.

This brings us to the use of the blue, green and virtual water concept. **Blue water** is the component of the rainfall that moves through the hydrological cycle and ends up in rivers, lakes and groundwater. This is the water that we primarily manage and use. **Green water** in the hydrological cycle, is the rainfall that is intercepted by vegetation and by the soil, and is taken up by plants to create biomass and then evapotranspired back into the atmosphere. This part of the hydrological cycle has not been given much attention and is poorly managed. Since there is almost twice as much water in the green cycle as opposed to the blue cycle (Falkenmark and Rockstrom, 2004, Rockstrom 2005), much can be gained by improving the efficiency of green water management and biomass production.

The concept of **Virtual water** was introduced by Allen in 1997 as an economic tool and an alternative means of measuring the global distribution of water through trade (Allan 1997, Allan 1998). What was unique and captivating about this concept was that it focused not only on the trade of water itself, but on the trade of water imbedded within goods and commodities. The definition of virtual water is the amount of water required to produce a given good or service (Allan, 1998, Wilchens, 2001, and Chapagain and Hoekstra, 2004a). Many authors suggest that a water crisis is imminent in many parts of the world (Rogers et al. 2006). As a result we need to improve water management, and focus on reducing demand and improving the efficiency of water use. Significant savings can be made in water use if the concept of virtual water is incorporated into water allocations. This is a relatively new area of investigation, thus basic research is required to ensure that the results are credible and capable of influencing policy and the governance of the water resource.

To determine the virtual water use we need data on crop water requirements over the growing season, evapotranspiration rates, the annual yield and the amount of water used in processing the crop. This concept has been applied globally by UNESCO (Chapagain and Hoekstra, 2004) to determine water balances for most of the countries in the world. However, conducting virtual water calculations on a country by country basis is only useful for overall comparative purposes and for global trade studies, but it does not address regional and seasonal differences. To conduct a global study on water requirement for crops the UNESCÕ group use average crop water requirement, evapotranspiration and yield data for each country and then determined the overall water needs, including how much is consumed within each country, and how much is exported and imported. To make the “Virtual Water” concept useful to water resource managers and decision makers requires that such calculations be made on a watershed or river basin scale. Conducting annual water balances are only viable in a watershed context because this allows determination of water inputs (rainfall and snow) and outputs (discharge, groundwater losses, and evapotranspiration) and thus forms the basis for water allocations for different uses. In calculating water balances usually no consideration is given to the amount of water that is exported and imported in and out of the watershed in the form of products. This can be a significant component in watersheds where agriculture is the dominant land use activity, and where global trade is significant.

1.2. Agricultural-Urban Conflicts and Water Reallocations

When water resources become scarce then conservation, water sharing, improving efficiency of use and water re-allocation among users will become essential policy tools. Given that 40% of all food is produced from 17% of irrigated agricultural land and given increased climatic variability, the pressure to irrigate more land is increasing. Many people have suggested that irrigation water use efficiency in agriculture can be significantly improved (Postel, 2006). However, this should not only include the water application technology and management, but also the plant efficiency to use water. There are large differences in water demand between different crops and different trees, and this is an important component of green water management that needs to be taken into consideration when developing conservation water strategies. In many countries water for agriculture is subsidized and farmers hold the water rights. The urban pressure in many places is now so great that farmers are willing to sell their water rights to cities because the economic returns for the farmers for food production are lower than what they can obtain by selling water to urban centers. In California farmers sell or allocate their water rights to municipalities either on a permanent basis or during droughts (Gleick, 2005). Arriving at sustainable and equitable water use between urban and agricultural needs will be one of the great challenges facing the world in the next 30 years. This is particularly relevant to the Okanagan Basin because the population growth is stressing the available water for agriculture as well as the agriculture land base itself. Since agriculture uses 70% of the consumed water the sector is a likely target for water trade-offs.

1.3. Water Needs for Food

For most staple crops it takes about 1,000 litres of water to produce 1 kg of grain. Rice requires 2-3 times this amount, while meat production takes 4-30 times more water per kilogram. Figure 1 shows the low and high estimates of water needed to grow one kg of food. As our diet becomes protein (meat) rich, more water is needed to produce that diet. This is illustrated in Figure 2 which shows a comparison of the water requirements for a daily diet in the different parts of the world. It takes about 5,400 L of water to maintain a North American daily diet. The water requirement for maintaining the daily diet in developing countries is about half of the North American requirement, and if the rest of the world strives towards a North American diet we would need twice as much water for food production. It is estimated that about 30% of the current food consumption is in livestock products (Greenland, 2005) and all indicators show that food habits are shifting towards a more meat based diet (Smil, 2000), as countries like China and India move up the development ladder. China is the best example, where meat consumption has increased dramatically since 1999. This is even the case in India where meat consumption has increased in spite of the cultural and religious taboos. These trends are clear indicators that water requirements for food production will increase significantly in the near future.

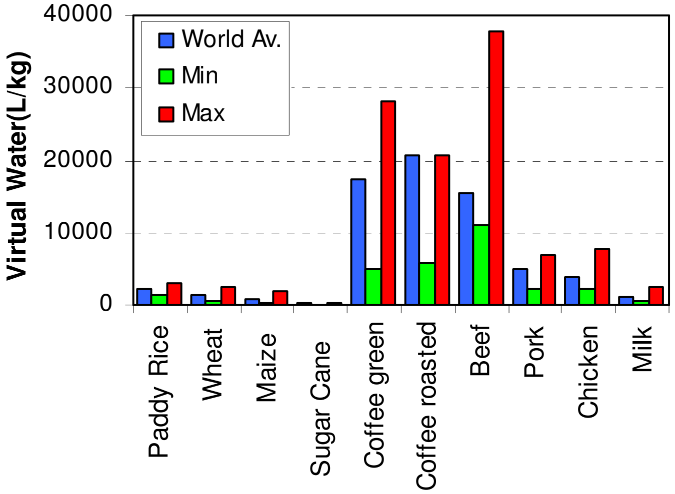


Figure 1. Global estimates of virtual water requirements to produce different crops and meat.

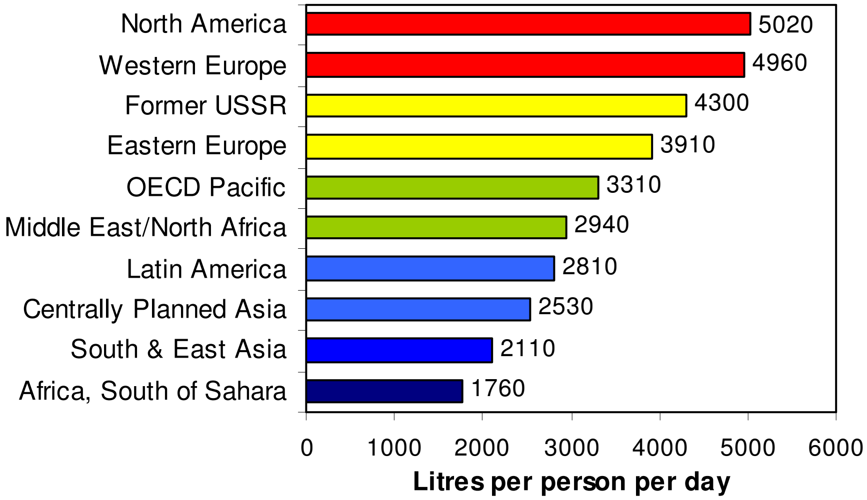


Figure 2. Water requirements to maintain different diets in the world.

2. A Summary of Global Virtual Water for Food and the Water Footprint

Land rich countries with favourable climates and sufficient water resources will have the advantage to produce water intensive crops and food products, while countries with a small arable land base and scarce water resources will likely import food that is water intensive to grow. Matching crop water demand with prevailing climatic conditions has the potential to use water more effectively and the potential to save large amounts of water.

2.1. *Water Requirements for Different Crops in Different Regions*

As part of a UNESCO program Chapagain and Hoekstra (2004) and Hoekstra and Chapagain (2007) published data on virtual water requirements for most crops for all countries in the world. This database can now be used to compare the water requirements and crop water efficiency for different crops in different regions. Depending on the prevailing climatic, soil and management conditions water demand for the same crop differs greatly between regions. As the example in Figure 3 shows water requirement for a range of crops show that New Zealand has the lowest water demand requirement per ton of crop for maize, potato, and grapes. Canada has slightly less water requirements than the USA for maize, potato, apples and grapes but the USA has the lowest water requirements for wheat.

These results show that matching crops to appropriate prevailing climatic conditions can result in substantial gains in water requirement. What this suggests is that some countries can produce crops in a much more water efficient manner than others. When that crop is exported, the water used to produce that crop can not be used for other purposes within that country, the country effectively loses water to export. In a water scarce country it might therefore be of advantage not to grow water intensive crops and instead import these crops in order to save the scarce water resources for domestic or other strategically important activities. This is actually happening in many dry parts of the world and an overall summary of the actual virtual water exports and imports can readily be calculated for each country.

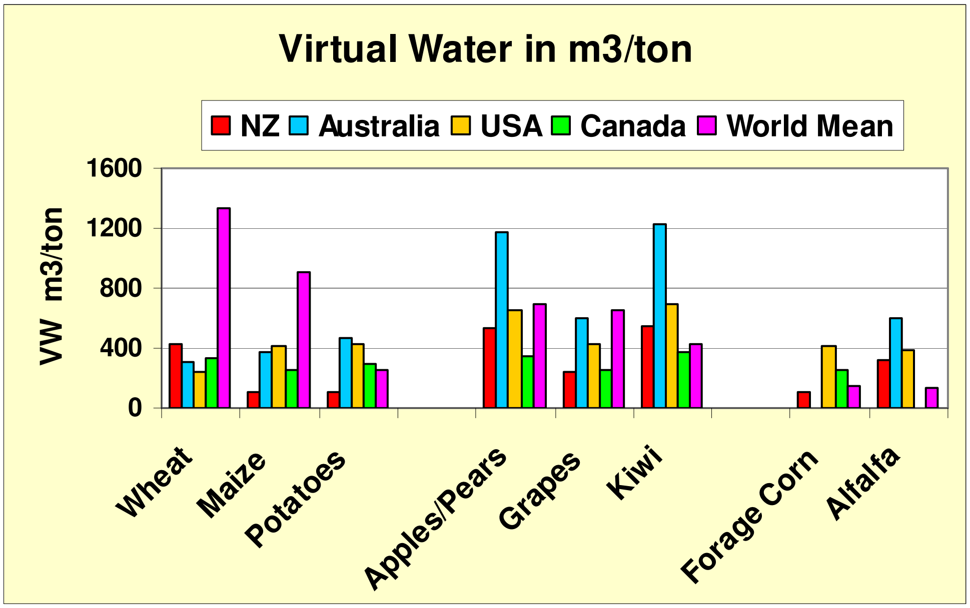


Figure 3. Differences in virtual water requirements for crops in different countries.

2.2. ***Virtual Water Export and Import for Selective Countries*.**

Chapagain & Hoegstra (2005) and Hoekstra and Chapagain (2007) determined that in terms of food trade the USA, Australia, and Canada are the greatest virtual water exporting countries, while Japan, the Netherlands, S-Korea and Indonesia are some of the greatest virtual water importers.

The net virtual water requirements to produce crops and meat can be calculated from the climatic conditions and the production data (either per hectare or per ton of crop). In addition the amount of the food exported and imported needs to be known. The difference between the amount of exported and imported water is the net virtual water trade and the data for some of the greatest trading countries is provided in Figure 4. As stated earlier, Australia, the USA, Canada, Brazil and Argentina are the largest virtual water exporters, while Japan, the Netherlands and Germany are among the largest virtual water importers. Australia exports a large portion of virtual water in meat, while a significant portion of the imported water in Japan is from meat production.

Another way of showing water requirements is to determine the water footprint for internal and external water use on a per capita basis. As shown in Figure 5 the USA, Canada, Brazil, and Argentina have very large virtual water footprints for internal food production and consumption but import relatively small amounts of virtual water in imported food. In contrast Jordan, the Netherlands, Japan and the UK import more than twice the virtual water in food as is produced and consumed internally.

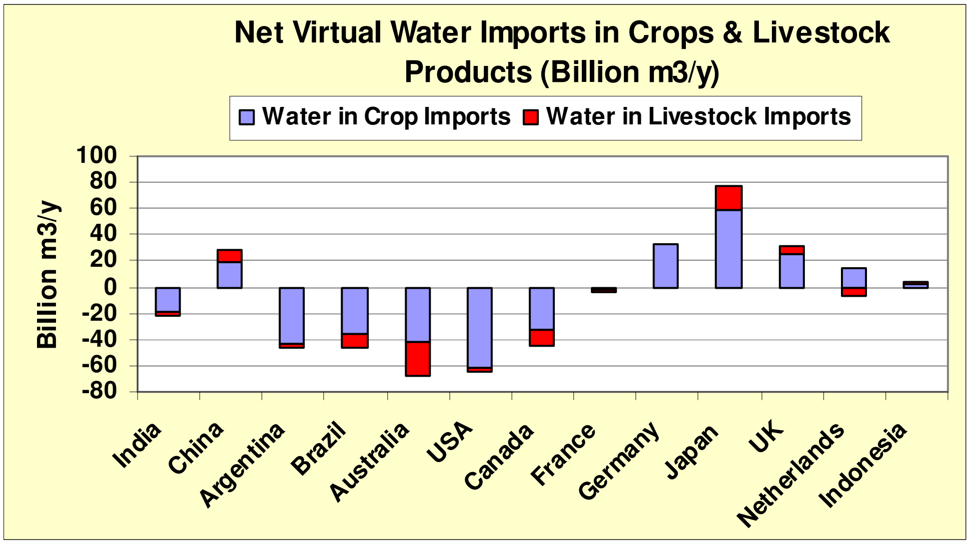


Figure 4. Net virtual water exporters and importers for crops and meat.

Figure 6 shows the proportional difference between the percent of virtual water used for internal food produce vs. external water in food imported. India, China, Brazil and Argentina use most of the water for internal food production, while the Netherlands, Jordan, Japan and the UK receive the largest percentage of virtual water from imported food. This also shows that Australia and Canada have a small reliance on water through imported food. China and India are relatively self-sufficient and Japan, the Netherlands and Jordan are most heavily reliant on virtual water imports.

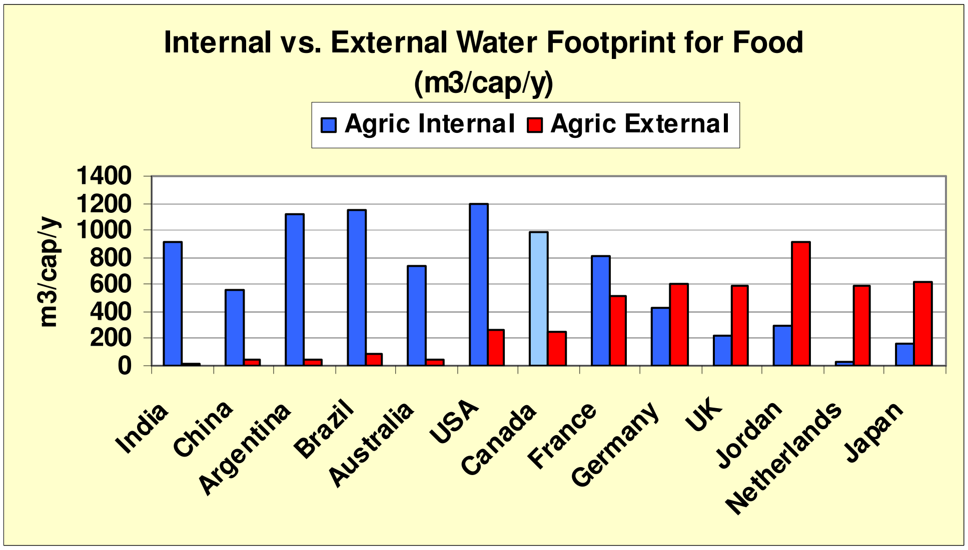


Figure 5. Internal and external water footprint based on agricultural production.

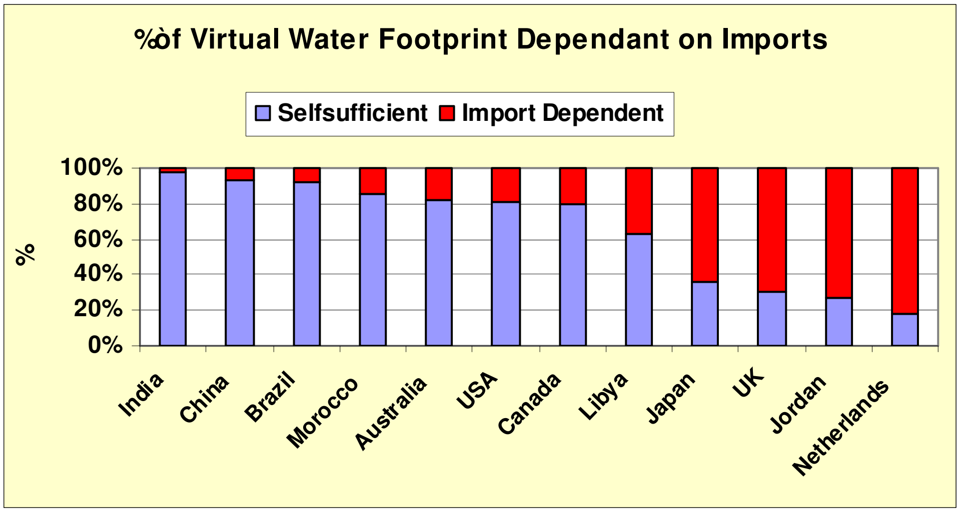


Figure 6. Differences in percent virtual water used internally vs. water imported in food.

2.3. Available water vs. dependency on imported virtual water

If the proportion of imported virtual water is calculated with what is available in annually renewable water in each country and expressed as a percentage, it is evident from Figure 7 that virtual water imported into Brazil, Canada, India and Australia is less than 1% of what is available within the country. The proportion for China and the USA is between 2-4%, and for the Netherlands, Japan, Morocco and the UK is between 17 and 34%. In countries like Jordan and Libya the virtual water in imported food exceeds that available water by 520-665%.

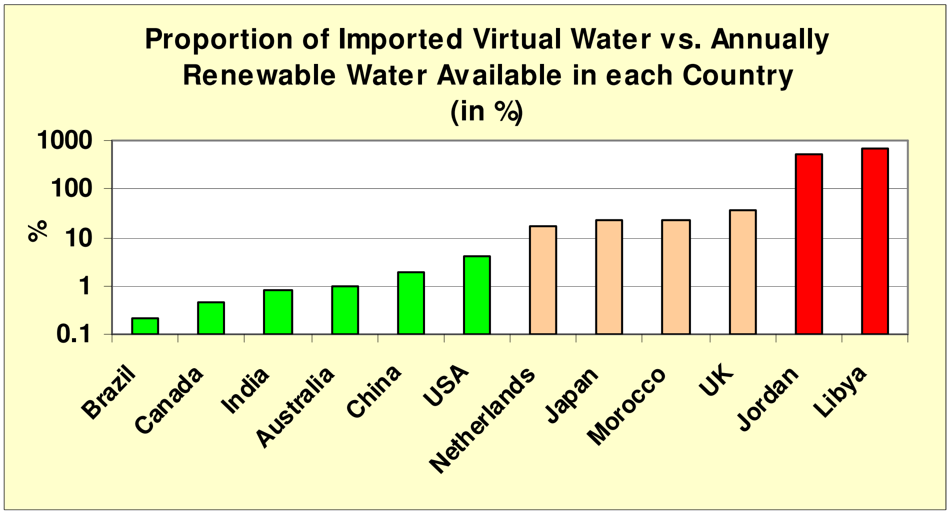


Figure 7. Percent virtual water imported vs. annually renewable water in each country.

2.4. Implications for Canada

What these results show is that in countries where water resources are, or are becoming scarce, reliance on virtual water imports is a very sound strategy. However, this will put pressure on countries like Canada which appear to have considerable capacity to produce additional food for export. The question that then needs to be addressed is where within the country are the climatic conditions and available water resources sufficient to expand food production and which are the most water efficient crops to grow in different climatic regions.

Intensive livestock production is very water consumptive and is primarily taking place in the semi-arid part of the country. Given the concerns about increased climatic variability, expansion of this activity might need to take place in a more favourable climatic area. What is needed is a better documentation on water requirements for different crops in different climatic regimes. This would allow decision makers to select and promote the most water efficient crops that have the best economic viability. Similarly, crops like tree fruits, which can only be grown in unique climatic conditions, should be given preference over more water intensive crops in those areas where water resources are under pressure. Matching crop water efficiency with prevailing soil and climatic conditions is an effective way to conserve water in agriculture and this should be the agricultural strategy for future expansion of agriculture in Canada.

The following case study illustrates these concepts. The Okanagan Basin was chosen because it represents a key basin in a semi-arid area in Canada. It is a region that is highly sensitive to climate change and the basin is under considerable water stress due to intensive agriculture and rapid urban and recreational expansion (Cohen et al., 2006; Merritt et al., 2006; Neilsen et al.,2006; Langsdale et al., 2008).

3. Introduction to the Okanagan Basin

The Okanagan Basin is located in central British Columbia. See the location map provided in Figure 8.

The Okanagan basin is at a crossroad. Almost all surface water resources (blue water) are fully allocated and questions are being raised on how to provide sufficient water to meet the continuously increasing demands from urban, recreational and agricultural activities. A summary of some of the key development pressures are provided in Table 5 which indicates that population growth has been very rapid and most of the development activities are water consumptive. The area also receives a large number of tourists, who come to enjoy water based recreation, wine tasting and skiing.

