An Assessment of the Most Suitable Water Levels for Osoyoos Lake (Study 1)

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Submitted to:
Alvin Josephy
Contract Coordinator
Washington State Department of Ecology
300 Desmond Drive SE
Lacey, WA 98503

Submitted by:

State of Washington Water Research Center
Washington State University
Pullman, Washington 99164-3002

Lai Tran, Kirti Rajagopalan and Wes Helander, Civil and Environmental Engineering
Michael Barber, State of Washington Water Research Center
Marc Beutel, Civil and Environmental Engineering
Cailin Orr, School of Earth and Environmental Science

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Executive Summary

The focus of this study (Study 1) was to examine the projected 2040 water demand from Osoyoos Lake and explore ranges of lake elevations that could potentially be used to meet the demand. The purpose was to examine whether or not it would be necessary to modify the specifications of the current Order of Approval when it comes up for renewal in order to help meet the projected demand. The basis for this recommendation was predicated on existing data and reports. We also considered the views of different stakeholders who are affected by lake levels. Based on our results, specific recommendations are summarily listed below.

Recommendations

- From the study results, we do not see a necessity in changing the current Order specifications related to Osoyoos Lake elevation management. The elevations can be managed at levels desired by stakeholders affected by lake levels.
- Inflows are of primary importance in Osoyoos Lake since storage capacity of the lake is limited. Therefore, it is worthwhile to explore the option of managing Osoyoos Lake based on inflows (and having the new Order include inflow based criteria) rather than elevation targets or using a hybrid management approach.
- The percent of the demand that can be met is mainly a function of the amount of inflow into Osoyoos Lake. Storage in Osoyoos Lake has limited ability to address deficits. Therefore, there is a need to try to negotiate minimum trans-border flows that are more in line with historical inflows analyzed in this study rather than agreed upon flows so that a degree of certainty can be attached to what percentage of the demand can be met.
- Instream/fisheries requirements constitute about 90% of the total demand in most months. Hence, this is the component that will be affected the most in case of a deficit. There is a need to better quantify the exact implications of not meeting all of these requirements and come up with minimum required inflows at an acceptable risk in addition to optimal requirements. This will help manage Osoyoos Lake based on expected inflow amounts and allow meeting instream/fisheries requirements to the maximum extent possible.

1 Introduction and Objectives

Zosel Dam is located on the Okanogan River near the city of Oroville in north central Washington State. The dam sits in the Okanogan River downstream of Osoyoos Lake, which stores water for irrigational, domestic, recreational, and fishery uses. Osoyoos Lake is part of the Canadian Okanagan River Basin in British Columbia (BC) and the United States (US) Okanogan River Basin in Washington (WA) (Figure 1). Zosel Dam has four spillway gates with a capacity of 3,000 cubic feet per second (cfs) (85 cubic meters per second (m^3/s)) and two fish ladders (Ecology, 1990). The Oroville Tonasket Irrigation District (OTID) operates the dam under contract with the Washington State Department of Ecology (Ecology), which has the direct responsibility over the dam. The International Joint Commission, under the Boundary Water Treaty of 1909, prescribes the allowable levels of Osoyoos Lake in Canada and the United States in an Order of Approval. The International Joint Commission appoints a six member (three from US and three from CAN) International Osoyoos Lake Board of Control to supervise the implementation of the provisions of the Order of Approval (www.ijc.org). The current Order of Approval will terminate on February 22, 2013.

There are a number of studies being conducted to examine what, if any, changes need to be made regarding the operation of Zosel Dam before renewing the Order of Approval. The State of Washington Water Research Center (SWWRC) at Washington State University, as part of a more comprehensive Osoyoos Lake Drought Study, was tasked to assess of the most suitable water levels for Osoyoos Lake to inform development of a new Order of Approval (Study 1).

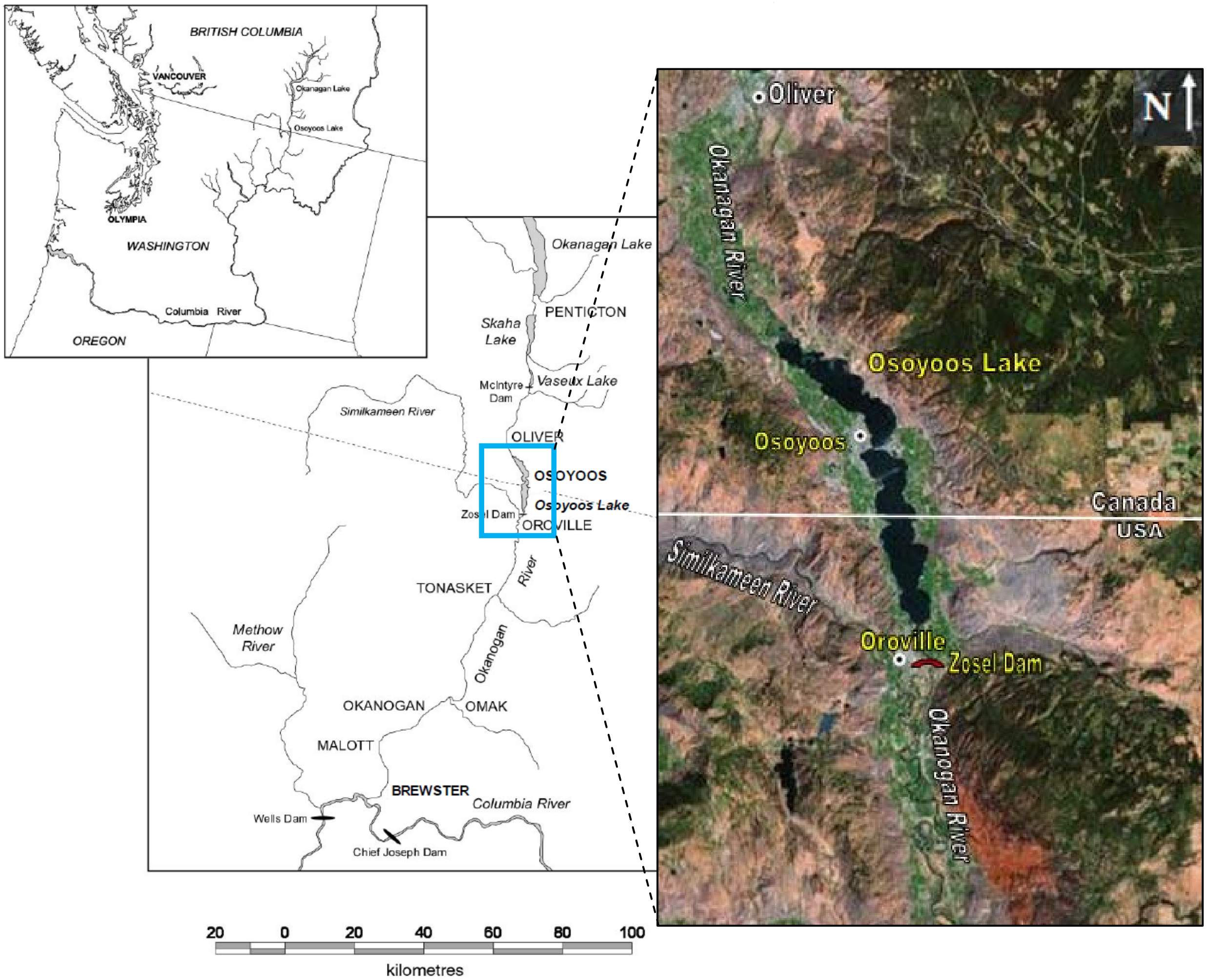

Figure 1. Map of Osoyoos Lake including Okanagan River (BC), Okanogan River (WA), Similkameen River, and the town of Osoyoos (BC), and the city of Oroville (WA). Modified from Google Earth and Glenfir Resources, 2006.

The overall objectives of this study are to validate the preferences for minimum as well as maximum lake levels for both drought and non-drought years and recommend suitable levels to meet water demands in drought years. As indicated in the original scope of work our goal was to analyze existing information to answer the following key questions:

1. What is the volume of water that will be needed from Osoyoos Lake by the year 2040 (assuming the 2013 Orders will be in effect for approximately 25 years)?
2. What range of lake levels will meet storage requirements?
3. Could wet and dry years be managed under a single set of lake elevation targets?
4. Who are the stakeholders affected by lake levels and what are the impacts of the lake levels necessary to store the required volume of water?
5. Can a portion of the required water be supplied from off-site locations?

2 Background

2.1 Lake characteristics and Zosel Dam operations

Osoyoos Lake is composed of three major basins: north, central, and south (Figure 2). Based on a 1966 bathymetric map (Figure 3) developed by the Province of BC, the lake has a surface area of 5,756 acres (2,329 ha). The maximum depth of the lake in BC is 208 feet (63.4 m) in BC and 80 feet (24.4 m) in WA. The surface area of the lake in BC, which includes the north and central basins and part of the south basin, is 3,706 acres (1,500 ha). The surface area in WA, which includes only part of the south basin, is 2,049 acres (829 ha). Using methods outlined by Taube (2000), we calculated the volume of the lake as a function of elevation (Table 1). The maximum lake depth is controlled by the natural sill at the lake outlet, which is at elevation 906.0 feet (David Cummings, Ecology, personal communication). At this elevation, the lake has a volume of 242,200 acre-feet (298.8 million m^3) rounding to the nearest hundred. At an elevation of 913.0 feet (278.13 m), the lake volume is 272,300 acre-feet (335.9 million m^3). During drought conditions, the dam could operate between 910.5 to 913.0 feet (2.5 feet of storage) in the summer, resulting in a storage of around 14,000 acre-feet (17.3 million m^3). For normal conditions, the dam operates between 909.0 to 911.5 feet in the winter and between 911.0 to 911.5 feet in the summer.

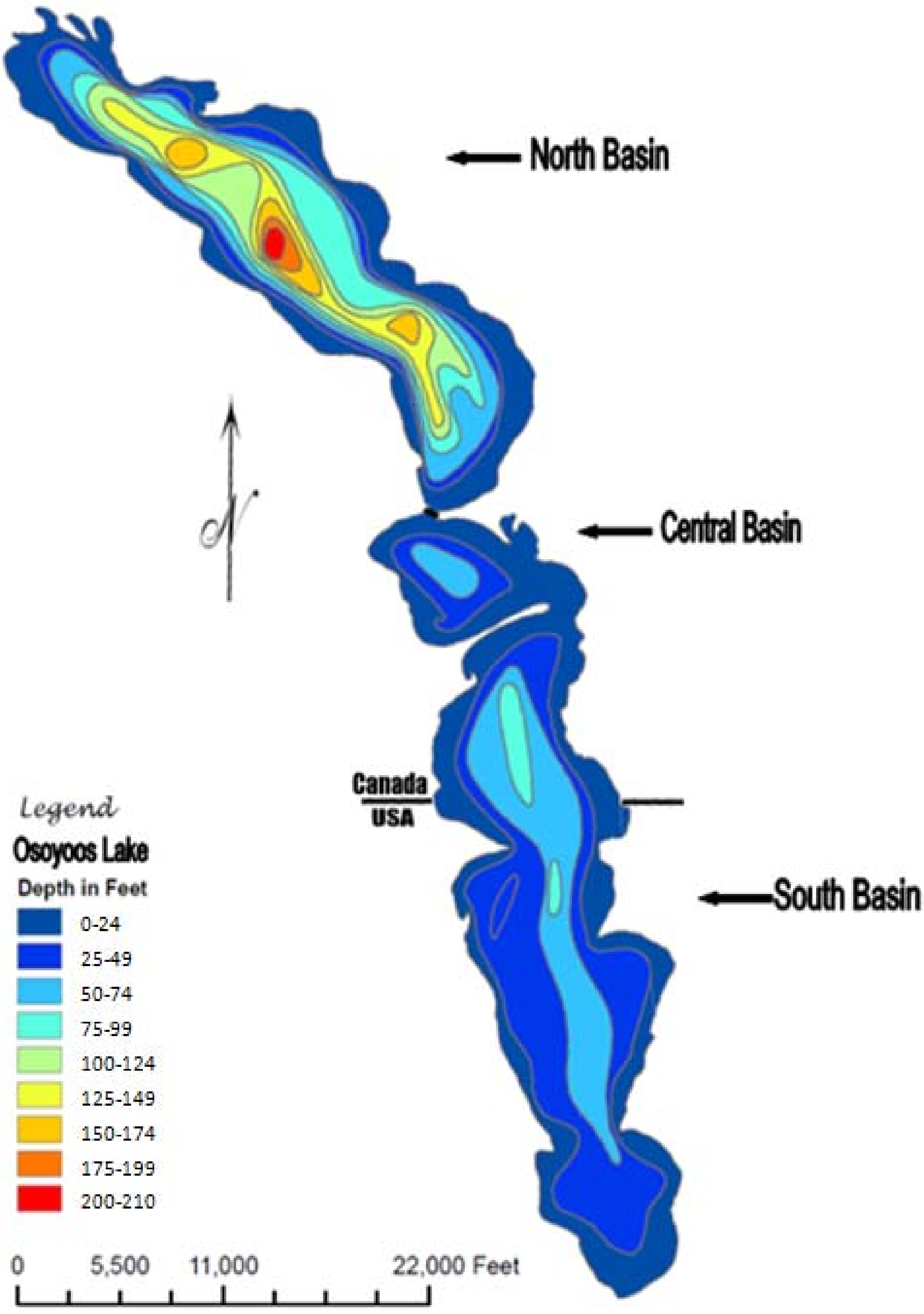

Figure 2. A Bathymetric map updated from Anglers Atlas, 2002. Map survey conducted August 1966 by the Province of BC

Table 1. Osoyoos Lake volume and storage for drought and normal conditions.