Agriculture alone uses about 70% of the available freshwater resources. Water purveyors deliver about 76% of the water to agriculture which is predominantly from surface water sources. A total of 24% of the agricultural use comes from individual farms accessing their own water supplies, of which about 16% comes from groundwater and, 8% from water licences held on streams and lakes. The dominant land use of the lower elevation areas of the basin is agriculture and urban development and the upper elevations are covered by forests. The annual rainfall in the lower elevations of the basin, where agriculture is dominant, ranges between 300 and 500 mm per year. Most of the rainfall occurs during the winter months, while July, August and September are the driest months. Because of its unique climate and topographic setting, the basin is known to produce some of the best tree fruit (peaches, pears, cherries, plums, apricots) and grapes in Canada, which now supplies 33% of Canadian wine production.

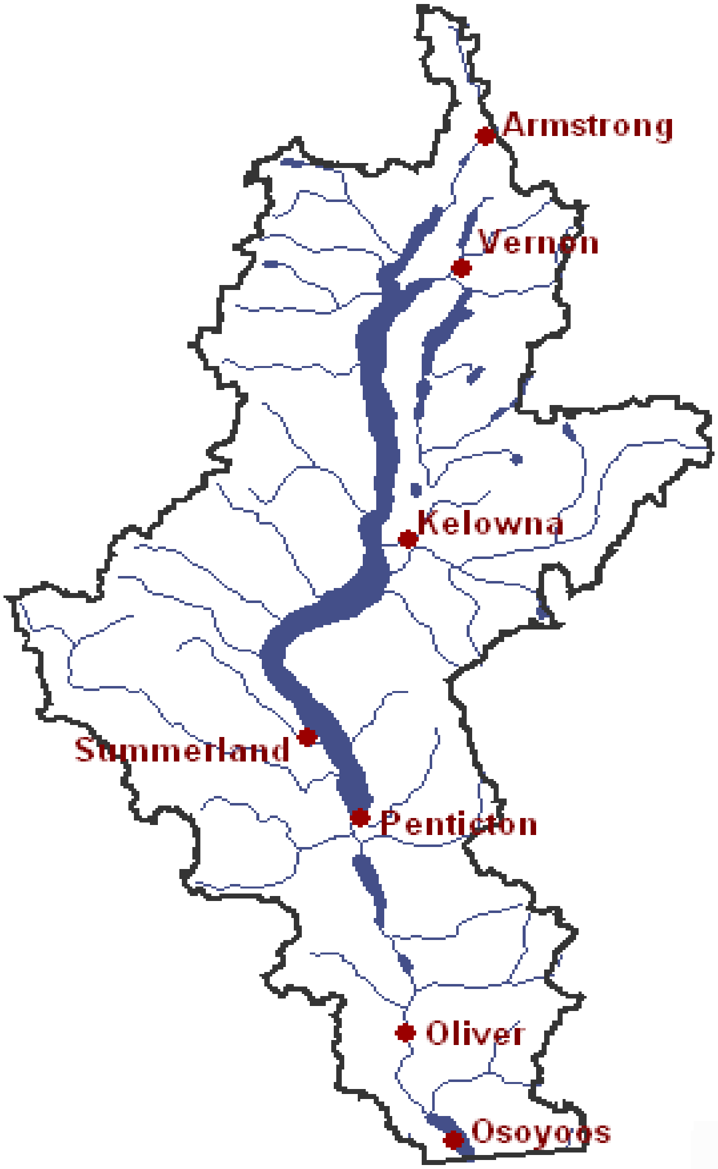


Figure 8. Overview of the Okanagan River Basin in British Columbia.

Table 1. Development pressures in the Okanagan Basin between 1981 and 2006.

Indicators	1981	2006	% Increase
Population	140,000	340,000	41%
Water Storage Reservoirs	88	150	70%
Golf Courses	10	45	350%
Ski Resorts	4	8	100%
Vineyard Areas (ha)	1191	2800	135%
No. Farmers growing Grapes	224	442	97%

3.1. Overview of Agricultural Trends in the Okanagan Basin, 1981-2006

To provide an overview of the agricultural activities in the Okanagan Basin and to show the major trends in agricultural land use activities the data from the Agricultural Census (Statistics Canada 2006) was complied for 1981-2006. The evaluation was done in four parts: 1. Summary of agricultural land use in 2006; 2. Changes in number of farms producing different crops 1981-2006; 3. Changes in areas under different crop production; and 4. Changes in animal numbers 1981-2006.

3.1.1. Summary of agricultural land use in 2006

Because there are relatively large climatic differences between the upper (North) and lower portion (South) of the Okanagan Basin, detailed Agricultural Census Data was used for three census subdivisions as defined by the regional districts of the Okanagan-Similkameen (RDOS), the Central Okanagan (CORD) and the North Okanagan (NORD) (Statistics Canada, 2006). Overall, the basin has 3865 farms covering an area of 189,066 ha of farmland. Of all farms 82% grow crops, 13% of the agricultural land is irrigated and 3% is in tree fruit production. The various areas and number of animals for the 3 enumeration areas and the total for the basin are provided in Table 2. A large portion of the agricultural land base is used for grazing and does not have a supply of water for irrigation purposes.

The major agricultural activities are in the RDOS and NORD but the activities are quite different. Fruit and grape production is concentrated mainly in the southern part of the basin, while livestock operations (dairy, beef, pigs, chickens) are primarily produced in the NORD region. About 10% of the agricultural area is irrigated in the RDOS and NORD area but 26% of the agricultural land is irrigated in CORD.

The same trend is reflected in farm numbers with the majority of fruit and grape farms being located in the RDOS and CORD and the majority of livestock farms in the NORD. The only exception is the number of horses which is largest in RDOS. This implies that more recreational or hobby farm activities are taking place in the southern part of the basin.

3.1.2. Changes in number of farms producing different crops, 1981-2006

Over the past 25 years there has generally been a decline in the number of farms with the greatest drop in the number of farmers growing different types of fruit. The exception is the number of grape farmers which has increased dramatically. The numbers of cattle, pig and chicken farms have also declined significantly but farms with livestock related to recreational activities (horses, sheep and goats) have increased (Table 3). This confirms the regional and global trends towards larger, more intensive farm production. Overall, the average farm area has increased from 38 ha in 1981 to 49 ha/farm in 2006. The area for fruit trees per farm has not increased very much the number of trees/ha has. The number of livestock/farm has increased significantly for cattle (54 animals/farm in 1981 vs. 89 animals/farm in 2006) and chickens (296 chickens/farm in 1981 vs. 2028 chickens /farm in 2006).

Table 2. Summary of the area under different use and animal numbers for the three enumeration area and for the total agricultural area in the Okanagan.

Indicators	RDOS	CORD	NORD	TOTAL-OK
Total area farmed (ha)	85241	27201	76624	189066
Number of Farms (#)	1621	1017	1227	3865
Area Irrigated (ha)	8049	7048	6701	21798
Area in Vegetable (ha)	234	110	195	539
Area in Fruit,(ha)	3452	2374	363	6189
Area in Apples (ha)	1920	1806	322	4048
Area in Cherries (sweet & sour)	699	357	21	1077
Area in Peaches & Apricots (ha)	590	90	10	690
Areas in Grapes (ha)	1714	1110	14	2838
Number of Cattle & Calves	24825	4416	39633	68874
Number of Dairy Cows	16	0	5538	5554
Number of Beef Cattle	8487	1574	10766	20827
Number of Pigs	202	204	3726	4132
Number of Hens & Chickens	12741	82946	1108689	1204376
Number of Horses	1107	246	404	
Number of Cattle Farms	206	87	479	772
Number of Dairy Farms	8	0	68	76
Number of Chicken Farms	190	158	246	594
Number of Fruit & Berry	1171	609	163	1943
Number of Grape Farms	324	101	17	442
Number of Apple Farms	618	367	95	1080

Table 3. Trends in number of farms with different activities between 1981 and 2006.

No. of farms by type	**Number of farms in 2006**	**% Change in farm Numbers 1981-2006**
Total farm numbers	3865	- 9%
No. growing crops	1889	-18%
No. growing apples	1080	- 46%
No. growing pears, cherries, plumbs, peaches, apricots	295 to 568	- 51% to - 68%
No. of grape farmers	1889	+ 97%
No. raising cattle	772	- 40%
No. raising pigs	92	- 66%
No. raising sheep	154	+ 15%
No. raising goats	126	+ 21%
No. raising horses	944	+ 10%
No. raising chickens	594	- 51%

3.1.3. Changes in areas under different crop production 1981-2006

As shown in Figure 9, the total agricultural area in the Okanagan Basin has increased but the area under crop production has remained the same. The reason for the increase in agricultural area is likely the expansion of natural pasture and expansion of grapes into areas not previously used for agriculture.

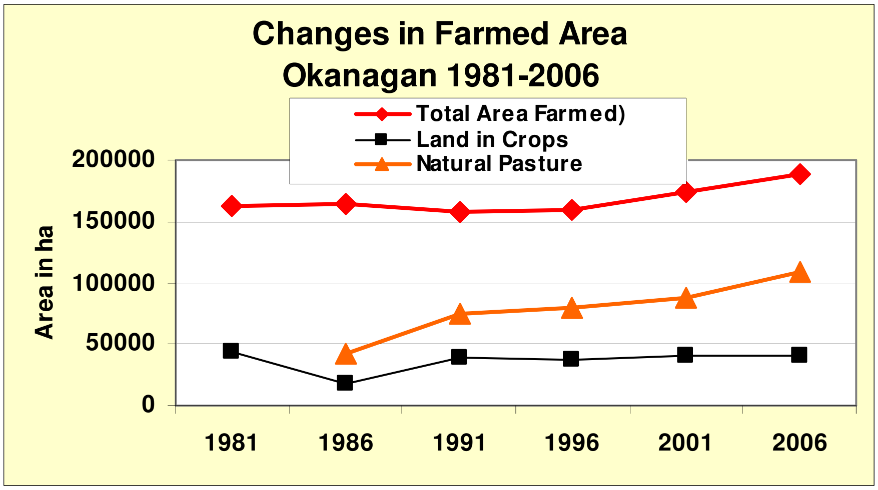


Figure 9. Changes in area farmed, crop production area & natural pasture 1981-2006.

Most of the field crop production has remained the same (Figure 10), but there has been a small decline in the areas used for staple crop production.

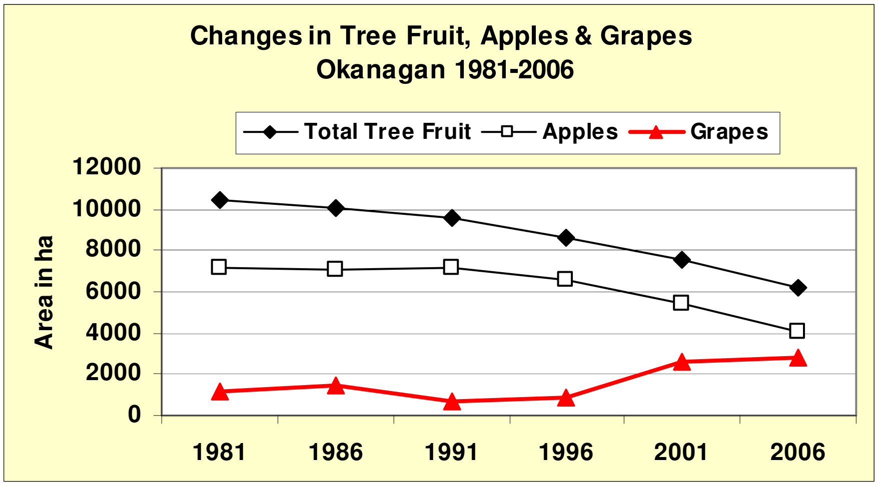


Figure 10. Changes in field crop areas 1981-2006.

Fruit production is showing some interesting trends. As shown in Figure 11, the total area under fruit production has declined significantly between 1981 and 2006, including the area under apple production. In contrast, the area under grape production has increased significantly since 1996.

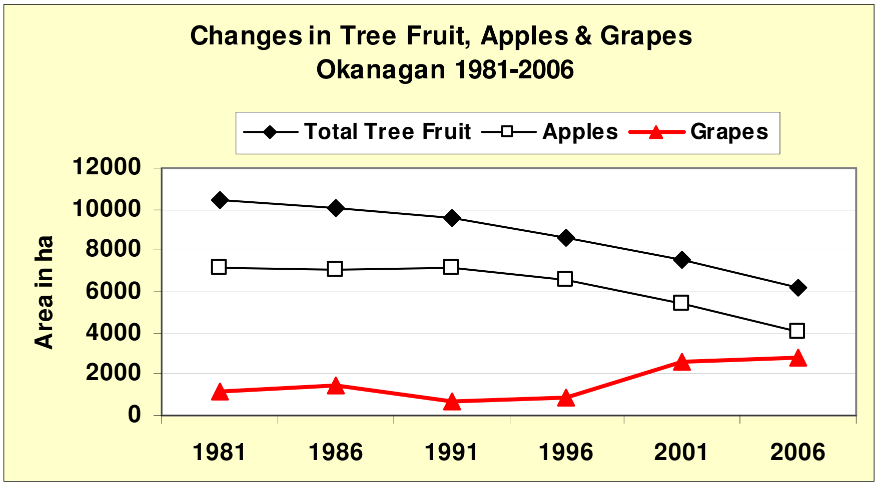


Figure 11. Changes in total fruit, apple and grape area between 1981 and 2006.

The change in the other fruits produced in the basin between 1981 and 2006 is provided in Figure 12. This shows that all areas under different fruit production have declined except for sweet cherries which declined until 1996 but have since increased significantly.

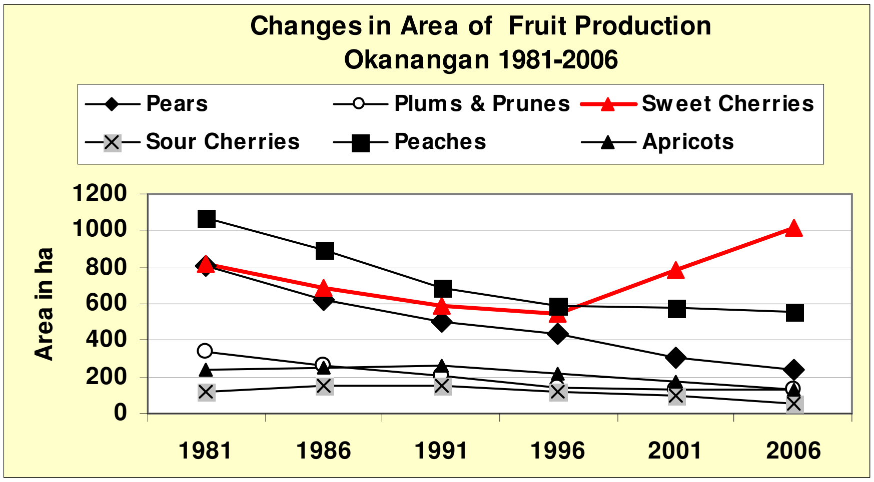


Figure 12. Changes in areas of different fruit production between 1981 and 2006.

3.1.4. Changes in animal numbers, 1981-2006

The most dramatic decline has been in the number of pigs produced in the basin (Figure 5). The decline from 40,000 pigs in 1981 to less that 5000 in 2006 suggests that only small operations remain. In contrast the number of sheep, horses, goats and llamas has increased reflecting the expansion of hobby farm activities (Figure 13).

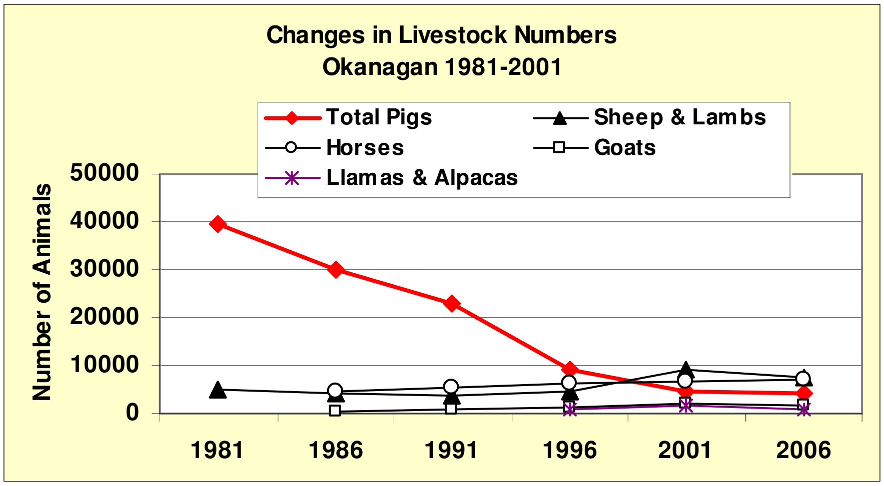


Figure 13. Changes in the number of pigs, sheep, goats, horses and llamas 1981- 2006.

The trend in cattle numbers is provided in Figure 14, which shows some fluctuations but only a slight increase in total cattle and beef cattle, while dairy cow numbers have remained the same.

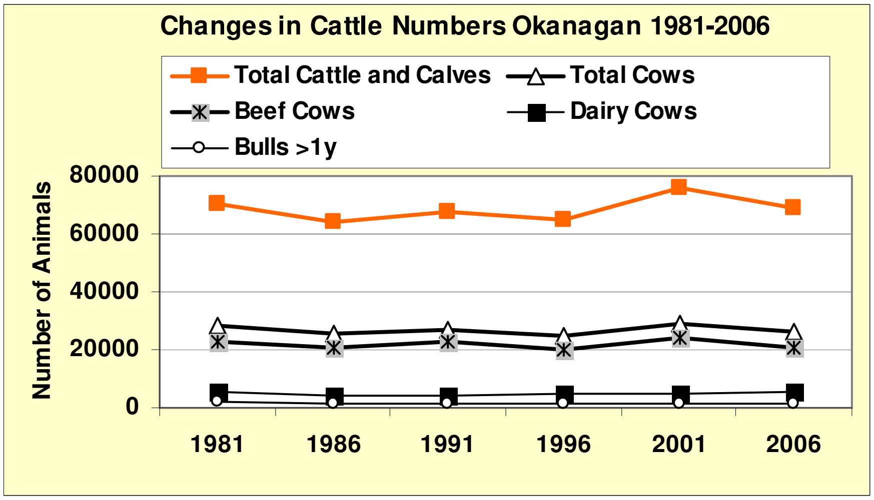


Figure 14. Changes in Cattle numbers between 1981 and 2006.

The most dramatic changes have occurred in the number of chickens produced in the basin (Figure 15). There was a steady increase from less than 400,000 in 1981 to 1.2 million in 2001, with no change over the past 5 years. This stabilization is likely the result of the impact of the avian flu which occurred in the Lower Fraser Valley in early 2000 and it remains to be seen if the increase will continue in the near future.

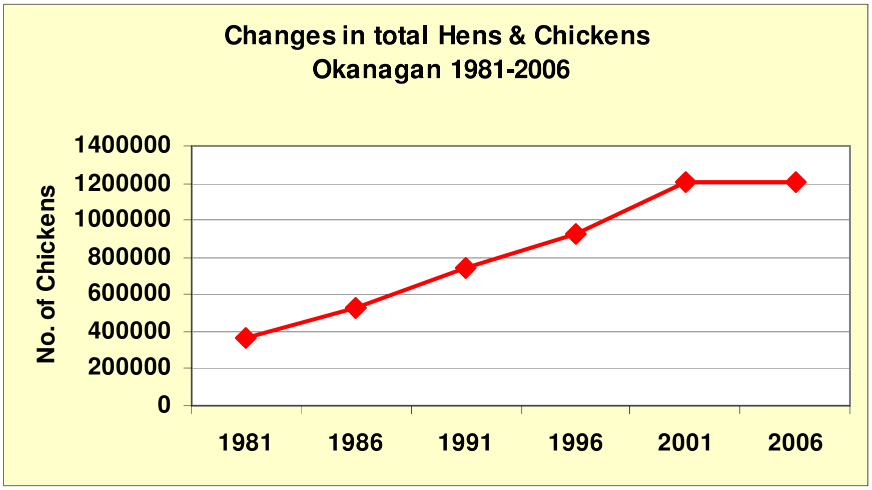


Figure 15. Changes in the number of Chickens 1981-2006.

3.2. Production Trends in the Okanagan Basin

Since no detailed production data is available for the Okanagan, the BC annual production data for fruit and berries was used as a base to calculate average yields and farm gate values per ton of production. This can be justified since most of the fruit production in B.C. occurs in the Okanagan. A proportional comparison is provided in

Table 4 and is based on the annual fruit and vegetable production report (Statistics Canada, 2008).

Table 4. Proportional Okanagan share of B.C. fruit & berries production area.

Comparison of Fruit & Berry Production in B.C and the Okanagan			
Crops	**Okanagan Area**	**British Columbia**	**Okanagan Share**
	Ha	**Ha**	**%**
Apples	4128	4462	92.5%
Pears	250	310	80.7%
Plums and Prunes	139	179	77.5%
Cherries (sweet)	1048	1295	80.9%
Cherries (sour)	61	75	80.6%
Peaches	565	587	96.3%
Apricots	133	138	96.2%
Grapes	2876	3150	91.3%
Strawberries	46	439	10.4%
Raspberries	38	2028	1.9%
Blueberries	33	4767	0.7%
Cranberries	37	1635	2.2%

Note: Based on Agricultural Census data (Stats Canada 2006 and 2008)

The yield trend for B.C. over the past 10 years is provided in Figure 16. The results show that apple yields fluctuated between 19-25 t/ha but are on a decline since 2005. The yield for most other fruit crops have increased except for pears which are recovering from a dramatic decline in the 2001-2003 period.