Lake Elevation, ft (USCGS)	Lake Volume, acre-feet (million m^3)	Lake Storage during winter normal condition, acre-feet (million m^3)	Lake Storage during summer normal condition, acre-feet (million m^3)	Lake Storage during summer drought condition, acre-feet (million m^3)
913.0	272,300(335.9)	22,100(27.3)	11,200(13.8)	14,000(17.3)
912.5	269,500(332.4)	19,300(23.8)	8,400(10.4)	11,200(13.8)
912.0	266,700(329.0)	16,500(20.4)	5,600(6.9)	8,400(10.4)
911.5	263,900(325.5)	13,700(16.9)	2,800(3.5)	5,600(6.9)
911.0	261,100(322.1)	10,900(13.4)	Datum	2,800(3.5)
910.5	258,300(318.6)	8,100(10.0)	-	Datum
910.0	255,600(315.3)	5,400(6.7)	-	-
909.5	252,900(311.9)	2,700(3.3)	-	-
909.0	250,200(308.6)	Datum	-	-

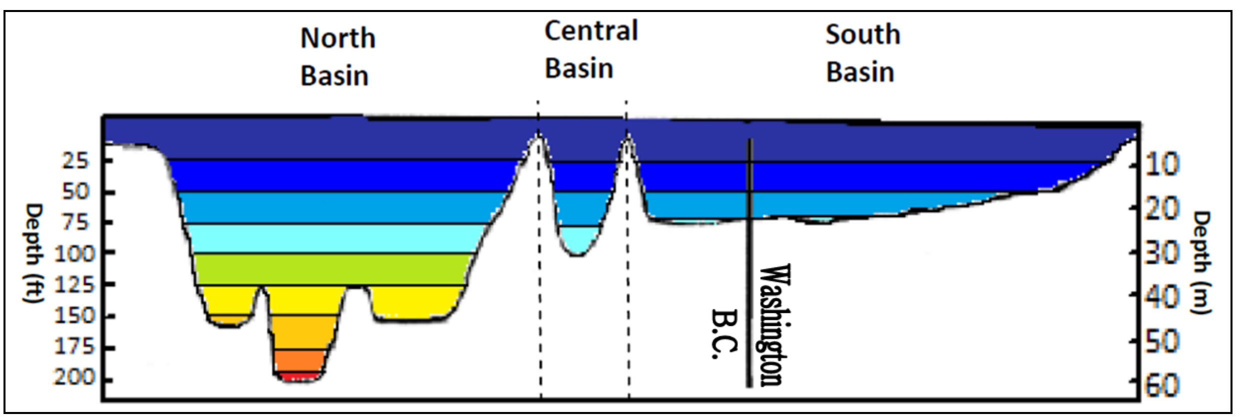

Figure 3. Cross-sectional view of Osoyoos Lake with depths for the north, central, and south basins modified from Hyatt et al. (2007).

Osoyoos Lake levels are currently managed between elevations of 909 feet and 913 feet (288.06 m and 278.28 m, respectively). The Oroville Tonasket Irrigation District operates and manages Zosel Dam as per Condition 7 of the 1982 Order of Approval to the extent possible, thereby keeping Osoyoos Lake surface elevations between 911.0 and 911.5 feet from April 1 to October 31, except under drought conditions. Additionally, the order requires that Osoyoos Lake water levels should be maintained between 909.0 and 911.5 feet from November 1 to March 31 (Figure 4).

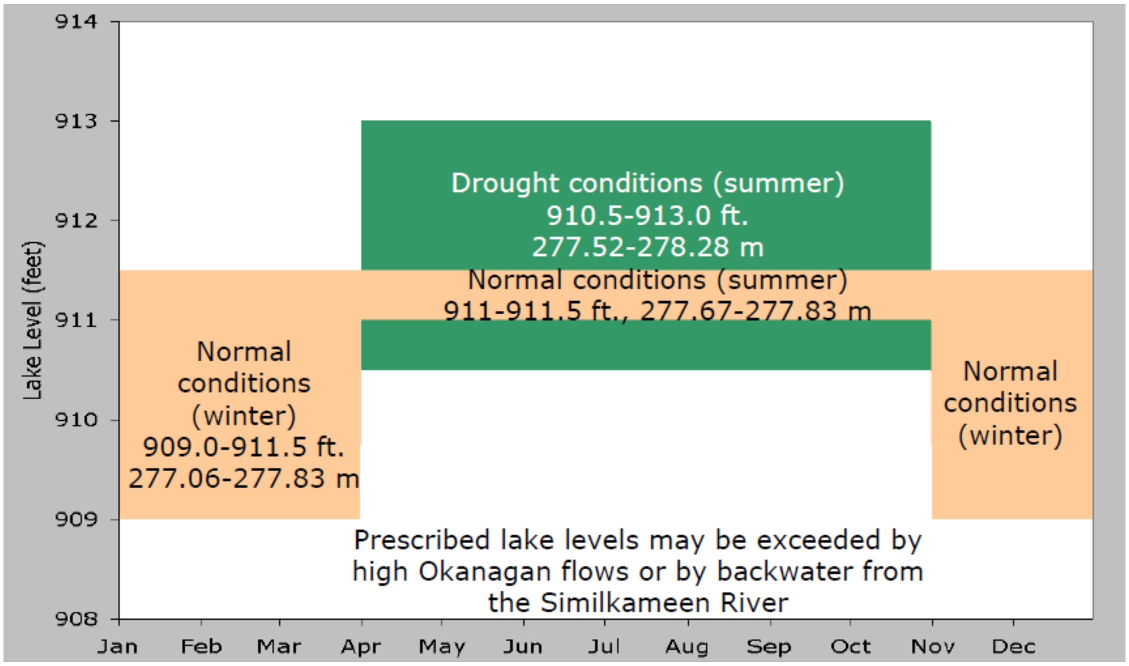

Figure 4. Diagram of the International Joint Commission Order of Approval for Condition 7 (tan) for normal water years and Condition 8 (green) for drought conditions (International Osoyoos Lake Board of Control, 2009).

During drought years, the 1982 Order of Approval allows for the level of Osoyoos Lake to be raised to 913.0 feet beginning April 1 to allow for additional storage for domestic use, irrigation use, and fish flows (Figure 4). Lake elevation must be returned to below 911.5 feet by October 31. A drought year is declared when any of the following criteria (Conditions 8a, 8b, and 8c of the 1982 Order of Approval) are met. However, at the discretion of the Osoyoos Board of Control and when the conditions are no longer met, drought declarations can be rescinded.

8a. The volume of flow in the Similkameen River at Nighthawk, WA for the period April-July as calculated or forecasted is less than 1.0 million acre-feet (1.2 billion m^3); or

8b. The net inflow to Okanagan Lake for the period April through July as calculated or forecasted is less than 195,000 acre-feet (240 million m^3); or

8c. The level of Okanagan Lake fails to or is forecasted to fail to reach an elevation of 1122.8 feet (342.23 m) Canadian Geodetic Survey Datum during the months of June or July.

Dam operations are also based on a number of current regulations related to fishery flows, trans-border flows, and instream flows including: (1) the Okanagan and Okanogan Rivers flow requirements for salmon and steelhead production plan (Washington State Department of Fish and Wildlife, 1990), (2) a 1980 British Columbia/Washington State cooperation plan for trans-border flows (British Columbia Washington State, 1980), (3) a 1974 US water resources agreement regarding instream flows at Oroville, WA (Washington Administrative Code, 1988).

According to the non-binding agreement in the 1980 between British Columbia Ministry of Environment and Washington State Department of Ecology, during normal and first year droughts the Ministry of Environment will try to operate the minimum trans-border flow range from 175 cfs (5.0 m^3/s) in January to a peak of 340 cfs (9.6 m^3/s) in August and back down to 175 cfs (5.0 m^3/s) in November at Oliver, BC gauge. However, during the second and subsequent drought years, the flows would not be less than 100 cfs (2.83 m^3/s) from April 1st through October 31st at the border (British Columbia Washington State, 1980).

The confluence of the Similkameen River and the Okanogan River is approximately 3 miles downstream of Zosel Dam, although there is a connector ditch between the two rivers north of Driscoll Island that is only about 1.25 miles downstream of the dam. The terrain in this area is relatively flat with less than 10 feet of elevation difference between the water elevation at the dam and the water surface at initial contact with the Similkameen. The mean annual flow in the Similkameen River is 3.5 times higher than the flow of the Okanogan River. During very high flows in the Similkameen River, typically between April and the end of June, the flow direction in the Okanogan River may reverse, moving upstream, overtopping the weir on the left side of Zosel Dam, and discharging into the south end of Osoyoos Lake. The combination of backwater and inflow from the Okanagan River upstream of Osoyoos Lake can increase lake levels above 913 feet. This is a natural phenomenon that would occur irrespective of whether the dam existed or not. Condition 9 of the 1982 Order of Approval allows the dam operator to manage the lake level as close as possible to the elevations in Conditions 7 and 8 in years of appreciable backwater from the Similkameen River.

In a drought year of 1992, the prolonged exposure of lake level above 912.5 had a significant public concern on the flooding of waterfront property and beaches. As a result, for 1993(only) Ecology and BC Ministry of Environment had signed a non-permanent memorandum of understanding (MOU). The agreement states that during a drought year, Ecology will not raise the lake above 912.5 feet, and in return the BC Ministry of Environment will release up to an additional 2,850 acre-feet (3.5 million m^3) from Okanogan Lake in April or May when pulsing flows are required to flush migrating sockeye salmon smolts out of Osoyoos Lake and downstream through Zosel Dam (IOLBC, 1994). There have been a number of formal and, more recently, informal agreements reached at the local level between Ecology and the MOE regarding lake level management and minimum trans-border flow augmentation in drought years. Each agreement is specific to the operation during that drought year only. The agreements do not imply that similar agreements would necessarily be reached in any subsequent drought years as it has always been understood that the decision as to whether or not a future agreement would be made will always be based on water supply conditions in the individual year. The dam continues to operate below 912.5 feet to the extent possible during drought years (Tom Scott, Oroville Tonasket Irrigation District personal communication).

2.2 Normal year and drought year classifications

Based on data presented at the International Osoyoos Lake Board of Control 2010 annual meeting, drought has been declared 12 times in the 24 year span between 1987 and 2010 (Table 2). In drought years, lake levels were generally maintained between 910.5-913.0 feet (Figure 5). The declaration was rescinded in four years when either the drought condition criteria were not ultimately met (1998, 2004, 2010) or the rescindment occurred prematurely (1987) (Figure 6). Thus, drought was declared in 8 of 24 years, giving a drought occurrence frequency of about one in three (33%). Drought criteria conditions 8a (low flow in the Similkameen River), 8b (low inflow to Okanogan Lake) and 8c (low levels in Okanogan Lake) were met 33% of the time, 25% of the time and 21% of the time respectively (IOLBC, 2010). In 1998, the Board rescinded the drought declaration as a result of unusually heavy precipitation in May. The lake and dam were operated initially as drought year between April 1 and July. Then, after the declaration was rescinded, it was operated as a normal year between July 10 and October 31. Similarly, a drought declaration was rescinded on July 2, 2004 due to a revised forecast of high runoff in the Similkameen and Okanogan Basins. On June 21, 2010 a drought declaration was also rescinded and the lake levels were lowered to 911.5 feet by July 13. However, year 2010 (listed in Table 2) was not used to analyze supply and demand due to lack of flow data at the time.

Twelve out of 24 years between 1987 and 2010 were considered non drought years according to the Order of Approval (Table 2). During these years, the target lake levels were 909.0 and 911.5 feet for winter and 911.0 and 911.5 feet for summer. However, the Okanogan and Similkameen Basins are snowmelt-dominated regions, and the rapid melt of snow and ice, caused the lake to increase above 911.5 feet from April through June (Figure 7). The years 1990, 1996, and 1997 were extreme wet years with prolonged lake elevations above 913.0 feet (Figure 8). During these years the Similkameen River backflowed over the top of the 195 feet (59.4 m) overflow weir on Zosel Dam and into Osoyoos Lake.