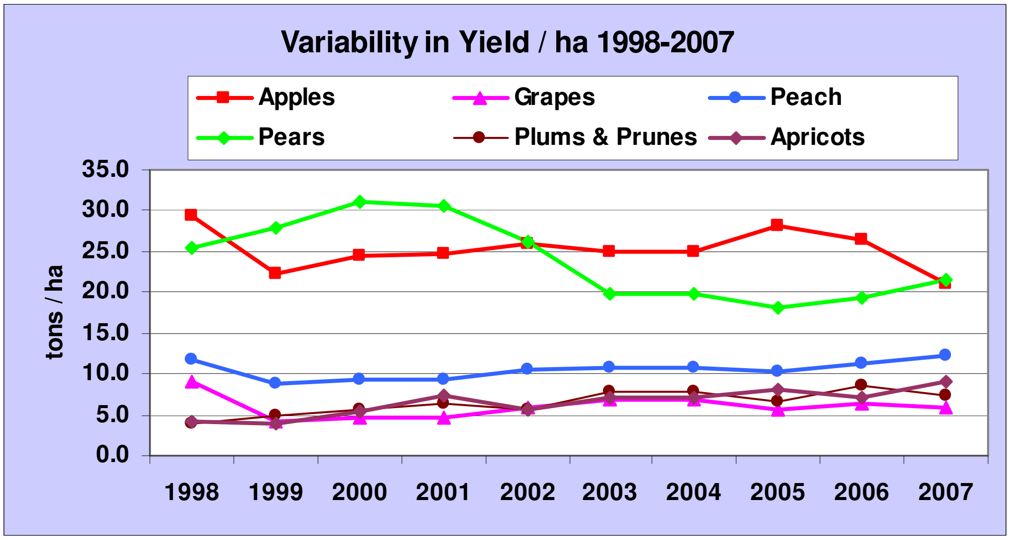


Figure 16. Variability in yield data for fruit production in B.C. in t/ha.

The farm gate value of the production in $/kg is provided in Figure 17, The results show that grapes have the greatest value per kg, followed by apricots and plums, while apples have the lowest value. Apples and grapes make up the greatest overall farm gate value in the Okanagan Basin (Figure 18), while all other fruits make up a much smaller portion of the farm gate dollars. Over the past 4 years the overall farm gate values for apples has increased in spite of large reduction of areas under cultivation (Figure 11). The farm gate values for peaches and plums have not experienced a significant increase.

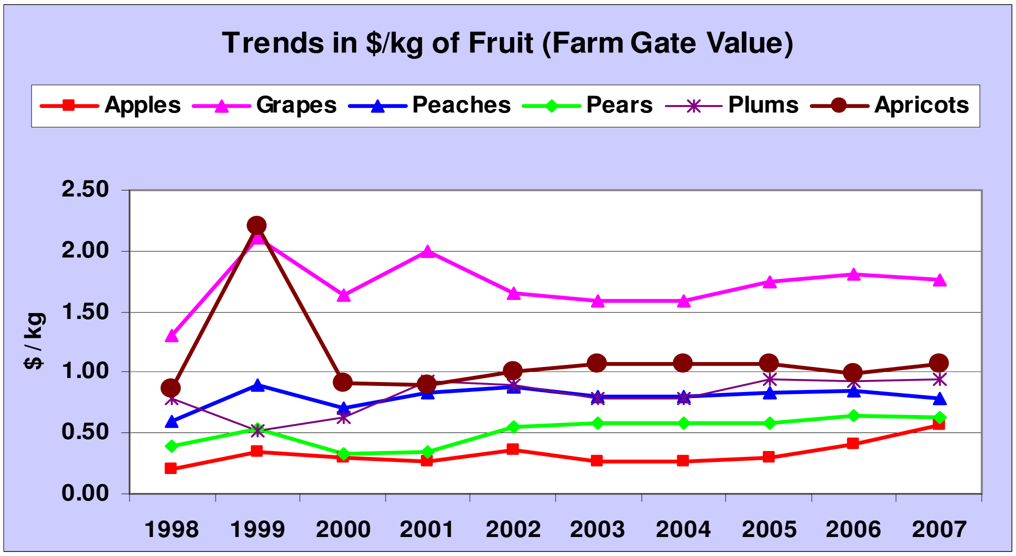


Figure 17. Farm gate value in $/kg.

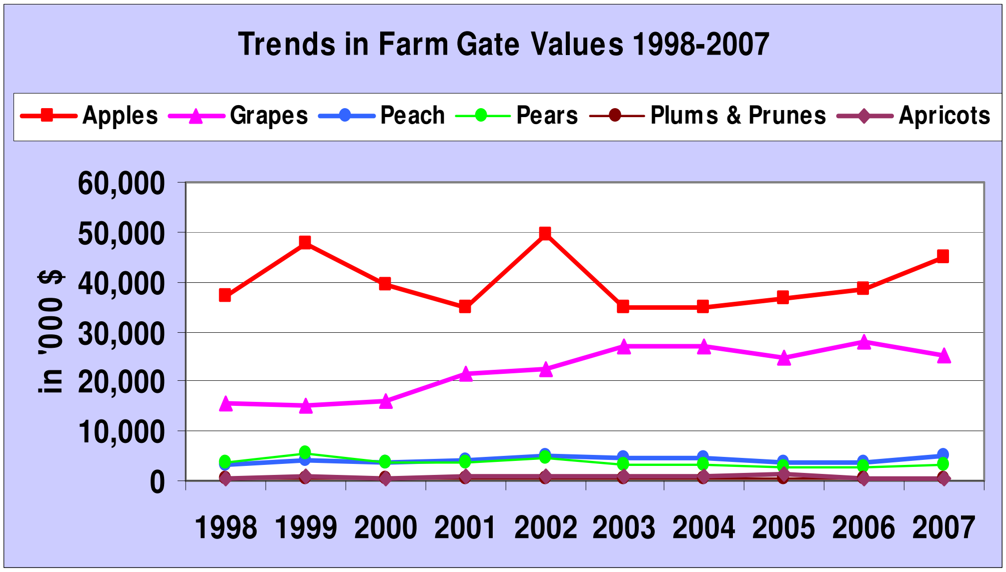


Figure 18. Overall 2006 farm gate value for apples and grapes in the Okanagan Basin.

A detailed land use survey for all agricultural land was produced by the B. C. Ministry of Agriculture and Lands and Agriculture and Agri-Food Canada in 2006 (See Chapter 4 for details). The indicators provided in Table 5 were used for the subsequent evaluation of the blue, green and virtual water use and the derived values for production.

Table 5. Indicators used for subsequent evaluation.

2006		**Farm Gate Values**		
Crops	**Yields in t/ha**	**$/ha**	**$/ton**	**Total: Million $**
Apples	21	9076	424	35.61
Apricots	6	5951	1015	26.93
Grapes	5	9948	1850	3.63
Peaches	11	9332	861	2.26
Pears	18	11551	653	0.67
Plums	8	7383	954	0.63

With the exception of vegetables, little crop production data is regularly collected in B.C. and as a result, it was not possible to provide yield trends for other crops grown in the Okanagan. Average yield data for alfalfa and hay production for 2006 was obtained from producer groups and farms and these ranged from 2.5 t/ha to 4 t/ha. These figures are used to determine the virtual water use for livestock in chapter 7.

3.3. Summary of the Agricultural Trends

The largest agricultural areas are in the southern and northern potion of the basin and there is evidence that natural pasture expansion is responsible for the increase in the overall agricultural area between 1981 and 2006. Only 13% of the agricultural area in the basin is irrigated and there is clear pressure on farmers to become more efficient in the use of water. The fruit production, which is mainly concentrated in the southern portion of the basin, has declined steadily since 1981, except for cherry and grape production, which is expanding. Substantial cattle production occurs in the lower and upper portion of the basin but the population is relatively stable. Pig production has declined dramatically but chicken production has increased significantly in the upper portion of the basin. There is also an increasing trend towards more animals associated with hobby farming (horses, ponies, llamas, goats, sheep).

Farms are generally getting larger and have more animals suggesting intensification particularly for cattle and chicken farmers. However, the area under fruit production/farm has not increased significantly except for grapes.

The majority of the total fruit production in B.C. occurs in the Okanagan and the yields have generally increased. The farm gate values have increased for most fruits over the past 4 years and overall farm gate value in 2006 was $41 million for apples, $25 million for grapes, $3.6 million for peaches, $2.3 million for pears, $ 0.67 million for Plums, and $0.65 million for apricots.

4. The Water Demand Model

The Irrigation Water Demand Model (IWDM) was created by van der Gulik (BCMAL) and Neilsen (AAFC) and is a work in progress. It is a GIS based model that calculates the water use of crops in the Okanagan on a property by property basis and then sums the property values to achieve totals for the entire basin, sub basin, purveyor, local government or aquifer area. The data used to calculate crop water use include cadastre, crop type, soil type, irrigation system used and detailed climate data. The GIS laboratories at the Pacific Agri-Food Research Centre, Summerland and at the B.C. Ministry of Agriculture & Lands, Abbotsford cooperatively developed the spatially referenced layers for this work.

4.1. Cadastre

Initially all of the cadastral information was obtained from local governments in the Okanagan and then unified into one cadastral layer. This allows for the Okanagan to be divided into subcomponents that don't normally follow local government boundaries. Once the Cadastral layer was developed, all of the Agricultural Land Reserve (ALR) area in the Okanagan was sub-divided into 398 map sheets with orthophoto coverage.

The orthophotos served as a basis to digitize polygons on each cadastre that separated the different crop types as identified on the photo. Field surveys were then conducted and each property visited to verify if the polygons were correctly classifies. Corrections that needed to be made were noted on each map by hand and the sent back to the GIS lab for digitizing into the database.

4.2. Irrigation System Type

The field surveys also identified all of the irrigation system types that were being used on each polygon within the cadastres. If more than one irrigation system was used in a polygon, the polygon would be divided into two so that each could be identified separately. This information was noted on the map by hand and corrected digitally in the GIS lab. The field survey also identified polygons that had an irrigation system but were currently not being used.

4.3. Soil Type

Soil data was obtained from data that was already in digital form and added to the GIS database. Where a soil boundary divided a polygon two separate polygons were created. The field survey exercise and the soil data resulted in 105,000 agriculture polygons in the Okanagan depicting crop type, irrigation system and soil type.

4.4. Climate Data

Climate data was incorporated into the model by developing a 500m x 500m climate grid over the entire basin. Climate station data from 1961 until 2006 was available for a number of stations in the valley. A downscaling method was used to populate each grid cell with Tmin, Tmax and precipitation data for each day from 1961 until 2006. In addition 6 global climate models also populated each climate cell with daily data from 2007 until 2100.

The cadastres are each assigned a climate grid cell based on the majority of the area that falls within the grid cell. The climate data are used to develop a reference Evapotranspiration Factor (ET_0) for each climate cell for each day.

4.5. Crop Information

The attributes that are provided for each crop are the rooting depth, availability coefficient, drip factor and a crop coefficient. The drip factor is an adjustment factor that reduces water use for crops that are irrigated with a drip system. Depending on the type of crop a different factor is applied. The crop coefficient factor adjusts the ET_0 for each crop for each climate cell daily based on a crop coefficient curve.

4.6. Irrigation Water Demand Calculation

The model calculates crop water demand by determining the crop grown in a polygon, taking the ET_0 determined for each cell for each day in the growing season, applying the daily crop coefficient, applying the irrigation efficiency and drip factor, calculating percolation based on soil type and crop rooting depth and calculating the water demand for the polygon for that day.

Polygons are added to total the water demand for each cadastre daily. The days are summed to determine an annual demand for each cadastre. The annual demand for each cadastre is summed to determine overall water demand for a region, sub basin or the entire basin.

5. Crop Irrigation Water Requirements

5.1. Comparison of Land Use Survey Data

A detailed land use inventory of all the agricultural land in the Okanagan Basin was conducted by the B.C. Ministry of Agriculture and Lands and Agriculture and Agri-Food Canada (BCMAL, 2006). All irrigated fields were mapped using a combined orthophoto – field survey approach and all information was incorporated into a GIS database. The database consists of some 105,000 individual polygons for which each type of crop and type of irrigation was recorded. The soil texture class for each field was obtained from the matched soil survey information.

A comparison was made between the data provided by the 2006 Agricultural Census and the BCMAL/AAFC field based survey and the results as shown in Table 51 were remarkably close for those crops that could readily be compared. Some of the forage acreages could not be compared because the Census used different classification categories. However for the fruit acreages it is evident that we can have confidence in using the numbers generated by the BCMAL/AAFC survey for the irrigation calculations.

Table 6. Comparison of crop area between the Agricultural Census and the BCMAL/AAFC survey for 2006.

Total Area in the Okanagan Basin	**Agricultural Census 2006**	**BCMAL Survey 2006**
Vegetables	539 ha	531 ha
Fruit Trees	6189 ha	6290 ha
Apples	4048 ha	4283 ha
Pears	244 ha	236 ha
Plums	130 ha	71 ha

Cherries (sweet & sour)	1077 ha	1121 ha
Peaches	561 ha	447 ha
Apricots	129 ha	90 ha
Grapes	2838 ha	2734 ha

5.2. Overview of Irrigation Water Requirements for the Okanagan Basin

The data provided in this report provides preliminary information that has been calculated using the Irrigation Water Demand Model. The BC Ministry of Agriculture and Lands and Agriculture and Agri-Food Canada are still in the process of fine tuning the database, calibrating the model and determining final results. These results should be taken as estimates for this report. BCMAL and AAFC will be releasing a report in 2009 that will provide official results that will be slightly different than those shown here.

Using the BCMAL model the average irrigation water requirements (blue water) in 2006 for the different crops grown in the basin ranged between 370 and 970 mm. The total irrigation water requirements for all agricultural crops were estimated to be 132.2 million m^3/year on an irrigated area of 20,034 ha.

Figure 19 shows the area in hectares, total irrigation water requirements in m^3/y, and the water requirements on a m^3/ha/year basis for 10 different crop categories. The results reveal that forage crops and apples, which make up the largest acreages, require most of the irrigation water in the basin. However, on a per hectare basis, golf courses, turf production and nurseries are the highest irrigation water users. In contrast grapes have the lowest irrigation water requirements on a per ha basis. As shown in Figure 20, 45% of all irrigation water requirements are for forage and 32% are for tree fruit production.

Golf courses, turf and apricots are the next most water consumptive categories. Grapes, cereals and forage crops are the least water demanding crops. This information allows decision makers to compare water efficiencies between different crops.

A detailed evaluation of the water requirements for individual crops, crop groups, nurseries, turf and golf courses is given in Figure 22.

Irrigation water requirements within the tree fruit group vary up to 90%, with apples and sour cherries requiring the least and nectarine and apricots requiring the most water. Forage and vegetables are among the largest water users in the other groups. Some crops may have a higher proportion of more efficient irrigation systems which can also account for a variation in crop water demand.

We now have a new tool for water management decision making in periods of drought. The average irrigation water requirements for all crops are 6100 m^3/ha/y in the Okanagan in 2006. Figure 23 shows the deviation from the mean in m^3/ha/y for all crops and those in green are crops that have low irrigation water requirements, while those in red have high water requirements. Without considering economics and yields it could be argued that from a water requirement point of view growing grapes, pears, cherries and apples would be more efficient for water conservation than nectarines, apricots, peaches and plums. However, golf and turf are by far the most water consumptive activities and curtailing these activities during drought might be an effective water conserving strategy.

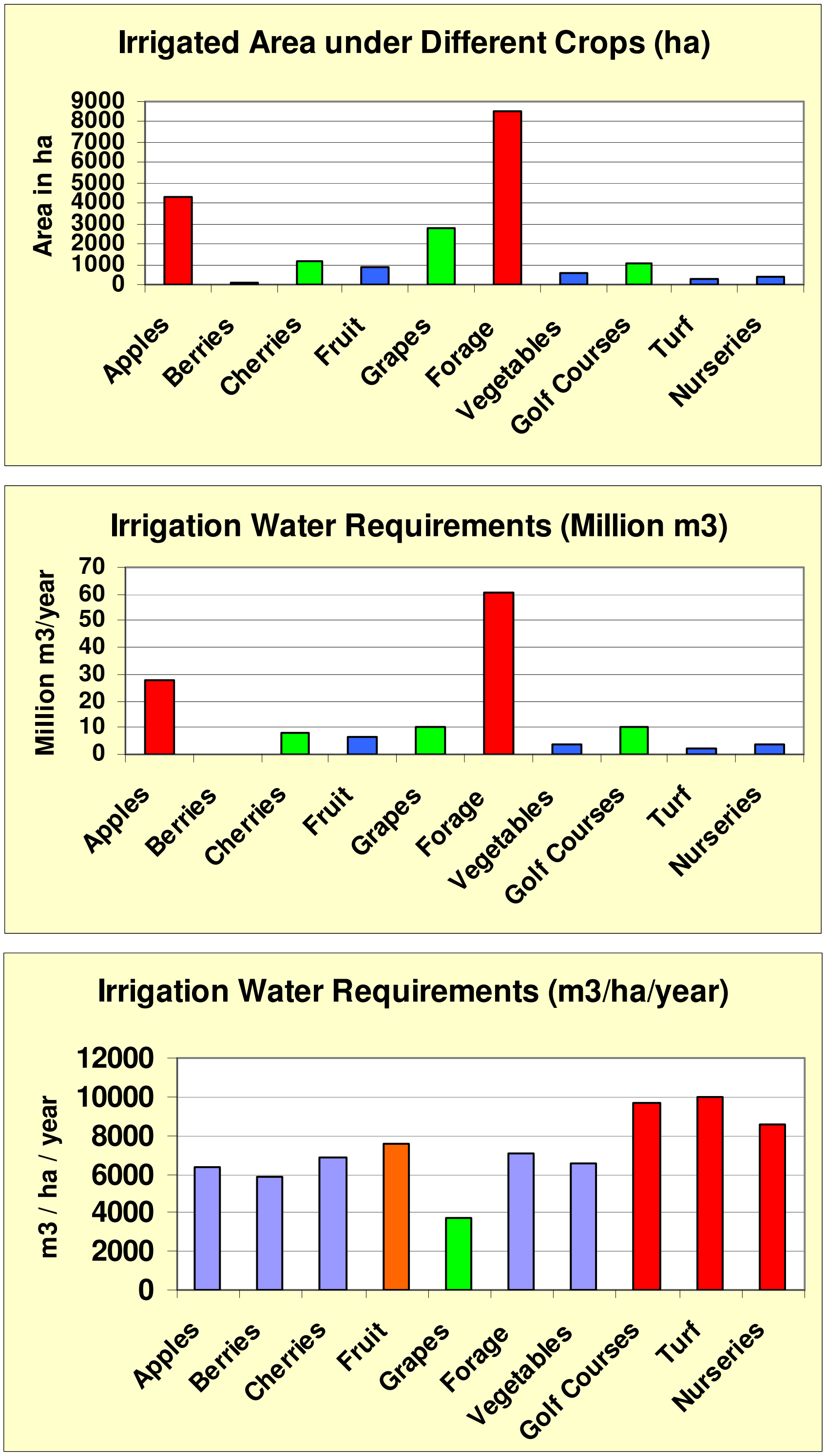


Figure 19. Land area and water requirements for different crops in the Okanagan Basin in 2006: Irrigated areas in ha; total irrigation water requirements in m^3/year; irrigation water requirements in m^3/ha/y.

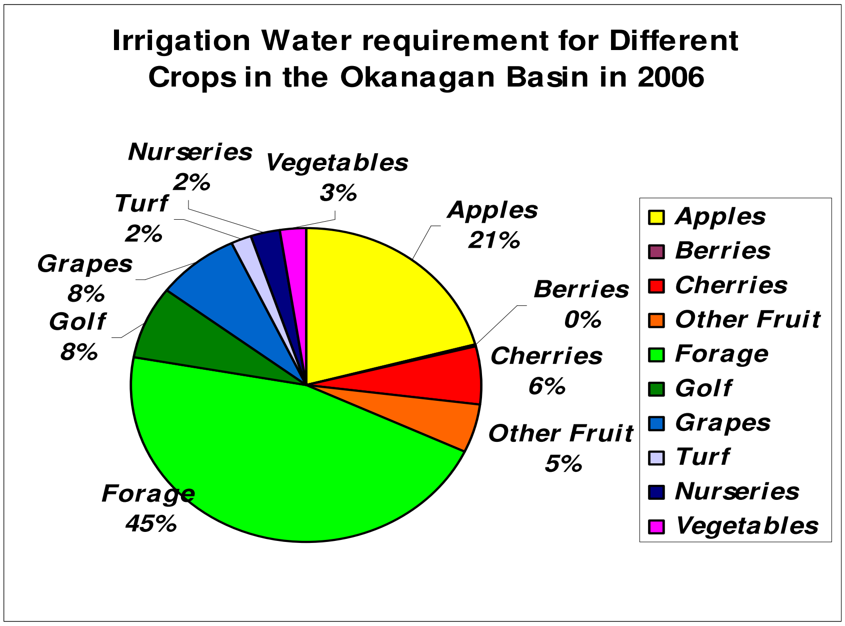


Figure 20. Percent irrigation water requirements for major crops in the Okanagan Basin in 2006.