Table 2. Drought declaration during 1987 to 2010 after completion of the new Zosel Dam on February 22, 1988 (IOLBC, 2010)

Year	Condition 8(a)	Drought Criteria met?	Condition 8(b)	Drought Criteria Met?	Condition 8(c)	Drought Criteria Met?	Drought Declared?	Drought Rescinded?
1987	1,003,453	no	178,900	yes	1,123.11	no	yes	yes
1988	933,296	yes	192,700	yes	1,122.32	yes	yes	no
1989	1,060,974	no	296,700	no	1,123.54	no	no	no
1990	1,566,775	no	536,000	no	1,124.90	no	no	no
1991	2,299,868	no	479,100	no	1,123.42	no	no	no
1992	735,541	yes	123,600	yes	1,121.87	yes	yes	no
1993	938,989	yes	458,300	no	1,123.56	no	yes	no
1994	885,375	yes	302,600	no	1,123.39	no	yes	no
1995	1,305,004	no	368,400	no	1,123.17	no	no	no
1996	1,661,380	no	654,000	no	1,124.07	no	no	no
1997	1,946,984	no	863,100	no	1,124.81	no	no	no
1998	1,230,960	no	391,000	no	1,123.47	no	yes	yes
1999	1,706,980	no	560,700	no	1,123.39	no	no	no
2000	1,070,039	no	431,200	no	1,123.41	no	no	no
2001	566,825	yes	192,300	yes	1,122.72	yes	yes	no
2002	1,546,158	no	417,900	no	1,123.70	no	no	no
2003	781,500	yes	137,600	yes	1,122.46	yes	yes	no
2004	1,143,082	no	269,000	no	1,122.80	no	yes	yes
2005	622,230	yes	328,900	no	1,123.87	no	yes	no
2006	1,065,000	no	452,800	no	1,123.90	no	no	no
2007	1,372,000	no	260,237	no	1,123.01	no	no	no
2008	1,221,200	no	306,400	no	1,123.77	no	no	no
2009	808,400	yes	148,570	yes	1,122.40	yes	yes	no
2010*	1,222,000	no	308,880	no	1,123.78	no	yes	yes

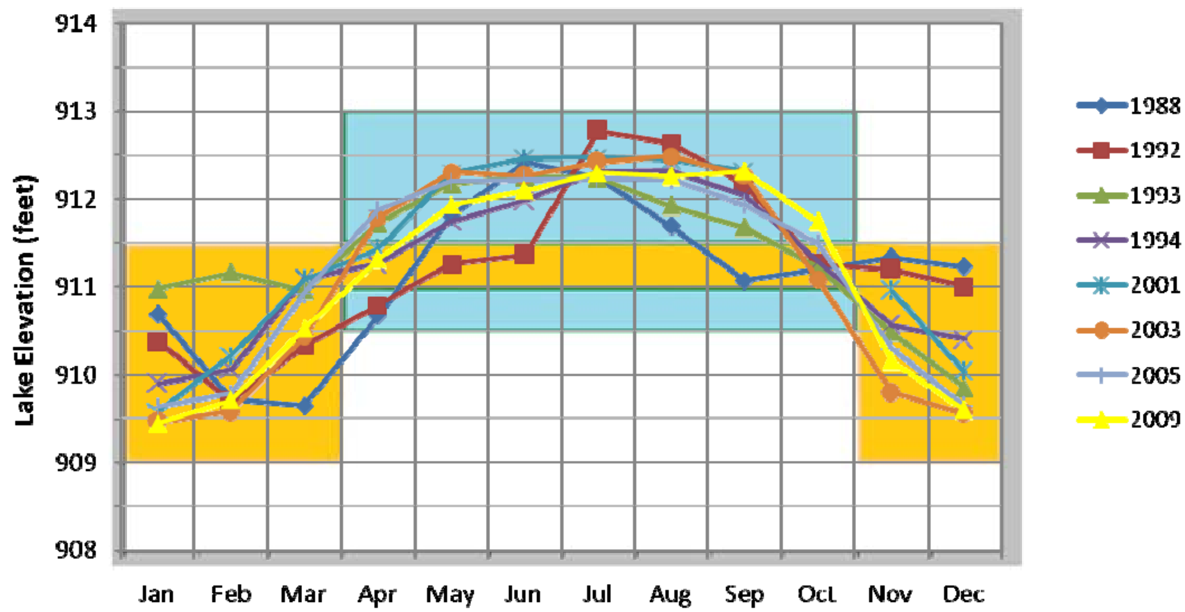

Figure 5. Monthly mean lake elevations for the eight drought years between 1987 and 2010.

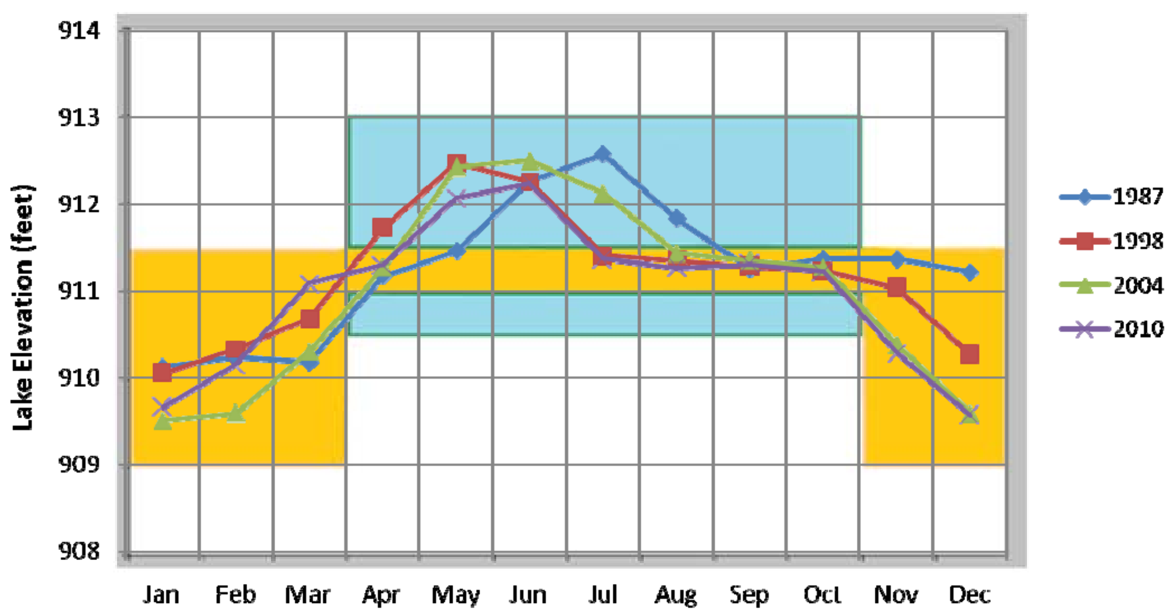

Figure 6. Monthly mean lake elevations for the four years between 1987 and 2010 when the drought declaration was rescinded.

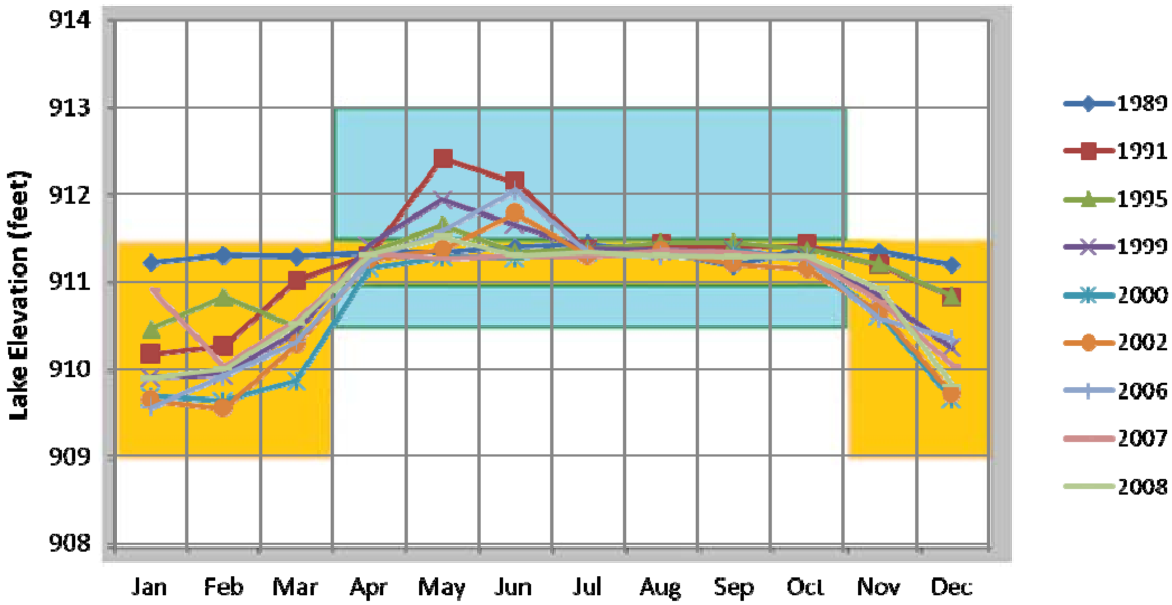

Figure 7. Monthly mean lake elevations for nine of twelve normal years between 1987 and 2010.

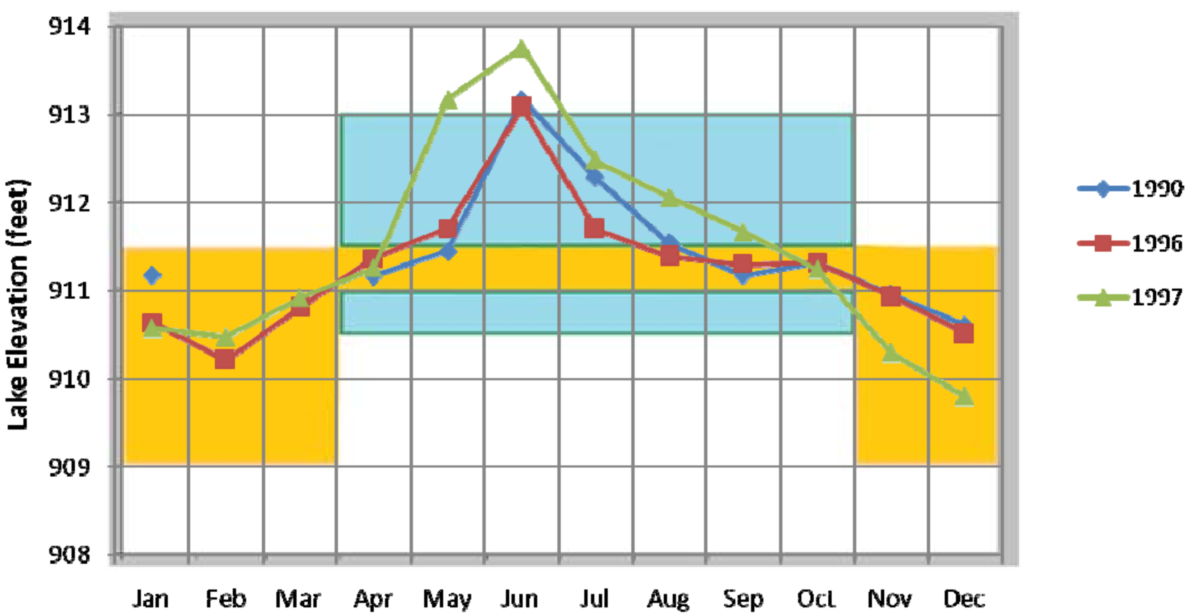

Figure 8. Monthly mean lake elevations for the three of twelve normal years when elevation exceeded 913.0 feet, 1987-2010.

3 Expected water demand in 2040s

In order to address the water demand expected in 2040s, we projected the increases of residential and agricultural demands due to population increase and climate change. Assuming the water rights are near fully appropriated, we kept the current water rights amounts as a cap for the maximum agricultural demand in future. We also considered in-stream flows and fisheries requirements while considering total demand in 2040.

We look at four different demand scenarios, the details of which are listed in Table 3. Scenarios 1 and 2 relate to current demand and scenarios 3 and 4 relate to 2040 demand. Current demand was considered as two scenarios. Scenario 1 uses agricultural demand based on actual crop irrigation requirements (plus transmission losses). Scenario 2 is a more conservative approach, which is using the water right of 4 feet per irrigated acre for the cities of Osoyoos and Oroville (Ron Fretwell, RHF Systems Ltd and Tom Scott, Oroville Tonasket Irrigation District, personal communication). For scenarios 3 and 4, the 2040 demand is based on low population growth and high population growth scenarios for residential water use. The 2040 agricultural water demand is capped at the current water rights of 4 acre-feet per acre. The assumption is that, additional water rights for summer diversions will not be given out since the water rights are currently over appropriated.