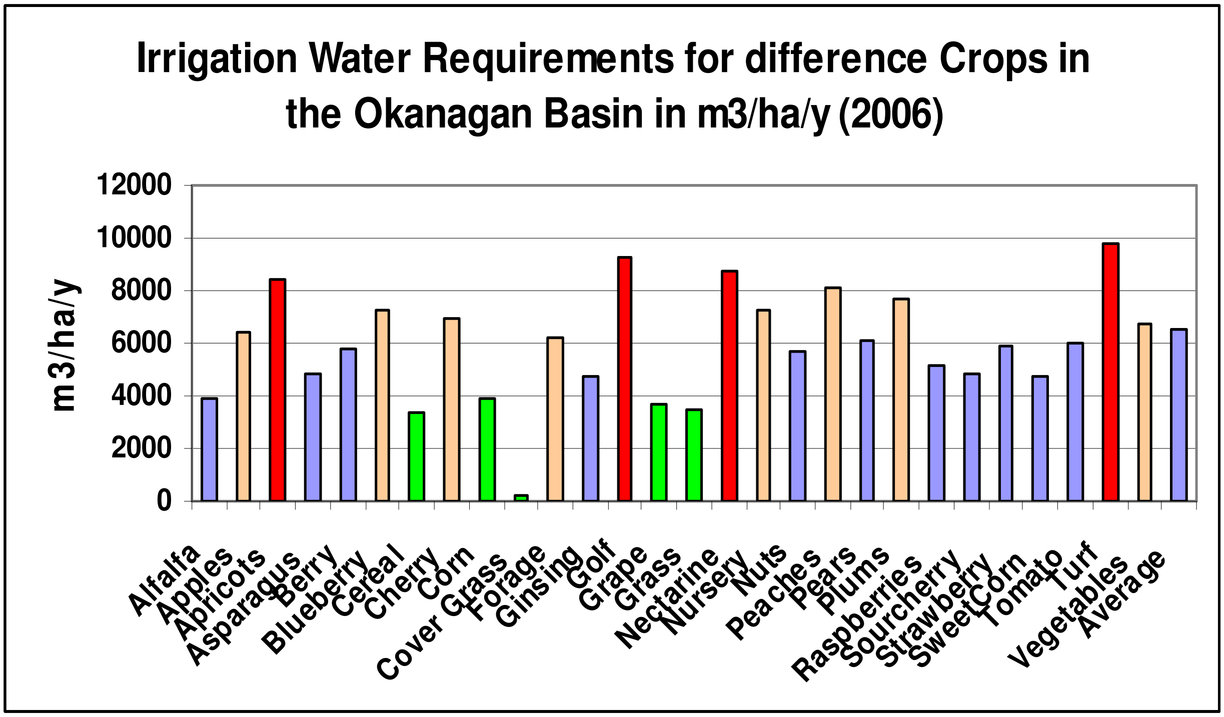
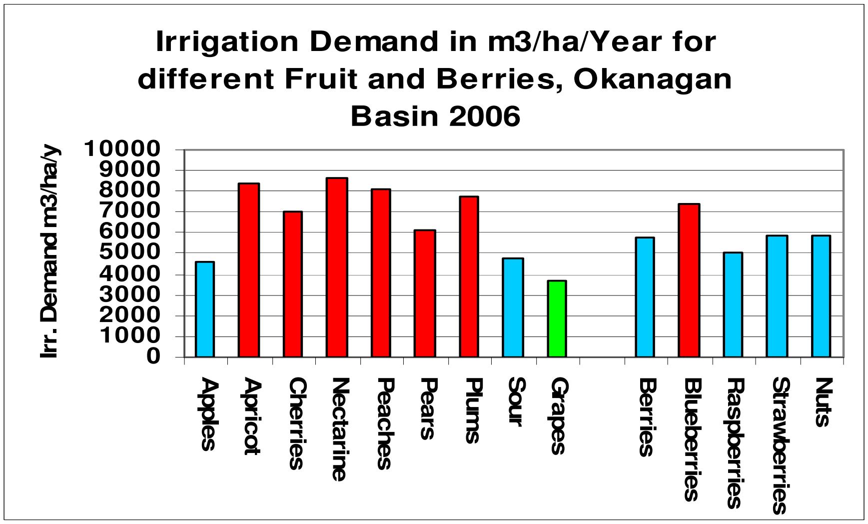
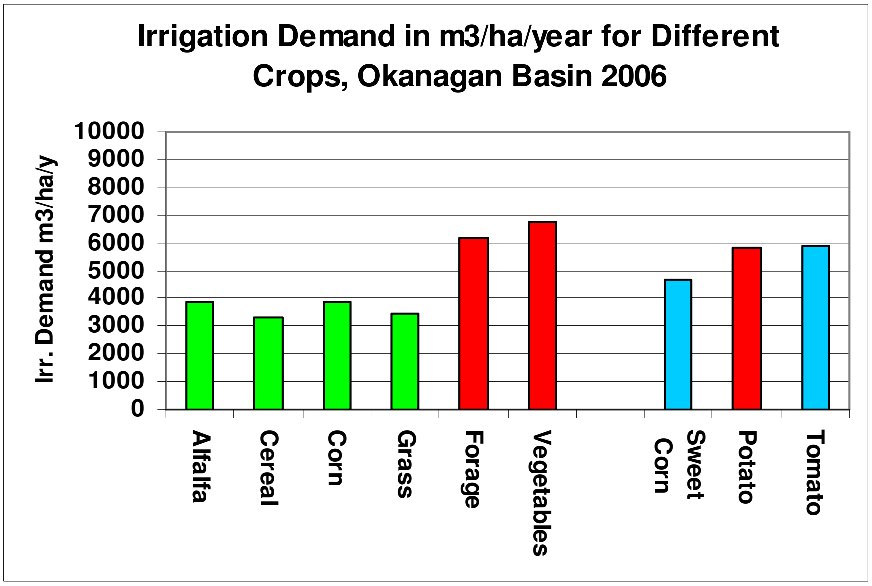


Figure 21. Comparison of irrigation water requirements for individual crops for 2006.





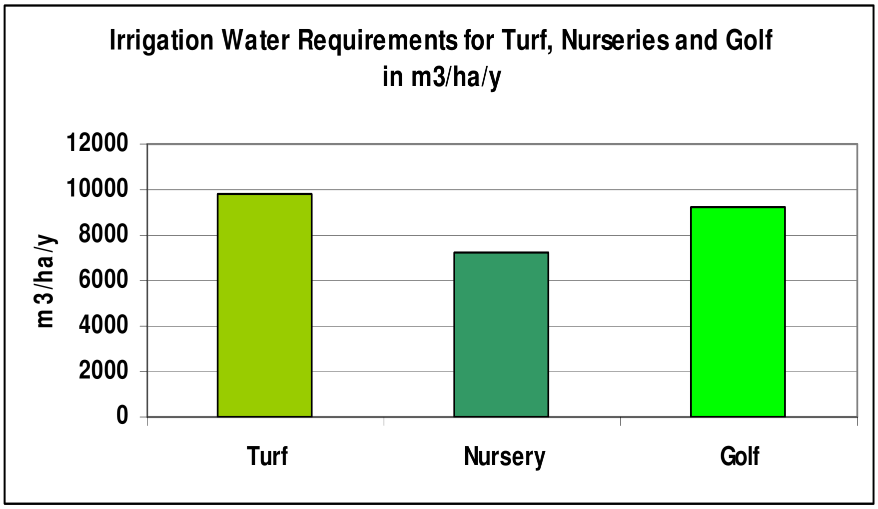


Figure 22. Detailed comparison of irrigation water requirement for different crops.

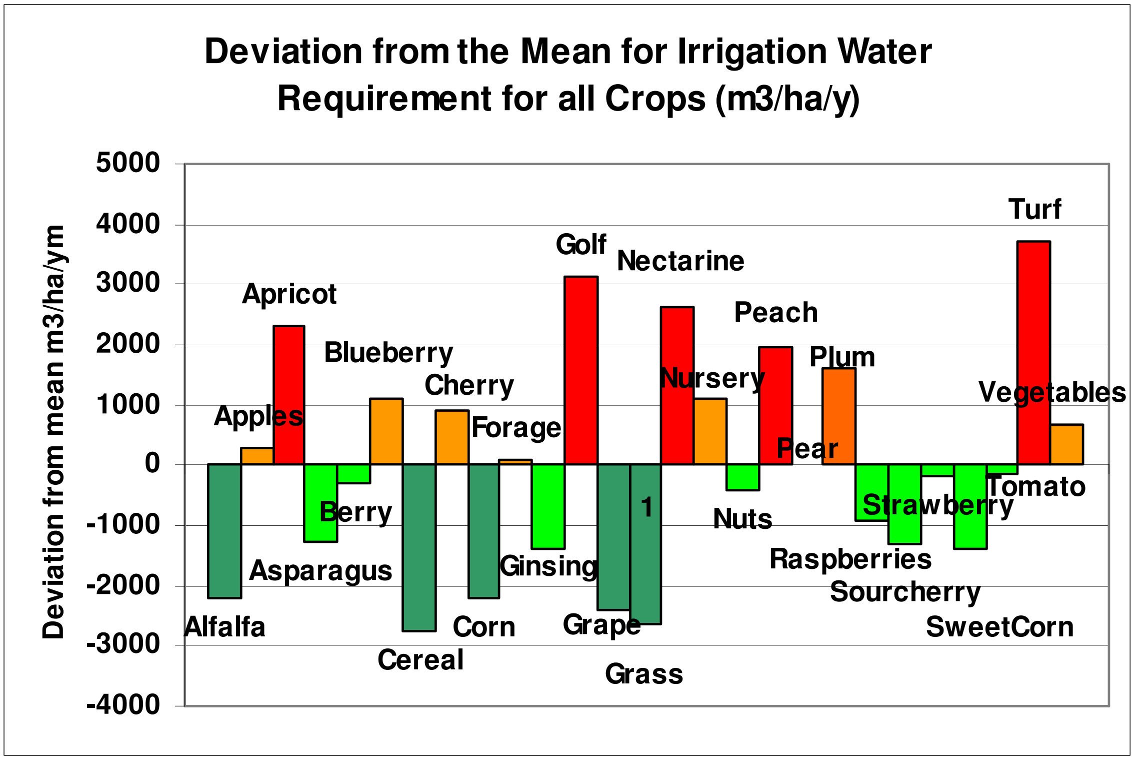


Figure 23. Deviation from the mean for the different crops in the Okanagan in 2006 in m^3/ha/y.

The irrigation water requirements can also be displayed spatially since all information was geo-referenced in a GIS database. An example of the overall spatial distribution of irrigation water requirement on a per hectare basis is provided in Figure 56.

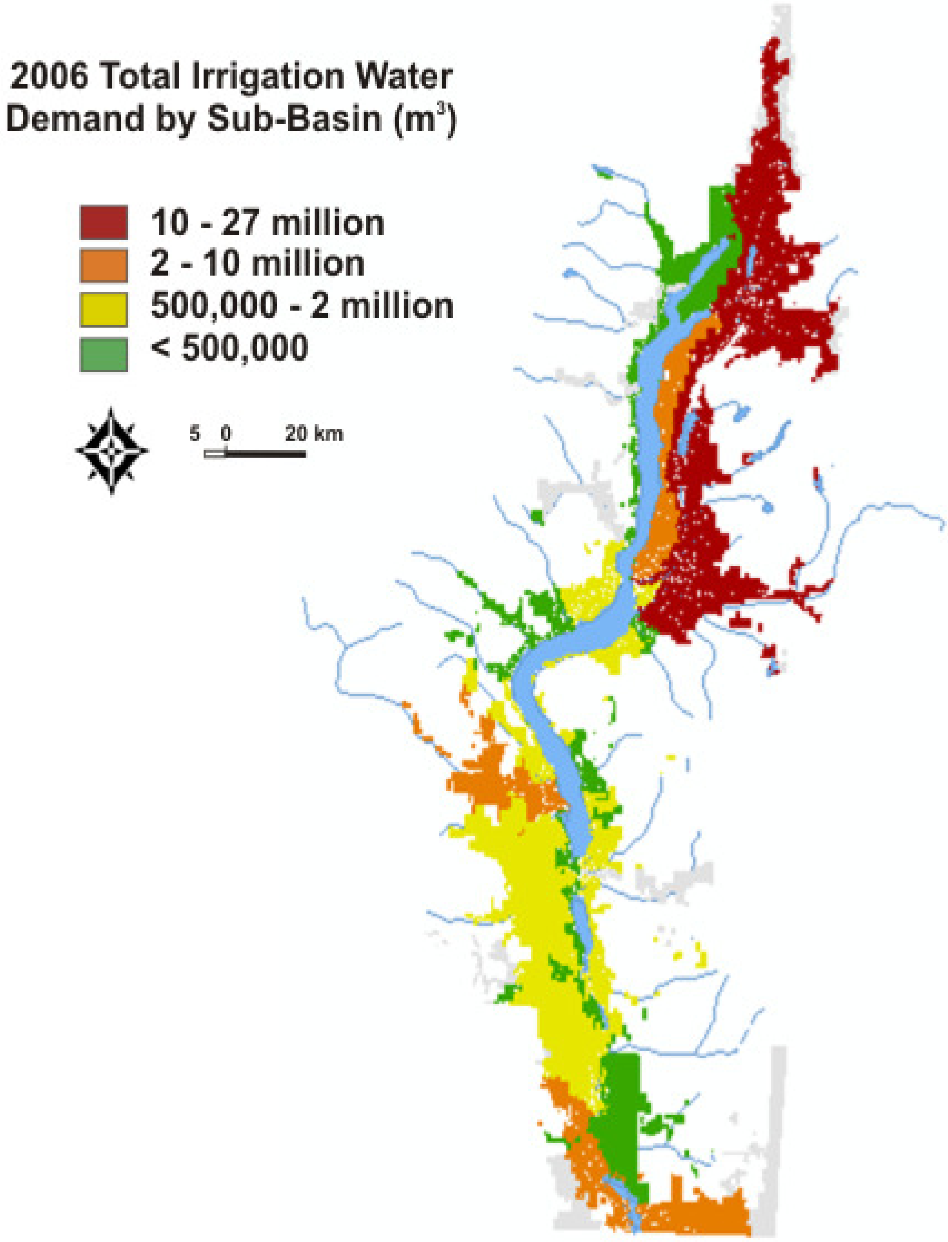


Figure 24. Irrigation water requirements by sub-basins in 2006 in millions m^3/y.

5.3. Detailed Irrigation Water Requirements in the 3 Regional Districts

Irrigation water requirements were also determined for the three regional districts as the climatic conditions in the south (Okanagan Similkameen Regional District-RDOS) are much drier than in the Central (CORD) and North Okanagan Regional District (NORD). As shown in Figure 25 nursery production requires significantly more water in the south (RDOS) than in the north (NORD) of the basin. This regional difference is most clearly evident in the NORD where all crops require significantly lower amounts of water per ha per year.

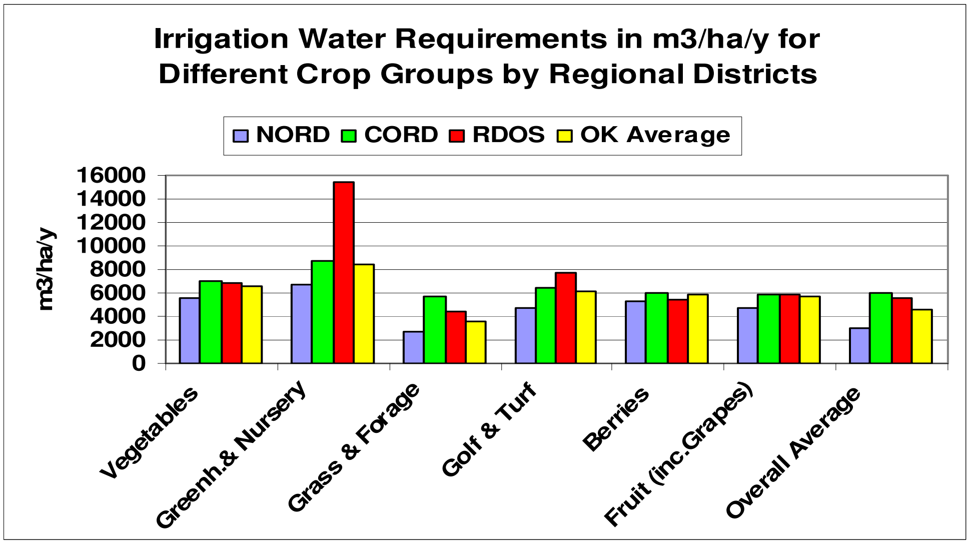


Figure 25. Differences in irrigation water requirements for different crop categories.

Since this is a unique area to grow fruit trees in Canada it is of interest to determine the differences in irrigation water requirements for different fruit crops and in a regional context. As shown in Figure 26, grapes, apples and sour cherries have the lowest water requirements (4000 - 5000 m^3/ha/y), cherries and pears require between 6000-7000 m^3/ha/y and the highest water requirement for fruits are for peaches, nectarines, and plums (7500-8500 m^3/ha/y). Placed in a regional context we can show that in almost all cases the water requirements in the south (RDOS) is higher than in the other districts. Some of these differences can be very large amounting to between 10-20 % (Table 7) of total water use.

If temperatures increase as a result of global warming, and water shortages become more frequent, we now have a scientific basis to identify the most water demanding crops that could be grown in the different parts of the basin.

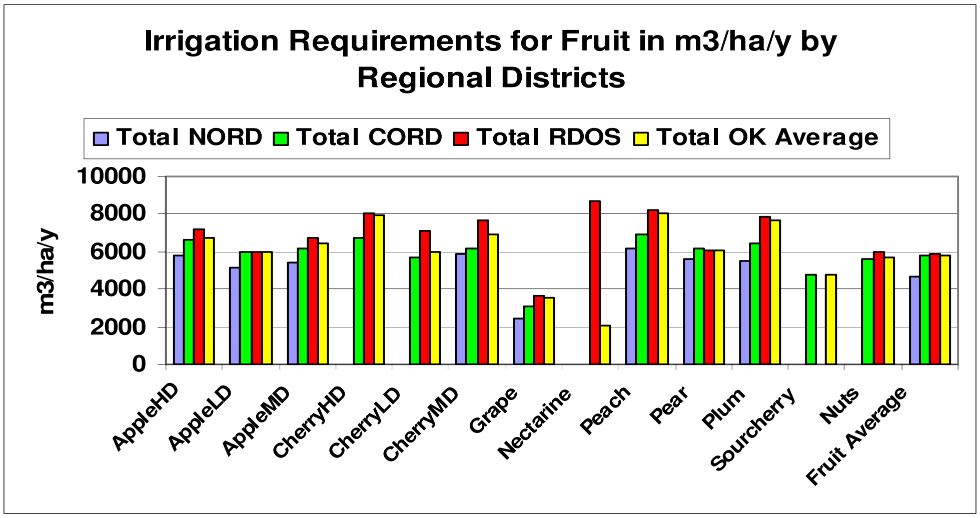


Figure 26. Irrigation water requirements for different fruit by regional districts.

Table 7. Differences between Irrigation water requirements for different fruit between the 3 regional districts in m^3/ha/y or %.

Fruit Type	**Difference in Irrigation Water Requirements between Districts**					
	NORD vs. CORD		**NORD vs. RDOS**		**CORD vs. RDOS**	
	m^3/ha/y	**%**	**m^3/ha/y**	**%**	**m^3/ha/y**	**%**
AppleHD	**781**	**13**	**1358**	**23**	**577**	**9**
AppleLD	**885**	**17**	**821**	**16**	**64**	**-1**
AppleMD	**766**	**14**	**1321**	**24**	**555**	**9**
CherryHD					**1396**	**21**
CherryLD					**1369**	**24**
CherryMD	**343**	**6**	**1781**	**30**	**1438**	**23**
Grape	**689**	**28**	**1259**	**51**	**571**	**18**
Peach	**706**	**11**	**2009**	**32**	**1304**	**18**
Pear	**599**	**11**	**475**	**9**	**124**	**-2**
Plum	**979**	**17**	**2370**	**43**	**1391**	**22**
Nuts					**333**	**6**

5.4. Irrigation Water Requirements in Local Communities

The districts can be further subdivided into local communities and four examples of the differences in water requirements are provided in Figures 27-30. The results show the difference in water requirements between the north and the south of the basin in a GIS map (Figure 27). Figure 28 gives the combined values for each local community in total m^3/y and m^3/ha/y water requirements for all crops.

The greatest water requirements are found in NORD, RDOS and the City of Kelowna. On a per hectare basis, Summerland is the least efficient followed by Kelowna and

CORD. The most efficient community is NORD, which requires < 3000 m^3/ha/y, while all other communities require between 5000-6300 m^3/ha/y.

The irrigation water requirements were determined for the different fruit crops produced in the basin. As shown in Figures 29 and 30, the largest irrigation water requirement for most fruit, on a per ha basis, is in the south (RDOS). This is expected because the southern part of the basin has a higher average temperature and lower average rainfall.