This section is organized as follows. Section 3.1 deals with residential, commercial and municipal water demand. Section 3.2 discusses agricultural demand in terms of water rights and actual irrigation need. Section 3.3 discusses the instream flow and fisheries requirements. Section 3.4 provides a summary and discussion of the total demand.

Table 3. Scenarios of demands considered

Scenario	Residential/Municipal/ Commercial Demand	Agricultural Demand	Instream flow/ Fisheries Demand
Scenario 1 (Current demand)	Current	Current-irrigation demand	Max flow of WA Administrative Code instream flow and Fisheries criteria flow
Scenario 2 (Current demand)	Current	Water rights of 4 feet/acre	Max flow of WA Administrative Code instream flow and Fisheries criteria flow
Scenario 3 (2040 demand)	Year 2040 (Low population growth scenario)	Water rights of 4 feet/acre	Max flow of WA Administrative Code instream flow and Fisheries criteria flow
Scenario 4 (2040 demand)	Year 2040 (High population growth scenario)	Water rights of 4 feet/acre	Max flow of WA Administrative Code instream flow and Fisheries criteria flow

3.1 Residential, commercial and municipal demand

Three main cities, Oroville in WA and Oliver & Osoyoos in BC are located near Osoyoos Lake. Since Oliver gets 75% of its water from the Okanagan River and 25% from ground water wells, the demand from this city was ignored in this study. The other cities take their water primarily from ground water sources. Due to their proximity to Osoyoos Lake and given the fact that the source of ground water recharge is not clear we decided to include them for the purposes of this report.

The plan was to collect metered water use data, however, the data was unavailable or difficult to obtain due to the limited time and the short of resources available from local governments. As an alternative, we obtained the current water demand in monthly percent used and the per capita usage from the City public works departments of Oroville, WA and assume the same per capita usage for Osoyoos, BC. Based on per capita consumption and 2040 population projections (high and low growth rates), we projected water demand for the cities in 2040 (Table 4). Population growth rates for Oroville are based on US census data for 1990 and 2000 and US Office of Financial Management data for 2008 (www.city-data.com). Population growth rates for Osoyoos were based on 1991, 1996, 2001 and 2006 census data from BC Statistics. Projected annual water demand ranges from around 368 to 546 acre-feet (0.45 to .0.68 million m^3) for Oroville, WA. These numbers are higher, around 1,719 to 3,048 acre-feet (2.1 to 3.8 million m^3) for Osoyoos.

Table 4. 2040 Annual Residential/Commercial/Municipal Water Demand Projections.

	Oroville	Osoyoos	Total
Current Population	1,638	5,133	6,771
Annual Population Growth Rate (low growth scenario)	0%	1.5%	-
Annual Population Growth Rate (high growth scenario)	1.0%	3.0%	-
2040 Projected Population (low growth scenario)	1,638	7,676	9,314
2040 Projected Population (high growth scenario)	2,439	13,602	16,041
Per Capita Water Demand, gallons per day	200	200	-
Current Annual Water Demand, acre-feet	368	1,151	1,519
2040 Annual Water Demand (low population growth rate), acre-feet	368	1,719	2,087
2040 Annual Water Demand (high population growth rate), acre-feet	546	3,048	3,594

Our projected demands have a few methodological caveats. The total projected water demand values for the City of Oroville might be underestimated. Oroville classifies its water users into three categories: city users, north end water users, and east lake water users (City of Oroville, Appendix to Water Use Efficiency Goals, 2003). Population data for the City of Oroville matches with the number of city users, who constitute about 70% of the total users. So the other 30% must be accounted for by census as population in other areas, which we ignored in this study. In addition, the per capita water demands used in our projections were based on commercial and municipal use, in addition to residential use. Thus our projections based on per capita use may be overestimated. Climate change effects are expected to increase regional residential water demand by 10 to 20% (Neilson et al., 2001; Okanagan Water Supply and Demand Project, Phase 2, 2010). Since the per capita usage, which is used to find future water demand is overestimated, we ignored the climate change effects so that we do not over estimate demand too much. The assumption is that this increase will have been captured in our over estimation of demand. The total projected annual demand for the cities of Oroville and Osoyoos in 2040 ranges from around 2,087 to 3,594 acre-feet (2.57 to 4.43 million m^3).

Monthly water demand data was available for the city of Oroville, WA. This data was used to find the percentage distribution of demand by month to be applied to Oroville and Osoyoos annual demand. Table 5 shows the total monthly current and 2040 water demand for residential, commercial and municipal.

Table 5. Total residential, commercial and municipal monthly water demand for the cities of Oroville and Osoyoos.

Month	Monthly % use	Current demand (acre-feet)	2040 demand; low growth rate (acre-feet)	2040 demand; high growth rate (acre-feet)
Jan	5%	76	104	180
Feb	5%	76	104	180
Mar	5%	76	104	180
Apr	5%	76	104	180
May	6%	91	125	216
Jun	15%	228	313	539
Jul	15%	228	313	539
Aug	15%	228	313	539
Sep	13%	197	271	467
Oct	6%	91	125	216
Nov	5%	76	104	180
Dec	5%	76	104	180
Total		**1,519**	**2,087**	**3,594**

3.2 Agricultural demand

The monthly agricultural water demand was calculated separately for WA and BC. The area of different crops cultivated in the area was obtained from various sources and the consumptive use was calculated using the Washington Irrigation Guide (Washington Irrigation Guide Appendix A, 2007), which lists irrigation requirements by crops. We also try to match these statistics with current water rights in the area. WA demand is described first followed by demand in BC.

In order to develop the demand for the WA we used WA Land Use Maps, Water Rights information from Ecology and interviewed Tom Scott from Oroville Tonasket Irrigation District. Land use maps obtained from the Washington State Department of Agriculture include data on irrigated areas. From this map, we identified an irrigated area of about 4,100 acres (1,659 ha) around Osoyoos Lake. This matches with the number of irrigated acres documented by the Orville Tonasket Irrigation District (4,093 acres (1,656 ha)). Since the water rights are 4 acre-feet per acre (Ecology and Tom Scott, Oroville Tonasket Irrigation District, personal communication), this translates to agricultural water rights of 16,400 acre-feet (20.23 million m^3) of water. A summary of water rights provided by the Washington Department of Ecology recorded water rights of 7,612 acre-feet (9.39 million m^3) for the irrigation district. The water rights data did not include the non-interruptible water right of one foot (5,700 acre-feet) of storage annually in Osoyoos Lake for the OTID. This water permit was transfer from storing water in Palmer Lake to Osoyoos Lake which was a settlement between the Washington State Department of Ecology and the OTID. However, about 3,000 acre-feet (3.7 million m^3) of water right are still unaccountable.