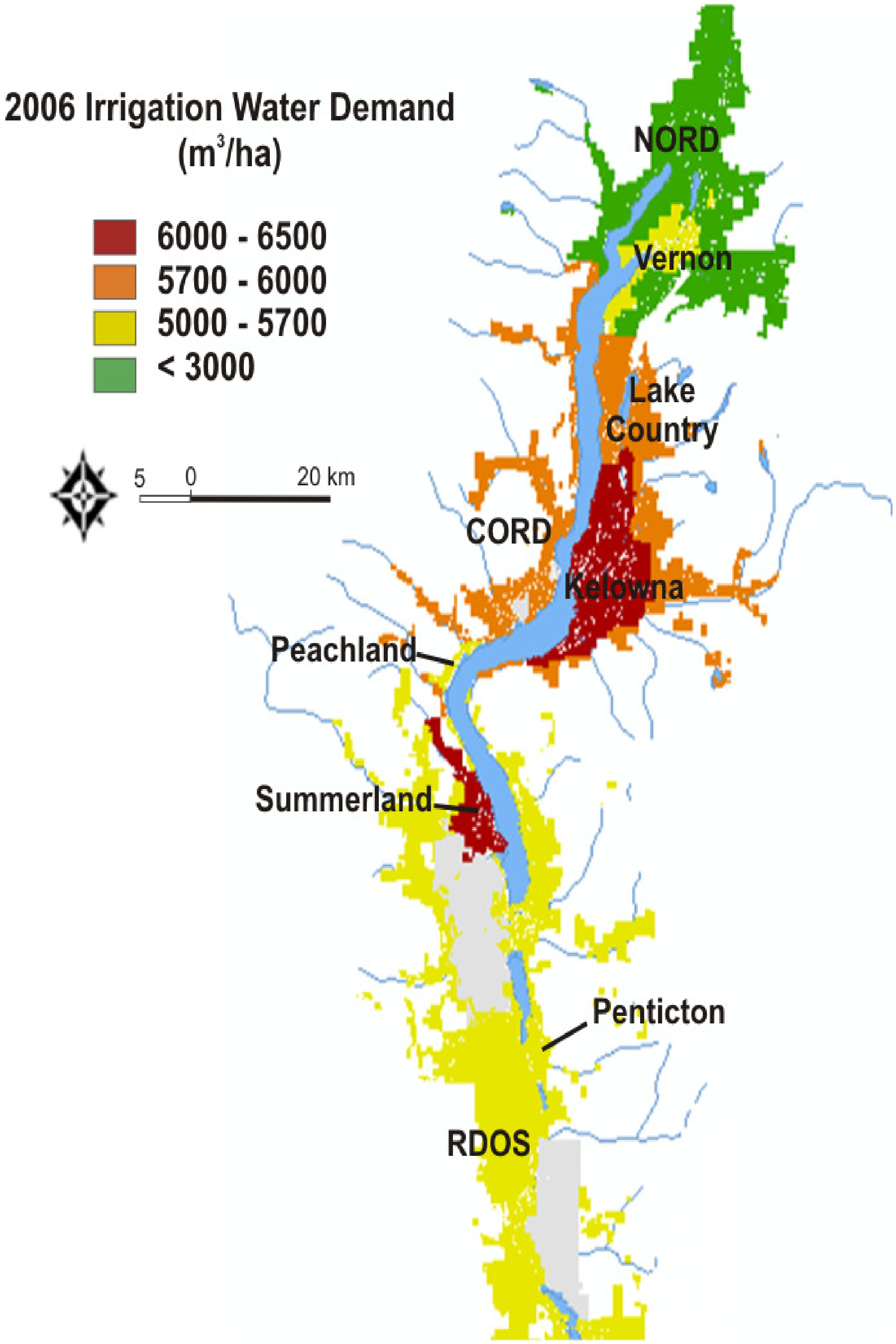


Figure 27. Differences in irrigation water requirements for the different local communities in m^3/ha/y.

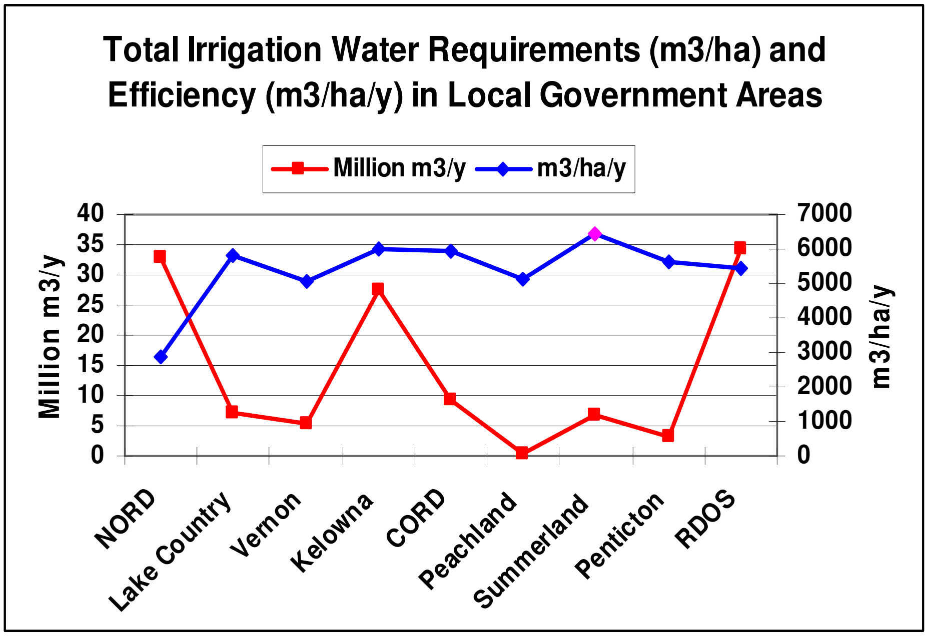


Figure 28. Total irrigation water requirements (m^3/y) and water use efficiency (m^3/ha/y) for the local communities from the north to the south of the basin.

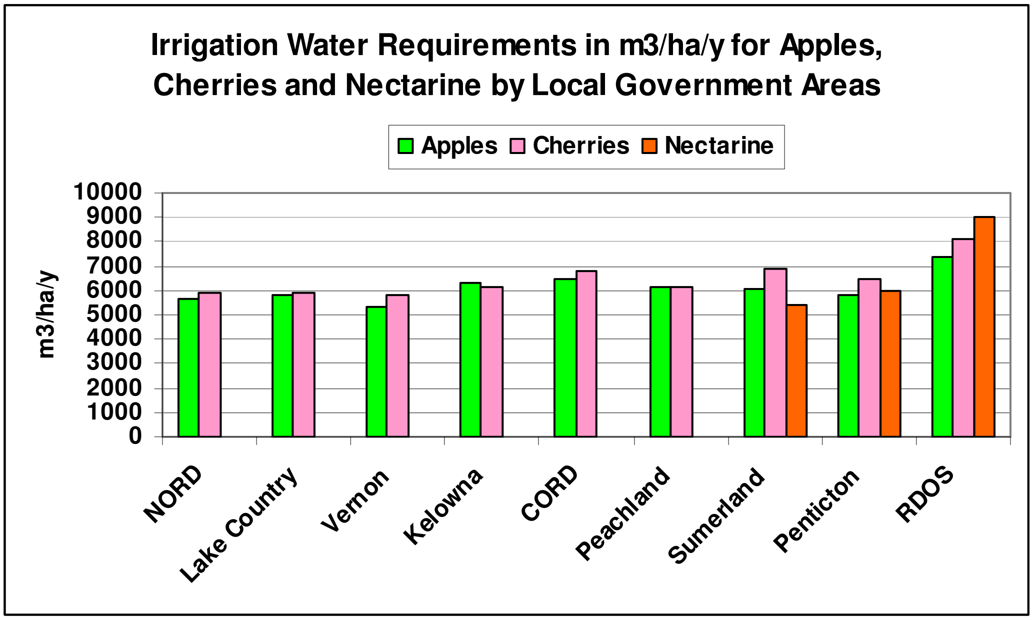


Figure 29. Irrigation water requirements for selected fruit crops in m^3/ha/y in local communities.

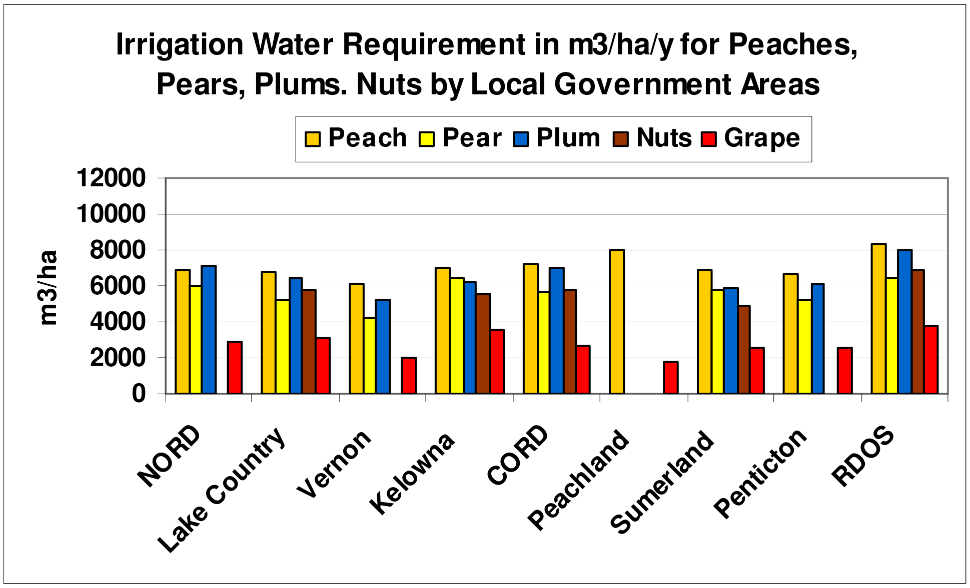


Figure 30. Irrigation water requirements for selected fruit trees in m^3/ha/y in local communities.

Some of these differences are not only a function of climate but also a function of the soil texture, irrigation systems, and management, which will be addressed in the next section.

5.5. Water Requirement as Influenced by Soil Texture and Irrigation Systems

5.5.1. Differences in water requirements for different soil textures

The soils were classified into 14 different texture classes and for the purpose of this analysis the and, 72% fell into the silt dominated category, 15% into the clay, 12 in the sand and 1% into the organic category.

The water requirement to grow crops on different soil textures can vary significantly and when using the data for an average rainfall year (2006) we can show that the differences between clay textures soil (5811m^3/ha/y) and a sand texture soil (9191 m^3/ha/y) is up to 3380 m^3/ha or 58% (Figure 31).

5.5.1. Differences in water requirements for different irrigation systems

Twenty different irrigation systems where identified in the Okanagan Basin and considering the overall irrigation water requirements we can get an idea on the efficiency of the different system by calculating the m^3/ha/y requirements for the different systems. As shown in Figure 32. Golf sprinklers and guns are the most inefficient systems using more than 9700 m^3/ha/y. In contrast, drip, sub-irrigation and pivot are the most efficient systems ranging between 3800-5800 m^3/ha/y. Of course not all irrigation systems can be used for all crops but the difference between the least and the most efficient systems are 6519 m^3/ha/y or 272%.

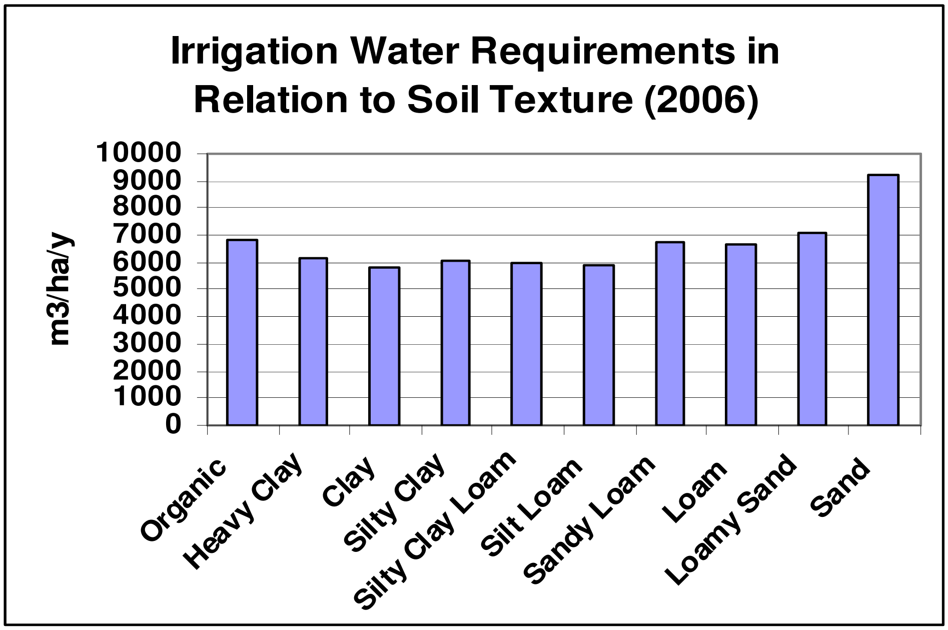


Figure 31. Differences in irrigation water requirements in relation to soil texture.

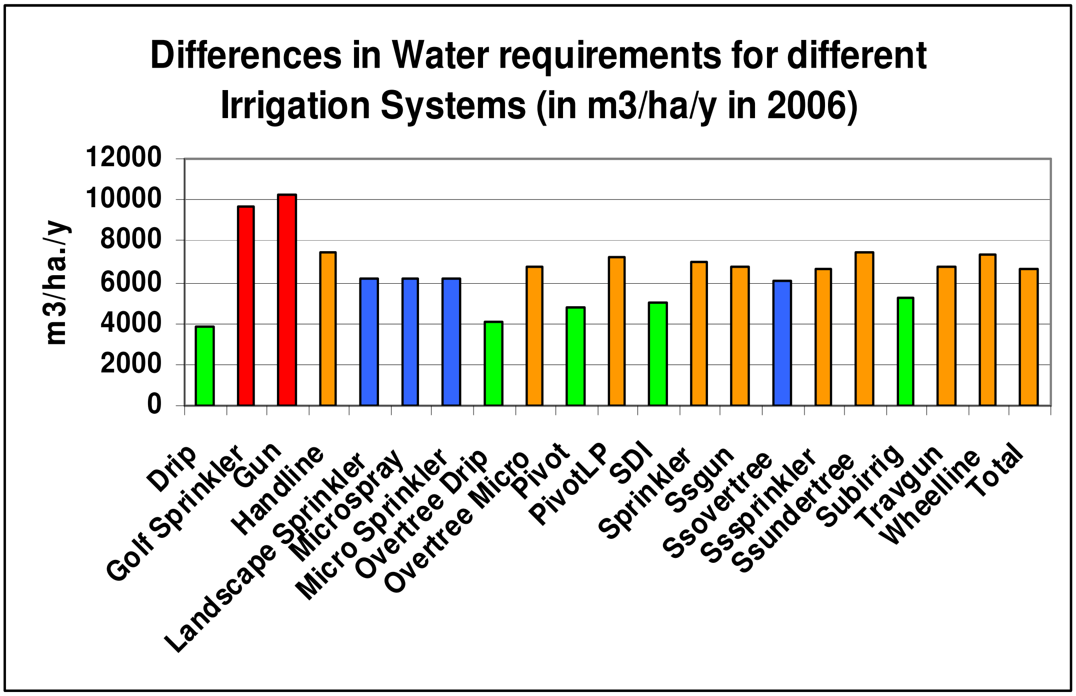


Figure 32. Differences in irrigation water requirement for different irrigation systems.

What these data show is that large reductions in irrigation water requirements can be made by considering the soils texture and the irrigation system. The most effective strategy is to select the best combination of crop, soil, climate, and irrigation system which can result in substantial savings of blue water use.

6. Differences in Water Requirement between Wet and Dry Years

6.1. Introduction to Wet and Dry Years

Climate change models suggest that the temperatures will increase in the region and although there is much uncertainty about precipitation trends there is sufficient evidence to suggest that greater attention needs to be given to the increase in annual climatic variability. As an illustration in 2003 the Okanagan experienced a very dry summer that coincided with large incidence of forest fires. In contrast 1997 was one of the wettest years, while 2006 was more of an average year. As shown in Figure 33, 1997 was particularly wet during the main months of the growing season and 2003 had several months with almost no precipitation. There was an average difference of 151mm of precipitation between the two years,

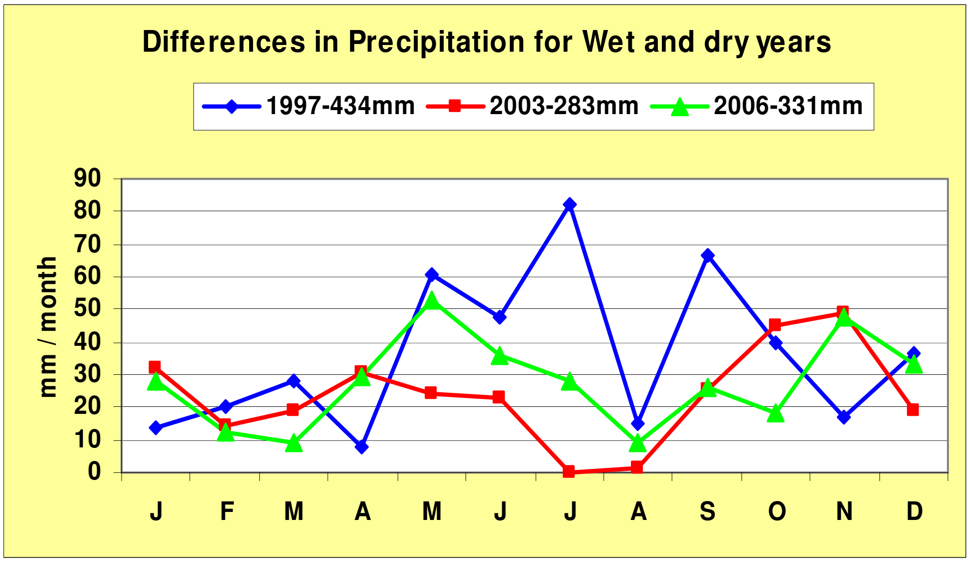


Figure 33. Differences in precipitation between a wet (1997) a dry (2003) and a more normal year (2006) in the Okanagan Basin.

The impact of dry cycles has obviously a significant impact on irrigation water demands and this is clearly evident in Figure 34 which shows the total irrigation water requirements for the basin for each of the three years. The results demonstrate that there was a 40% increase in water need between 1997 and 2003 which amounts to a 40 million m^3/year quantity just to maintain the same level of agricultural production. This confirms the hypothesis that the watershed is very sensitive to climate variability.

Forage production requires the largest amount of the irrigation water in the basin and this crop is also more sensitive the drought conditions than the other crops. The difference between the wet and dry season is the green water component and with increased climatic variability we expect these cycles to become larger, hence effective water management in agriculture is of fundamental importance in the Okanagan Basin.

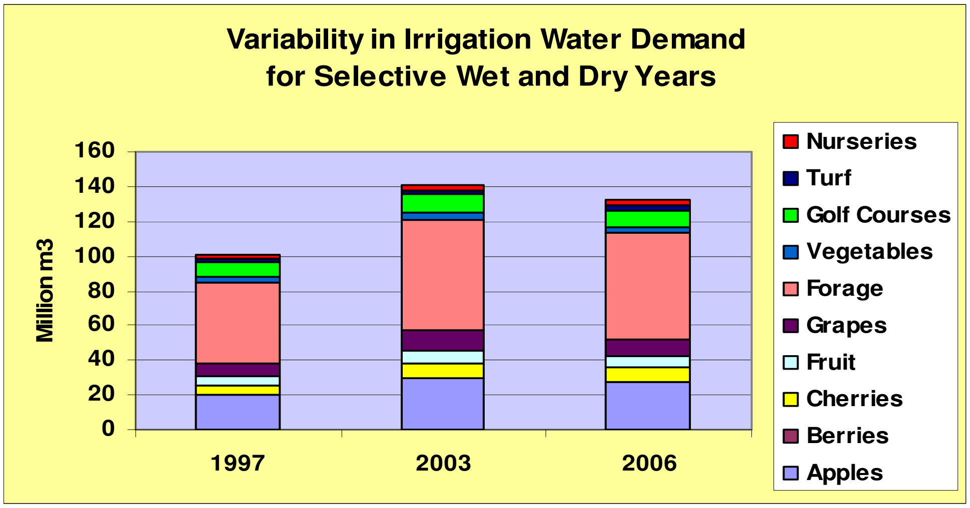


Figure 34. Difference in irrigation water requirements between wet and dry years

6.2. Sensitivity of Soil Texture to Climatic Variability

Soil texture is an obvious factor that influences water requirements and this is given in Figure 35 which shows that sandy soils are more sensitive than clay dominated soils. The average difference for all soil textures is 39% and the maximum difference in water requirements for the extreme soil texture classes can be 3000 m^3/ha/y for sandy soils and 1300 m^3/ha/y for clayey soils.

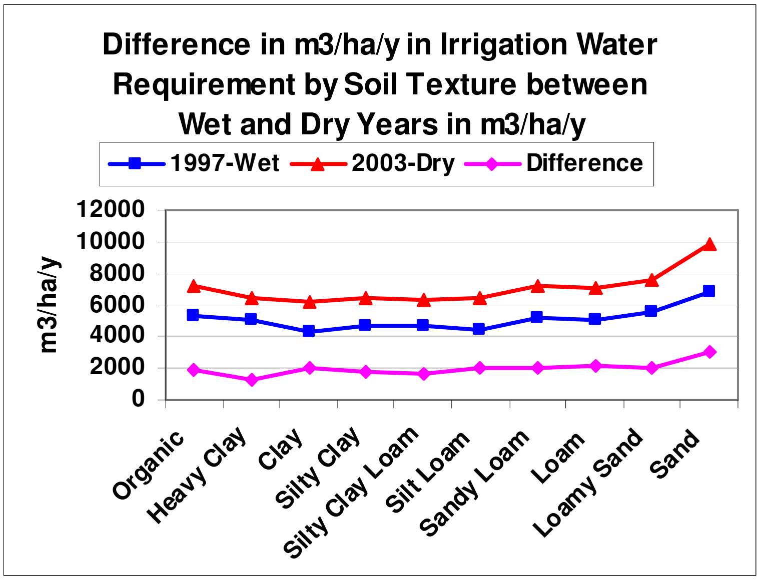


Figure 35. Differences in water requirements between wet and dry years for different soil textures.

6.3. Vulnerability of Irrigation Systems to Climatic Variability

Different irrigation systems have different efficiencies and the sensitivity to climatic variability was examined and given in Figure 36. The difference between wet and dry years ranged between 1383-2998 m^3/ha/y with a mean of 2001 m^3/ha/y. As expected the drip, sub-irrigation and pivot systems are the least sensitive with differences of less than 1600 m^3/ha/y and guns are the most inefficient.

What is interesting is that the variability between wet and dry years in m^3/ha/y is just about the same for soil texture and the different types of irrigation. These differences are large (between 30-40%) and need to be considered seriously in view of increased climatic variability.

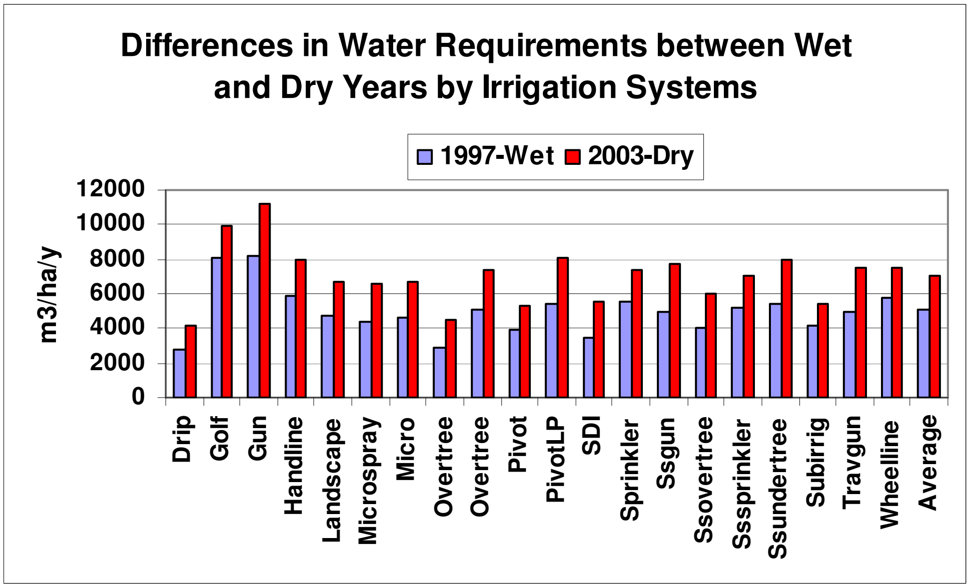


Figure 36. Differences in water requirements between wet and dry years for different irrigation systems.

6.4. Crop Sensitivity to Climatic Variability within the Basin

The combination of soil type, climate, irrigation efficiency, and type of crops all influence how much water is required for irrigation. To determine the combined impact of these factors could not be determined at this stage of the analysis because some modification to the model is necessary. However, the overall crop sensitivity to drought was assessed regardless of soil texture and irrigation systems. This was followed with a sensitivity assessment to climatic variations over spatial areas, by calculating the differences between the local government units from the north to the south of the basin.

6.4.1 Overall crop sensitivity to drought without considering soil and irrigation systems

To show the sensitivity of the crops to climate change the difference between the wet and dry year was determined for all crops regardless of soil and irrigation systems. The result given in Figure 37 indicate that almost all tree fruit (apples, apricots, cherries, nectarines, peaches, and plums), corn, greenhouse, nursery production and blueberries had the highest differences in irrigation water requirements between wet and dry years ranging between 2000-2850 m^3/ha/y. In contrast, alfalfa, cereals and grass had the lowest differences between wet and dry years with < 1200 m^3/ha/y. This suggests that from a quantity point of view fruit trees, and corn production, and greenhouse and nursery operations are the most sensitive production activities for increased climatic variability.

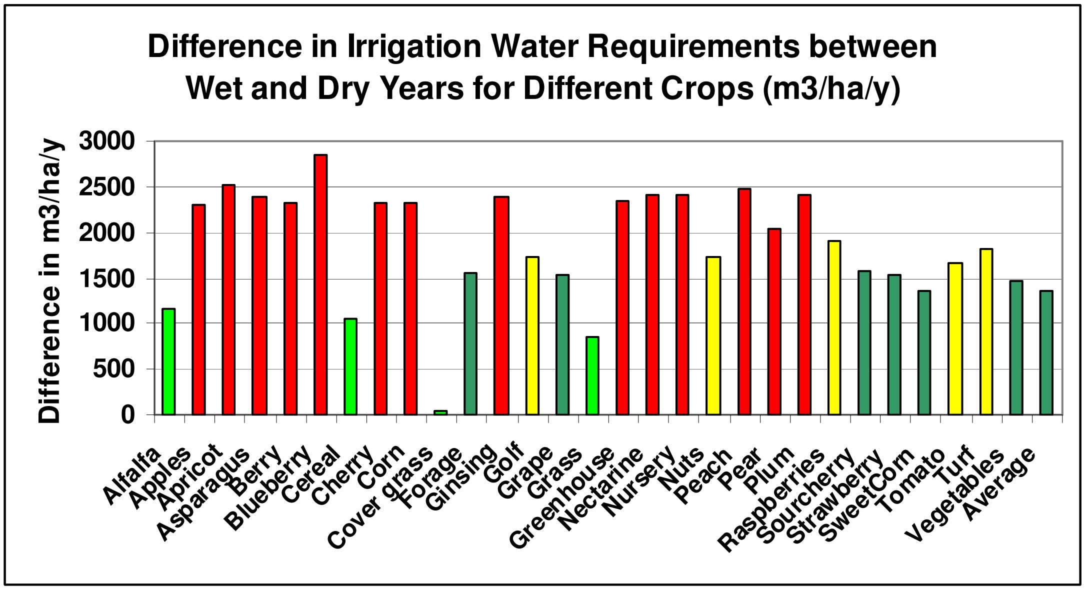


Figure 37. Difference in irrigation water requirement between wet and dry years in m^3/ha/y.

If the % difference between the wet and dry year is calculated then golf, grass, turf and vegetables vary by less than 30% between wet and dry years, while berry production, corn, selective vegetable, and grapes have the highest % difference with values >50% (Figure 38). The average % difference between wet and dry years is 43% and this clearly shows how sensitive these agricultural production systems are to drought and increased climatic variability. The detailed dataset for these calculations is provided in Appendix 1.

6.4.2. Crop sensitivity to climate over the spatial area of the basin from north to south based on local government areas

The differences between wet and dry years were assessed for all crops for each of the 9 local government areas. First an overall summary is provided for the differences in total irrigation water required for each local community (Figure 39) and then in terms of the differences in m^3/ha/y (Figure 40).

The results show that the largest amount of water is required in the NORD, Kelowna and RDOS, the most southern local community. All three communities are highly sensitive to increased climatic variability with the north having a greater difference between wet and dry years than the south (RDOS) or Kelowna.

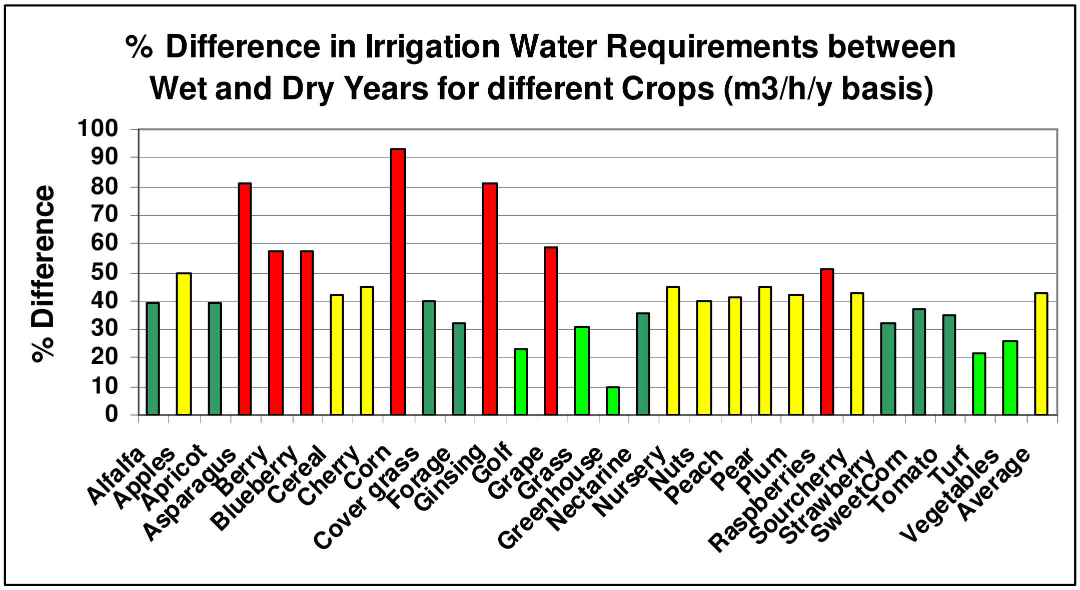


Figure 38. Percent difference between wet and dry years for individual crops based on irrigation water requirement measured in m^3/ha/y.

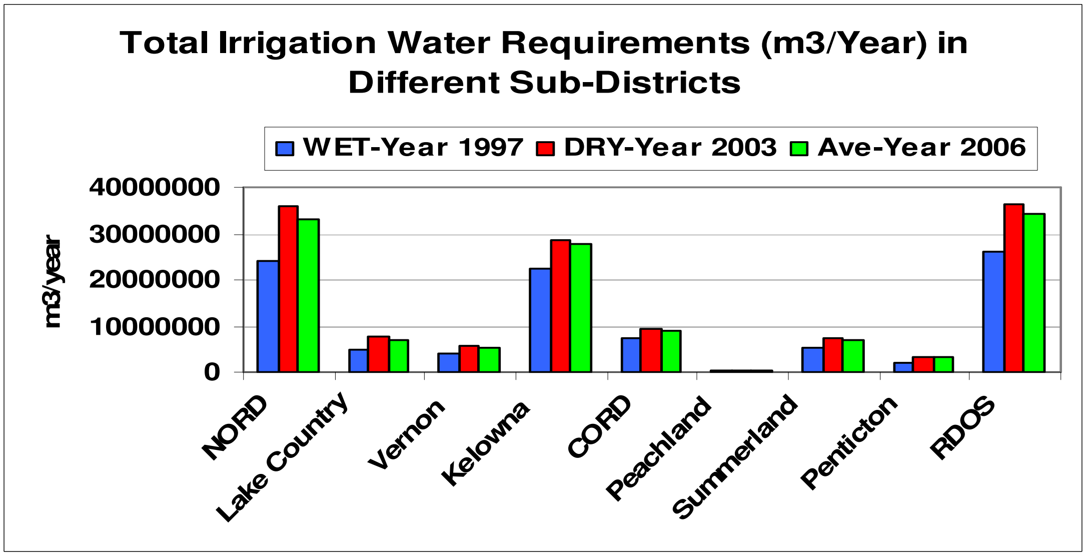


Figure 39. Difference between wet and dry years in terms of total irrigation water requirements between the local government areas in the Okanagan Basin.

In terms of sensitivity on a per hectare basis Summerland uses the greatest amount of water and together with Lake Country and Penticton is the most sensitive local community to drought (Figure 40). Peachland, CORD and NORD are the least sensitive.

The differences in irrigation water requirements in m^3/ha/y for individual crops for the different local communities are provided in Table 8. The results are highly variable and this reflects the differences in climate, soil and irrigation systems.

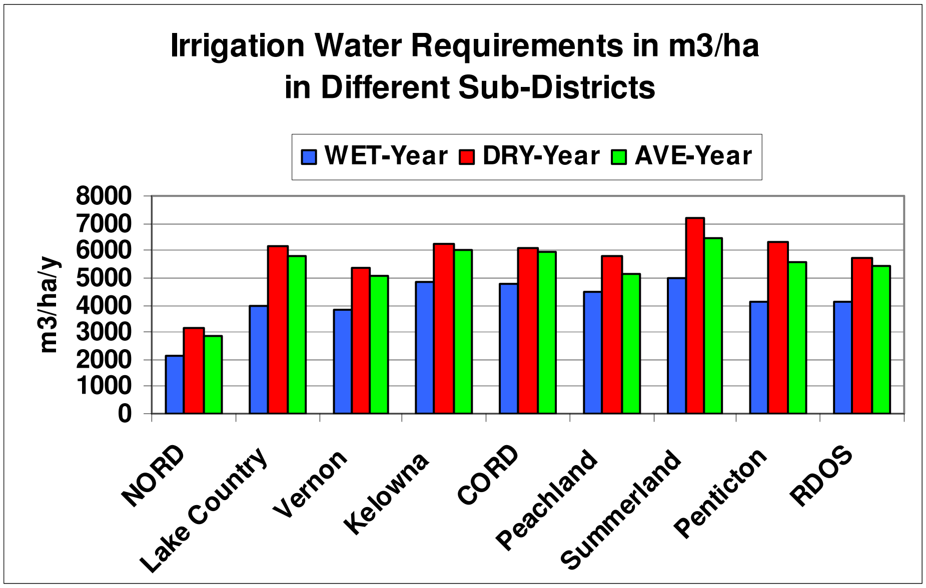


Figure 40. Difference between wet and dry years in terms of m^3/ha/y irrigation water requirements between the local government areas in the Okanagan Basin.

Table 8. Differences between wet and dry years in m^3/ha/y for different crops in different communities within the basin.

	Difference between Wet & Dry Years in Local Communities in m^3/ha/Year							
Crops	**NORD**	**Lake Country**	**Vernon**	**Kelowna**	**CORD**	**Peach-Land**	**Summer-Land**	**Penticton**	**RDOS**
Grass		1659	1916		1257		1890		
Forage	445	1275		248					
Alfalfa	1044	2312	2675	1206	1199		2047		1514
Cereal	1079			169	289				1162
Corn	2340			1780					1610
Vegetable	1731	1927	1644	1340	985	1212	1694	1740	1377
AppleHD	2552	2554	2415	2113	2132		2528	2786	2566
AppleLD	2392	2642	1994	2007	2113		2205	2258	2375
AppleMD	2449	2463	2090	2072	1781	2154	2338	2544	2438
CherryHD				1854	1389	1880	2629	2684	2445
CherryLD		2473		1730	1930		2448	2054	2282
CherryMD	2550	2528	2448	1997	1865	2155	2578	2441	2343
Grape	1768	1565	1192	1013	751	645	1294	1469	1621
Nectarine							1753	2378	2465
Nuts		2594		1592	1281		2111		2391
Peach	2937	2920	2552	2185	1900	2502	2578	2733	2432
Pear	2458	2294	1834	1837	1278		2258	2223	2205
Plum	3049	2698	2310	2080	1555		2166	2424	2449
Sourcherry				1575	1621				

Golf Courses	**1952**	**2555**	**973**	**679**	**795**	**1384**	**2455**	**2336**	**1470**
TurfFarm	**2855**			**710**	**1075**		**2455**		**2463**
TurfPark	**1139**	**2273**	**2455**	**1484**	**1227**	**1566**	**2200**	**2474**	**2034**
Nursery	**2631**	**3187**	**3218**	**2560**	**1699**		**2578**	**3083**	**2809**
Average	**2136**	**2373**	**2123**	**1547**	**1427**	**1687**	**2233**	**2127**	**2140**

This type of data is most valuable for decision makers in yeas of prolonged drought and in anticipation of increased climatic variability.

7. Virtual Water Requirements for Livestock in the Okanagan.

7.1. Method Used to Determine Water Requirements for Livestock

The virtual water content for livestock includes the virtual water content of their feed, and the volumes of drinking and service water consumed during their lifetime (Chapagain and Hoekstra 2003). As such, virtual water provides a more complete picture of water use in the livestock industry, and permits comparison between the dominant types of livestock which may have large differences in feed requirements, lifespan and weight.

Animal numbers of the Okanagan in 2006 compiled from Statistics Canada are presented in Table 9. Poultry comprise the largest number at 1.2 million birds, followed by cattle. However feed requirements and lifespan are significantly different with broilers marketed after 42 days (6 weeks); in comparison to beef cattle which are typically grazed on upland grass and forested rangelands from May to October, and shipped to Alberta feedlots at 1.5 years.

Based on typical volumes of drinking and service water consumed, and the total water required to grow their feed, the virtual water content per animal lifespan can be calculated. The method is illustrated in Figure 41. Water for drinking and servicing are based on literature values. Animal diets (feed volume) were developed independently based on animal nutrition and cross checked with feed suppliers and producers in the Okanagan. The virtual water content (VWC) of animal feed (m^3 water / ton feed) is calculated from the crop water requirements, local yields and water required in feed preparation.

7.2. Virtual Water Determinations for Livestock in the Okanagan

The VWC (m^3 water / ton live animal) for the dominant livestock raised in the Okanagan Basin is given in Table 10 and compared to global estimates. Virtual water requirements for feed comprise more than 95% of the virtual water requirements per animal lifespan. Differences between values calculated for the Okanagan and literature values are largely related to differences in feed and production systems. For example: broilers are cycled every 6 weeks in the Okanagan compared to 8 weeks cited by Chapagain and Hoestra (2003); corn which has a relatively low virtual water content is largely excluded from poultry diets in the Okanagan but is included in global estimates.

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Table 9. Animal numbers in the Okanagan Basin in 2006.

	Okanagan Similkameen	**Okanagan Central**	**Okanagan North**	**sum**
Cattle				
Calves	8,021	1,231	11,581	20,833
Steers	4,644	288	3,039	7,971
Heifers	2,812	1,267	8,014	12,093
Beef Cows	8,401	1,574	10,763	20,738
Dairy Cows	102	0	5,541	5,643
Bulls	585	56	695	1,336
total cattle and calves	24,565	4,416	39,633	**68,614**
Poultry				
Broilers	5,649	76,964	1,041,522	1,124,135
Pullets	1,818	1,205	22,791	25,814
Layers	5,273	4,777	44,377	54,427
Total poultry	12,740	82,946	1,108,690	**1,204,376**
Other				
Total pigs	202	204	2,736	3,142
Sheep and Lambs	1,396	813	4,478	6,687
Horses	1,899	1,581	3,426	6,906
Goats	399	246	1,107	1,752

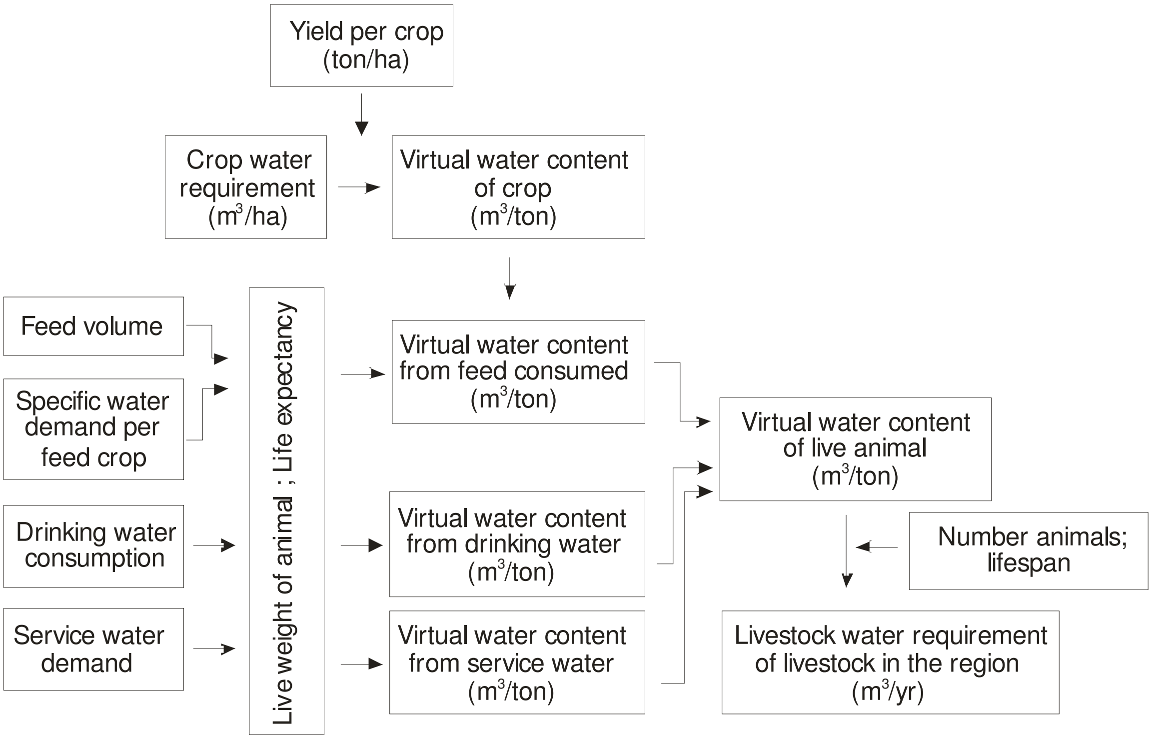

Figure 41. Schematic of VWC calculation for livestock.

Table 10. Virtual water content (VWC) of the dominant livestock raised in the Okanagan

Animal type		VWC (m^3/ton)	
		Okanagan	**Literature***
Beef	**Steers, bulls**	**6,178**	
	Cows	**14,518**	**11,915**
Dairy	**Cows**	**59,037**	**86,693**
Poultry	**Broilers**	**1,500**	**1,358**
	Layers	**17,500**	**9,563**
Pigs		**3,278**	**3,276**
Sheep	**Ewe, rams**	**5,653**	**5,648**
Horses		**5,563**	**5.567**
Goats		**4,758**	**2,775**

*Chapagain and Hoekstra 2003

On an annual basis, virtual water requirements for livestock (m^3/yr) can be determined from the virtual water requirements per animal for feed, drinking and service water, the number of animals and their lifespan (age). In the Okanagan, the virtual water requirements by livestock are dominated by beef (Figure 42) at 142 million m^3/yr. While dairy cows have a high VWC, their numbers are relatively low in the basin and require roughly half the annual virtual water requirements of beef. Poultry are dominated by broilers which have a low VWC, so despite their relatively high numbers (1.2 million at any given time) and short lifespan (6 weeks) their annual virtual water requirements are roughly half that of dairy.

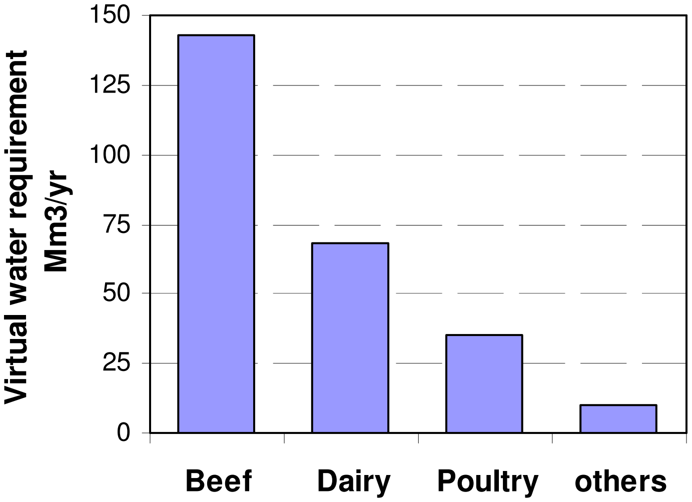

Figure 42. Virtual water requirement (million m^3/yr) of main livestock raised in the Okanagan.

As the VWC of livestock is dominated by the VWC of their feed, local versus imported feed stocks will have a significant impact on virtual water movement or trade. In the Okanagan, beef production relies on summer pasture and locally grown feed in the winter months (dominantly produced on-farm); i.e. grown within the basin. Dairy utilizes a mix of local and "imported" feed: the grain ration being grown outside the Okanagan basin; fodder (alfalfa silage, hay and corn silage) grown within the basin. Poultry feed is produced from grown entirely outside the basin. Fodder requirements for the cattle are shown in Table 11 for the basin as a whole along with rough estimates of the land base required to grow feed. Unimproved pasture (including forested rangelands) and hay and other fodder crops comprise the largest components by fodder type.

Table 11. Estimated locally grown fodder requirements for beef and dairy cattle.

Feed	Livestock	t/yr	Approximate ha required
Unimproved pasture	**Beef**	**78,800**	**78,000***
Hay and fodder	**Beef**	**58,370**	**19,400**
	Dairy		**3,600**
Grass silage	**Beef**	**10,670**	**2,500**
Alfalfa silage	**Dairy**	**24,625**	**5,300**
Corn silage	**Dairy**	**23,060**	**300**

* estimated VWC 1/3 of fodder crops

The relative proportions of feed grown locally and outside the basin are shown in Table 12 along with the VWC m^3/t (weighted by proportion of crop). On average, feed components grown outside the basin have higher VWCs than fodder feed grown locally.

Table 12. Feed source (t/yr) and associated VWC in m^3/t feed

	Locally grown (t/yr)	Grown outside the basin (t/yr) per animal	Average VWC feed (m^3/t) Local	Outside basin
Beef cow	**2.1**	**0**	**1,000**	**0**
Dairy cow	**8.9**	**3.2**	**700**	**1,050**
Broiler		**0.02**	**0**	**1,260**

Cattle production, both beef and dairy require significant virtual water due to the number of beef cattle and the high (relative) virtual water content of dairy cattle. Poultry, despite there high overall numbers have a low virtual water content and consequently relatively lower virtual water requirement.

7.3. Water Requirements for Livestock vs. Water Requirements for Crops

These calculations show that the hectares required for the feed is well within the production area of the basin, suggesting that hay, alfalfa and silage is sufficient to feed the beef and dairy population. What needs to be confirmed by the producers is the supplementary feed that is imported and the proportion of the feed that is irrigated vs. rain fed. This is vital before we can compare the virtual water requirements for livestock with those for crops not used for animal feed. What is evident from this preliminary assessment is that the virtual water requirement for beef is greater than the irrigation water requirements determined for all crops. Even if we subtract the irrigation water requirement for all locally produced feed it appears that beef and dairy production require substantially more water than all non-feed crops. When all livestock is included then the requirement are twice that of all crops. Much of this information is preliminary and will have to be fine-tuned once the livestock producers confirm the feed portions used in these calculations.

8. Water Requirements for Golf Courses

8.1. Overview of Golf Courses and Irrigation Water Requirements

In 2006 there were 45 golf courses in the Okanagan Basin. Each golf course was digitize from aerial imagery and orthophotos and incorporated into the GIS system. The irrigated areas (fairways) were separated from the surrounding landscape that is not irrigated. The total area for golf courses that was irrigated is determined to be 1048 ha. The start and end of the playing season was recoded to determine the length of the season where irrigation water was applied. For 2006 the model determined irrigation water requirements of 10.2 million m^3/year or 9708 m^3/ha/y. The per hectare requirement is well above the water requirements for most crops which generally ranges between 5000-6000 m^3/ha/y.

The size of individual golf courses is highly variable. Some courses are simple driving ranges, while others are either 9 or 18 -round courses. The size differences ranged from 0.4ha to 56.2 ha and the difference in total water requirements and m^3/ha/y requirements in relation to size is provided in Figure 43.

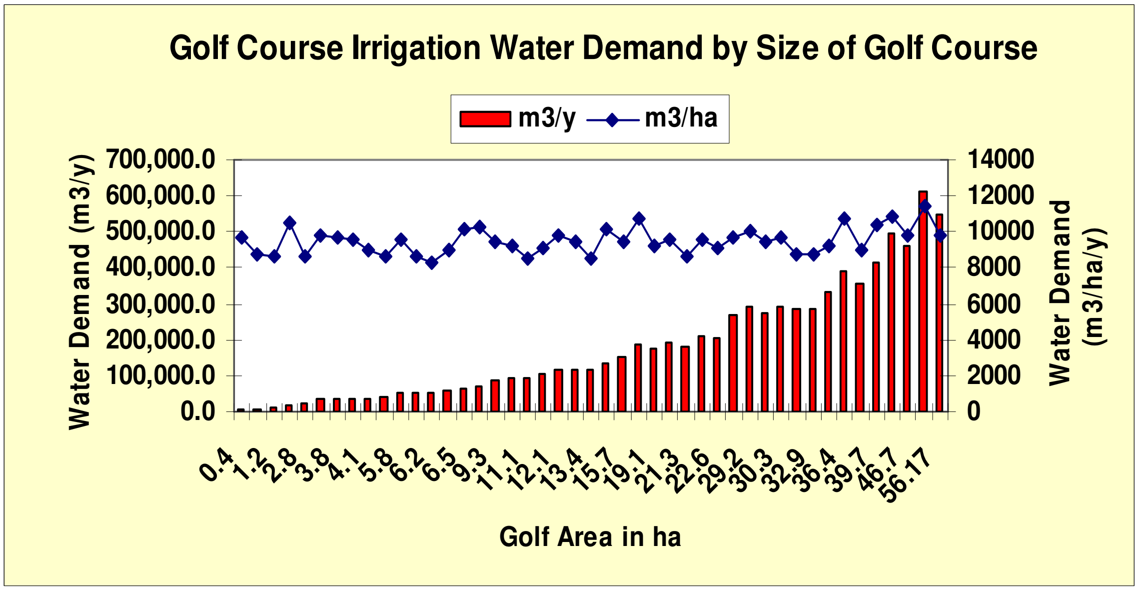

Figure 43. Irrigation water requirements in m^3/y & m^3/ha/y vs. size of the golf courses.

The results show that the requirements ranged between 8200-11500 m^3/ha/year. This is at least 1000-2000 m^3/ha/y higher than for all fruit trees, berries and vegetables. The variability between golf courses in m^3/ha/y is relatively small and as expected there is no relationship between size of golf course and m^3/ha water use. The total annual requirement for golf courses is more than the water requirement for all cherry production and about 20% less than all the grape production in the basin and the grape production covers 3 times the area covered by the irrigated golf area. The reason for increased water demand by golf courses would be the shallow rooting depths of turf grass, the extended growing season and the fact that the irrigation system efficiencies for golf courses are on average lower than other crops because drip systems are not used.

None of the golf courses have a water license and 93 % of the water requirements are provided from purveyors, while the remaining 7% is from groundwater. Thirty one % of the annual water is used in May-June and 51% in the July-August period.

Since the soil texture is likely modified during construction of the golf courses, no analysis of water requirements in relation to soil texture was performed. Similarly, almost all golf courses use golf sprinkler irrigation systems; hence irrigation efficiencies would not appear to be a factor between golf courses.

8.2. Calibration of the Modeled Water Requirements with Metered Data.

Letters were sent in 2007 to each of the golf courses to request metered data per annum for 2006 in order to calibrate the model results. Unfortunately only 4 golf course owners provided data and only two had sufficient detail to be used for calibration.

As expected the results showed that the actual water use for the two golf courses was significantly higher than those provided through the modeling calculation. We anticipated that most golf courses over-irrigate and the results in Figure 44 show that the over-irrigation was between 22 and 40%.

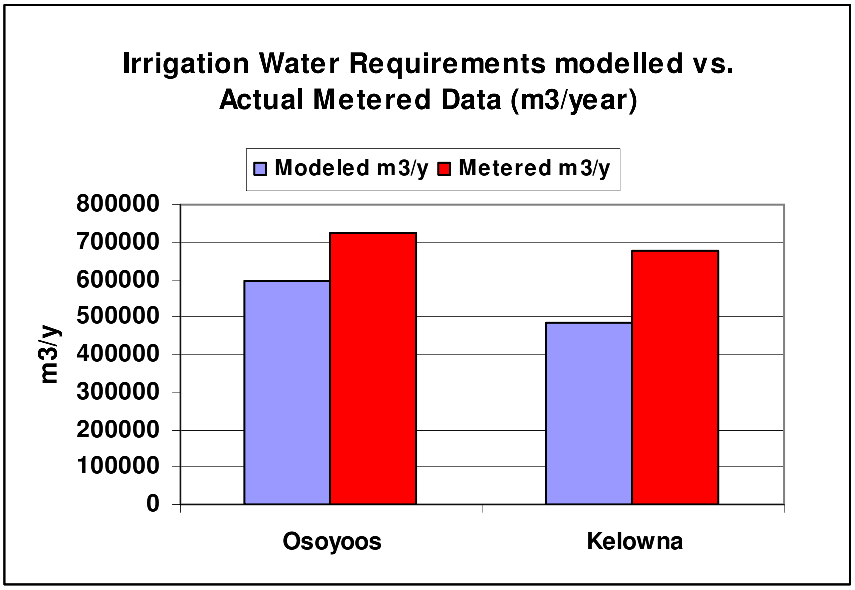

Figure 44. Irrigation water requirements vs. actual water use for two golf courses.

8.3. Relationship between Golf Course Size (ha) vs. Irrigation Water Requirements (m^3/ha/y)

It is obvious that the larger the golf courses the higher the annual irrigation water requirement but when we examine the per hectare requirement in relation to golf course size (ha) it is evident in Figure 45 that only a weak relationship exists. Although there is considerable variability, some of the larger golf courses tend to be less efficient than the smaller ones.

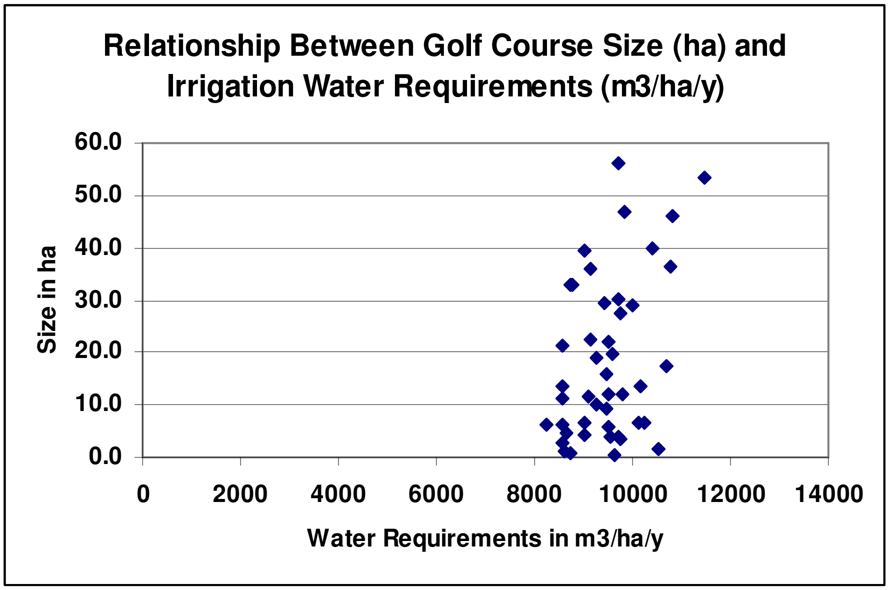

Figure 45. Relationship between golf course size and water requirements (m^3/ha/y).

8.4. Geographic Location of Golf Courses and Irrigation Water Requirement

The difference in irrigation water requirements for golf courses varies according to size of the course and location. The total requirements are provided in 5 different categories in Figure 46. The largest requirements are in golf courses in the RDOS area and one course in Kelowna each requiring more than 400,000 m^3 of irrigation water per year. The efficiency in m^3/ha/y is given in Figure 47 which shows that 8 of the 45 golf courses use more than 10,000 m^3/ha/y of irrigation water per year.

8.5. Differences in Golf Course Irrigation Requirement between Wet and Dry Years

The differences in irrigation water requirements between a wet year (1997) and a dry year (2003) is provided in Figure 48. The range of the difference was between 228 m^3/ha/y and 2830 m^3/ha/y with a mean of 2000 m^3/ha/y.

Assessing the spatial variability between wet and dry years between the local communities reveals that the golf courses in Lake Country, and Penticton have the highest water needs during drought, and golf courses in the NORD, Lake Country, Vernon, Summerland and Penticton are more vulnerable to climatic variability and require between 2190 and 2690 m^3/ha/y more water in a dry year as opposed to a wet year. This represents a difference of between 29-38%. In contrast, golf courses in Kelowna, CORD and Vernon have a difference of < 1600 m^3/ha/y and are much less vulnerable to climatic variability (Figure 49).

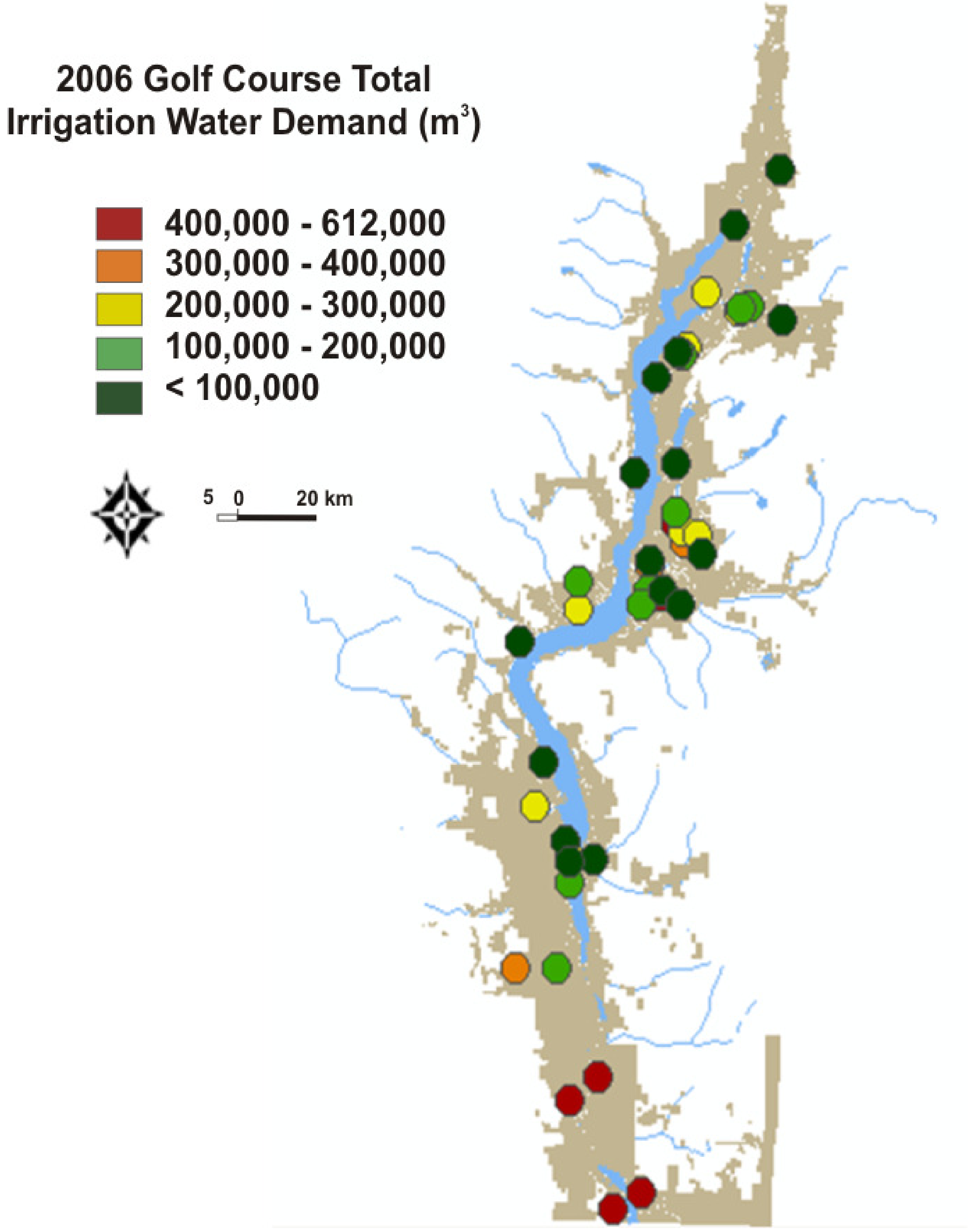

Figure 46. Differences in annual irrigation water requirements for the golf courses in the Okanagan Basin (m^3/y).

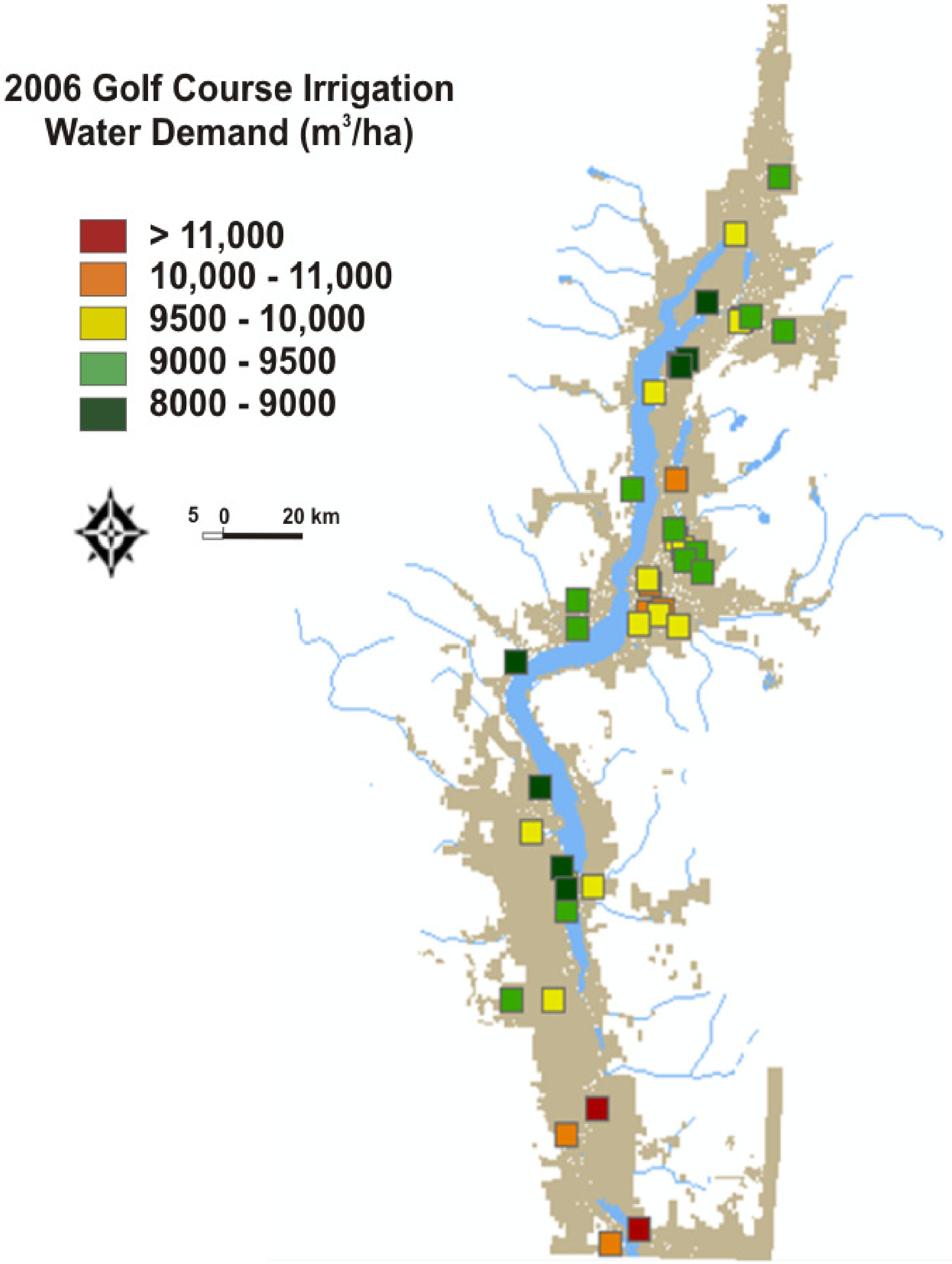

Figure 47. Differences in irrigation water requirements for golf courses in m^3/ha/y.

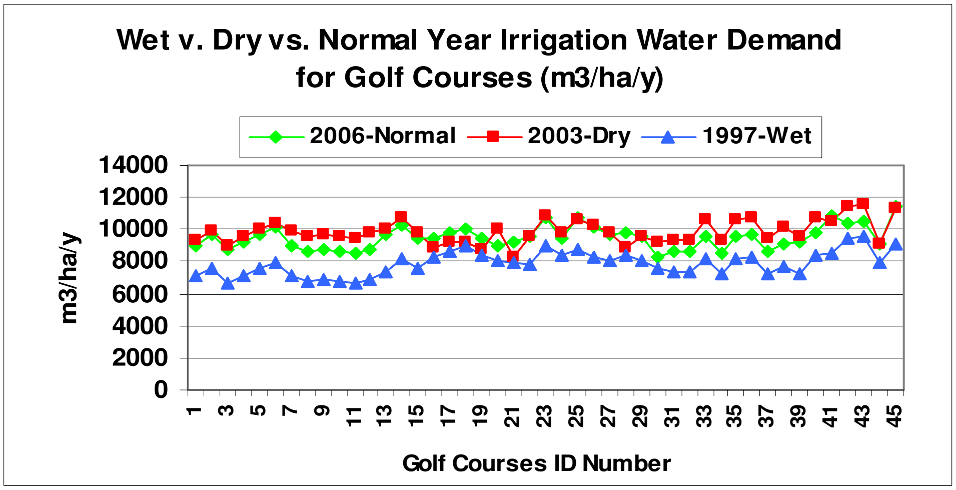

Figure 48. Difference in irrigation water requirements in golf courses between wet, dry and normal years.

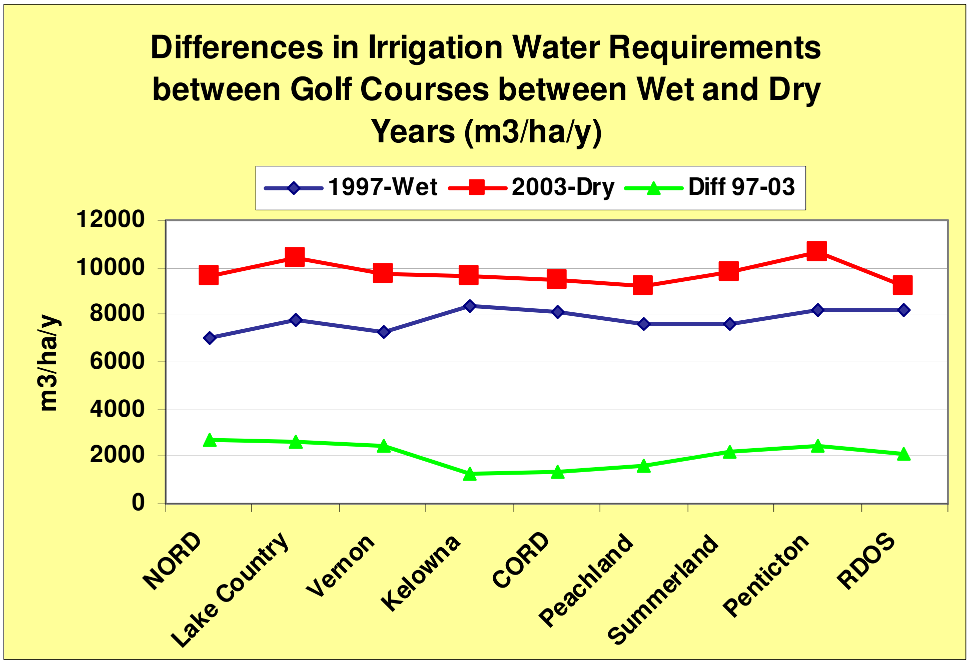

Figure 49. Differences in irrigation water requirements for golf courses in the local communities between a wet and a dry year (m3/ha/y).

8.6. Summary of Irrigation Water Requirements for Golf Courses

In 2006 the 45 golf courses in the Okanagan Basin required over 10 million m3 of irrigation water per year. This translates into a water requirement of over 9700m3/ha/y, which is significantly higher than the 6100 m^3/ha/y average for all the crops. There is a weak positive relationship between size of golf course and the per hectare water requirement. Since there is a relatively small difference in soil texture and most golf courses use the same type of irrigation systems it is the individual management and the spatial variability imposed by the local climate that are the most important factors to consider. From the limited calibration data available it appears that over-irrigation between 20-40% is common.

Spatially, golf courses in the south and one in Kelowna use the largest annual water and 8 golf courses use more than 10000m^3/ha/y.

There are large differences in water requirements between wet and dry years, ranging between a few hundred m^3/ha/y in Vernon to up to 2800 m^3/ha/y in the NORD. This represents a difference of between 29-38% for the most water sensitive golf courses.
This difference is primarily the green water contribution, since during a dry year the rainfall contribution to the golf courses is minimal.

Since golf courses make up about 6-7% of all the irrigation water requirements for all crops, significant savings are possible during drier than normal annual cycles. This may be accomplished by minimizing over-irrigation and significantly reducing the area that is irrigated. Irrigating only the putting areas and reducing the water applications for the rest of the fairway would save water and would result in a more environmentally friendly environment.

9. The Value of Water

If we know the irrigation water requirements for each crop, the yield per hectare, and the farm gate values, it is then possible to arrive at a new index of the value of water. Unfortunately the Province of B.C. and Statistics Canada only collects such data for selected crops and in most cases only as a summary report for the Provincial.

However, as shown in Chapter 3 (Table 4) detailed production data is available for B.C. for the fruit, berry and a few vegetable crops. This can form the basis for developing a number of indices to address the value of water. As shown in Table 13 the total area, the annual yield, the total production and the farm gate values were complied for the major fruit crops in the Okanagan Basin. These data were converted into \$/kg of crop, and \$/ha. This enabled us to arrive at a new water value index in terms of efficiency of m^3/ha/y, and \$/m^3 of irrigation water. The results given in Figure 50 show the value of water for the different fruit crops and it is clearly evident that grapes, followed by pears have the highest water value and are twice that of apricots and plums. Not considering labor and management, it could be argued that those fruit crops that are least water consumptive and fetch the highest farm gate \$ value should be given preference in water short areas. This is illustrated in Figures 51 & 52 which show the comparison of \$/ha of crop vs. m^3/ha/y of irrigation water requirements and \$/kg of crop vs. \$/m^3 of water. Grapes and pears come out to be the most effective fruit in terms of water conservation and \$ gained. It is suggested that this might be an interesting new way of assessing the value of water.

Table 13. Yield, production and farm gate values and a water value index for fruit production in the Okanagan Basin.

Crop	Area ha	Yield tons/ha	Production tons	Farm Gate Value Mio $	Value $ / kg	Value $ / ha	VW Mio m3	Value VW $/m3	VW / ha m3/ha/y
Apples	4297	26.3	113,011	38.50	0.34	8960	27.465	1.40	6392
Grapes	2737	6.4	17,517	27.73	1.58	10132	10.116	2.74	3696
Peaches	447	11.3	5,051	3.77	0.75	8434	3.608	1.04	8072
Pears	236	19.3	4,555	2.80	0.61	11864	1.440	1.94	6102
Plums	71	6.6	469	0.52	1.11	7310	0.547	0.95	7704
Apricots	90	7.2	648	0.53	0.81	5856	0.752	0.70	8356

The use of these types of water value indices is shown in Figures 50-52.

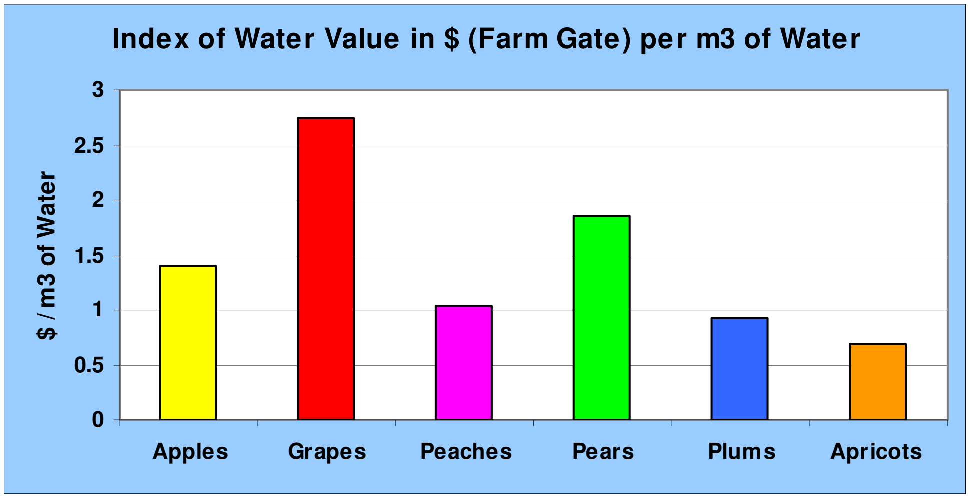

Figure 50. The value of water expressed in $\$/m^3$ ($ farm gate).

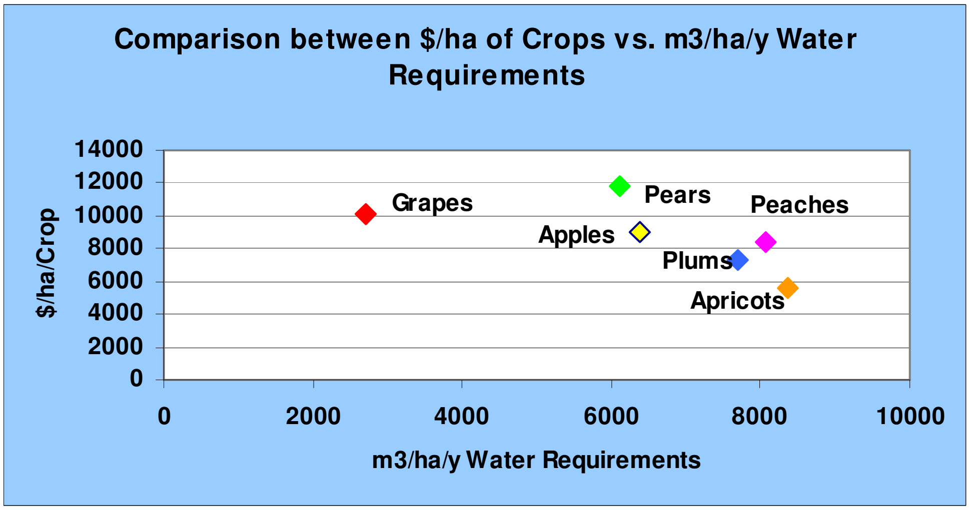

Figure 51. Comparison between $/ha of crops vs. m^3/ha/y of water requirements.

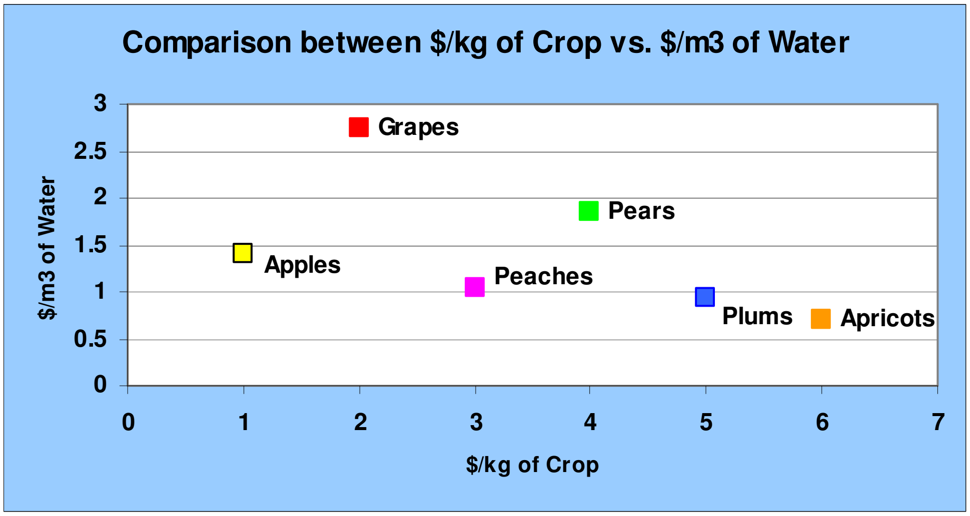

Figure 52. Comparison between $/kg of crops vs. $/m^3 of water.

10. Policy Implications

This is the first time that a detailed irrigation water demand model has been developed for agricultural water requirements in a major river basin in Canada. Since the model just became functional in October 2008, some fine tuning will be necessary. As a result, the data presented in this report is of a preliminary nature but is presented to show the potential usefulness of a water balance approach for decision makers.

Because the model is directly linked to a GIS data base it is possible to determine the irrigation water requirements for every agricultural field within the basin. Crop water requirements are influenced by climatic conditions, soil type, crop type, irrigation system efficiency, and management. The model now enables the users to determine the effects of a combination of these factors and how it affects their water use. Knowing the water requirements for each individual crop in each of the different micro-climatic conditions in the basin will enable decision makers and managers to decide how much water is required to optimize production.

The real advantage of such an approach is as follows:

10.1. Compare water requirements for different crops in different climatic areas in the Okanagan Basin.

As was shown in this report, different crops have different water requirements and matching the most water efficient crop with the most appropriate climatic conditions can result in substantial water savings. As an example, apricots and nectarines are much more water consumptive than the other fruit crops. Thus, when water resources become scarce, it might be wise not to grow water intensive fruit crops. In contrast, grapes are the most water efficient fruit crops and given current trend in converting apple orchards into vineyards can save considerable amounts of irrigation water. Given the relatively large differences in climate between the south of the basin and the north it can now be shown what crops are best grown in the different parts of the basin from a water efficiency perspective. It also allows for an overall comparison of crops that are most water consumptive and what the best strategy would be to conserve water during droughts.

10.2. Make recommendations on water use efficiency

The model results can be compared with the actual water use, wherever water metering is in place. This will prevent over-irrigation and provides farmers with the tools to decide what the most efficient irrigation regime should be for each soil type in each of the climatic zones within the basin. It will also be possible to compare the irrigation system efficiency between farms for the same crop, in the same climate zone and soil setting. Large water savings are possible by optimizing and matching soils, crops and irrigation systems.

10.3. Adaptation to increased climatic variability

Scenarios can now be developed to determine the differences in irrigation water requirement between a wet and a dry year. Over the past 10 years it was shown that up to 40% more water is needed in a wet vs. a dry year. This allows the development of scenarios for climate change adaptation, as it is now possible to determine how much more water is needed to produce the same crops as temperatures increase and precipitation becomes more variable. It also shows what crops are more sensitive to drought and provides us with a strategy to introduce resilience into the agricultural system by focusing on more drought tolerant crops.

This approach also provides a basis for developing a drought strategy. How do we allocate water most effectively during an extended drought? There are fewer water options for multi-year crops like orchards; hence water savings by not planting some annual crops is a more flexible option. The model can now determine how much water can be saved by such actions and what crops save the largest amount of water.

10.4. Building a Scientific Basis for Water Management and Conservation

Having the entire land use data geo-referenced and linked to the irrigation water demand model is a perfect base to develop a real time management tool for irrigation scheduling, efficiency assessment and developing water conservation strategies. It is clear that given current growth rates and agricultural trends that water scarcity in this basin is emerging rapidly. Agriculture which uses 70% of all freshwater in the basin will have to become more water efficient and these new tools provide key information in a most efficient and highly visual manner.

11. Summary and Conclusions

Canada is one of the few countries that has the potential to make a major contribution to reduce the emerging global food crisis since only a small portion of the available freshwater is used for food production. However, there are large regional differences in climate and in the more arid parts of the country much greater attention needs to be placed on determining the water efficiency of different crops. Matching crops to the most appropriate climatic conditions, paying attention to green water management and comparing water requirement for different soils and irrigation systems is critical.

These concepts were demonstrated in a case study in the Okanagan Basin in British Columbia, where an irrigation water demand model was linked to a detailed GIS based land use database. At the time of writing this report the model is still in the evaluation and calibration state and as a result the information presented should be considered preliminary. However, the approach presented provides a novel and comprehensive assessment of the water requirements for different crops at the basin scale in the driest watershed in the country.

Some of the exciting results obtained are:

1. Overall, 70% of all freshwater used in the basin is used for agriculture and 45% of the water allocated to agriculture is to irrigate forage crops, 41% for fruit production and 7% for golf courses.

2. In terms of irrigation water requirements turf, golf courses, apricots and nectarines are the most water demanding production systems, requiring between 8800-10,000 m^3/ha/y of irrigation water. In contrast grapes and cereals are the least water demanding crops with < 4000 m^3/ha/y.

3. Spatially the largest water consumption for agriculture is in the communities in the north and the south and in Kelowna, and in m^3/ha/y Summerland, the Central District and Kelowna have the greatest irrigation water requirements.

4. Soil texture plays a key role in determining water requirements and in the extreme case there is a 58% difference in water requirement between a sandy soil and a heavy clay soil.

5. There is a large difference in efficiency between irrigation systems. Guns and Golf Sprinklers are the most water demanding using > 9700 m^3/ha/y, while drip systems require < 4000m^3/ha/y.

6. There is a 40% greater irrigation water requirement between a relatively wet year (1997) and a dry year (2003), and fruit crops and vegetables seem to be most sensitive to increasing demand during dry years.

7. Water requirements for all livestock production were estimated to be approximately 140 million m^3/y. This includes the water requirements for locally produced feed. However, since it was not possible to determine the proportion of the feed that is irrigated it is not easily possible to compare the livestock virtual water requirements with the overall crop water requirements.

8. There are around 45 golf courses in the basin and all require large amounts of water. The water requirements are the same as for all vineyards but the m^3/ha/y requirements are some of the highest exceeding all crop requirements. Golf courses in the south and some in Kelowna are the largest water users and also the most inefficient on a m^3/ha/y basis. Since 7-8% of all available freshwater in agriculture is used for golf courses there are significant savings to be made during dry cycles by

reducing the irrigated areas in the fairways. Limited calibration data showed the over-irrigation by 21-40% is a common practice.

9. Having available data for yields, production, and farm gate values, it is possible to develop a water value index for each crop in the basin. This was done in terms of $\$/m^3$ and m^3/ha of irrigation water and the results for the fruit crops showed that using water for grapes is more valuable and than for apples and pears. All other fruit crops are substantially less valuable in terms of farm gate $\$/m^3$ of irrigation water requirement.

10. Combining the irrigation water demand model with the GIS database enables the determining of the irrigation water requirements for every crop on every field in the Okanagan Basin. This is setting the stage for developing strategies for water re-allocations during drought and helps predict water requirements for agricultural production in simulations of climate change scenarios. It allows for a comparison of water requirements for all different crops, determines efficiency of water use depending on crops, soil texture, irrigation systems, and climatic conditions.

11. These new tools will revolutionize how we determine a water balance for all water users in a watershed context. It will give decision makers for the first time scientifically based tools to make educated decisions on how water resources are distributed, allocated and used. This type of decision support tool will be instrumental in developing a comprehensive strategy for how to adapt to drought and climate change and how to effectively influence land use decision making in an effort to conserve water and use it in the most efficient manner.

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Appendix 1. Irrigation water requirement difference between wet and dry years for all crops in m^3/ha/y.

Crop	Area	Wet Year 1997	Dry Year 2003	Difference 1997-2003	Difference 1997-2003	Normal Year 2006
	ha	M3/ha/y	m3/ha/y	m3/ha/y	%	m3/ha/y
Alfalfa	4028.8	2978	4147	1169	39	3904
Apples	4292.7	4617	6925	2309	50	6398
Apricot	89.5	6390	8898	2508	39	8407
Asparagus	17.1	2961	5353	2392	81	4845
Berry	25.0	4064	6379	2315	57	5809
Blueberry	2.1	5046	7899	2853	57	7219
Cereal	881.9	2549	3611	1062	42	3340
Cherry	1068.6	5121	7436	2315	45	7000
Corn	854.0	2486	4799	2313	93	3908
Cover Grass	1348.8	157	197	40	40	194
Forage	65.0	4876	6423	1547	32	6201
Ginsing	26.8	2955	5345	2390	81	4705
Golf	1102.1	7699	9437	1738	23	9232
Grape	2737.5	2587	4123	1536	59	3695
Grass	10896.3	2786	3639	853	31	3470
Greenhouse	28.1	23055	25390	2335	10	24872
Nectarine	26.9	6704	9119	2414	36	8707
Nursery	360.1	5343	7752	2409	45	7212
Nuts	27.7	4306	6046	1740	40	5682
Peach	446.9	6028	8501	2474	41	8073
Pear	236.0	4476	6508	2032	45	6101
Plum	71.1	5692	8092	2400	42	7694
Raspberries	7.9	3744	5641	1898	51	5159
Sourcherry	52.9	3632	5208	1577	43	4792
Strawberry	26.9	4831	6359	1528	32	5904
SweetCorn	28.5	3724	5084	1360	37	4720
Tomato	2.0	4733	6388	1655	35	5951
Turf	240.0	8296	10118	1822	22	9811
Vegetables	451.3	5639	7103	1464	26	6768
Average	1015.0	5085	6962	1877	44	6543