Based on the Washington land use map, the irrigated area is divided among a number of different crops (Table 6) and used it with NRCS Washington Irrigation Guide (WIG) to obtain the monthly agricultural water demand. Monthly consumptive use by crop was tabulated using monthly crop requirements for the Chelan area for both WA and BC, the closest data point to Osoyoos Lake (Washington Irrigation Guide Appendix A, 2007). This guidance document estimates crop irrigation requirements for 90 locations throughout Washington for 60 different crops. These data were compiled using the Doorenbos and Pruitt Blaney-Criddle and SCS Blaney-Criddle Modified methods based on up to 29 years of NOAA weather data (Haller, 2008). Combining this data with the area of each crop we estimated monthly agricultural consumptive use that is shown in Table 7 and Table 9. For example, the requirement for apple is 0.853 feet of water for the month of July (not included transmission loss) and multiplies it with 1,830 acre (741 ha) of apple in WA to estimate consumptive use of 1,558 acre-feet (1.92 million m^3) (Table 7). Similarly for BC, using the July requirement for apple multiplies with 826 acre (334 ha) of apple in BC to obtain consumptive use of 705 acre-feet (0.87 million m^3) (Table 9). The monthly totals are rounded to the closest 10. Including assumed transmission losses of 10%, total agricultural water demand from Osoyoos Lake is around 11,900 acre-feet (14.68 million m^3) for WA and 8,400 acre-feet (10.36 million m^3) for BC. For the agricultural monthly use, we assuming the entire water right of 4 acre-feet per acre which is 16,400 acre-feet (20.23 million m^3) of water were used. We used the same monthly scaling factor for the total irrigation requirement to obtain the agricultural monthly use for April to October.

Table 6. WA Irrigated area by crop with for water rights from Osoyoos Lake.

Crop	% Area	Area in Acres
Apple	45%	1,826
Alfalfa/grass/pasture	24%	997
Pear/Plum	4%	179
Cherry	13%	543
Peach	1%	45
Grape and Corn	1%	60
Cereal grain and others	11%	451
Total	**-**	**4,100**

Table 7: WA Monthly agricultural water demand from Osoyoos Lake (acre-feet).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Apple	0	490	1,219	1,558	1,141	718	61	**5,190**
Alfalfa	0	304	542	641	464	304	33	**2,290**
Pear and Plum	0	57	109	140	103	64	5	**480**
Cherry	1	202	362	463	339	214	18	**1,600**
Peach	1	16	27	35	26	16	1	**120**
Grape and Corn	0	2	23	34	26	16	1	**100**
Cereal Grain and Others	71	229	301	273	22	5	19	**920**
Total Irrigation Requirement	70	1,300	2,580	3,140	2,120	1,340	140	**10,690**
Total Irrigation Requirement Assuming with Transmission Losses of 10%	80	1,440	2,870	3,490	2,360	1,490	160	**11,890**
Total Monthly Use Assuming the Entire Water Rights of 4 ft/acre is used	110	1,990	3,960	4,820	3,250	2,060	210	**16,400**

We used water rights information from the British Columbia Ministry of Environment and data based on the 2006 Land and Irrigation Systems Survey by the BC Ministry of Agriculture obtained from Anna Warwick Sears (Okanagan Basin Water Board) and Ron Fretwell (RHF Systems Ltd.) to develop the agricultural demand for BC.

Based on land-use irrigation systems survey from Ron Fretwell (RHF Systems Ltd.), the total area of irrigated land is 2,290 acres (927 ha) for a range of crops (Table 8). As per communications with Ron Fretwell, the above data could be missing First Nations cultivated land. The water rights documents indicate a higher irrigated area of 3,152 acres (1,276 ha). Hence, to be on the conservative side, we used a total irrigated area of 3,152 acres (1,276 ha) and distributed it among various crops as per the percentages in Table 8. In BC, the typical water right is also 4 acre-feet per acre (Ron Fretwell, RHF Systems Ltd, personal communication) this translates to water rights of around 12,600 acre-feet (15.54 million m^3).

Table 8. BC irrigated area by crop for water rights from Osoyoos Lake.

Crop	% Area	Area in Acres
Apple	26%	826
Alfalfa/grass/pasture	10%	307
Pear	2%	49
Cherry	12%	382
Peach	15%	463
Grape and Corn	31%	985
Others	4%	140
Total	**-**	**3,150**

Table 9. BC monthly agricultural water demand from Osoyoos Lake (acre-feet).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Apple	0	222	552	705	516	325	28	**2,350**
Alfalfa	0	94	167	197	143	94	10	**710**
Pear and Plum	0	15	30	38	28	18	1	**130**
Cherry	1	142	255	326	239	150	13	**1,130**
Peach	13	161	280	362	265	166	13	**1,260**
Grape	0	37	383	565	433	265	19	**1,700**
Others	22	71	93	85	7	1	6	**290**
Total Irrigation Requirement	40	740	1,760	2,280	1,630	1,020	90	**7,560**
Total Irrigation Requirement Assuming with Transmission Losses of 10%	40	820	1,960	2,530	1,810	1,130	100	**8,390**
Total Monthly Use Assuming the Entire Water Rights of 4 ft/acre is used	70	1,230	2,930	3,800	2,720	1,700	150	**12,600**

A recent 2010 report concerning an agriculture water demand model completed for the Okanagan Basin Water Board estimated the irrigated area and irrigation demand under water license for Osoyoos, BC (Gulik et al. Appendix A, 2010). The report provided agriculture demands for only the BC portions of the region. In the Osoyoos Lake area they modeled agriculture demand for the year 2003 and divided into four specific categories; Osoyoos Irrigation District, Town of Osoyoos, Town of Osoyoos Water Works and Osoyoos Indian Band. The total irrigated area of 3,548 acres (1,447 ha) corresponded reasonably well to our study area of 3,152 acres (1,276 ha). Comparing the irrigation demand of 8,342 acre-feet (10,289,658 m^3) from the water demand model to our estimated demand of 8,390 acre-feet (10,348,897 m^3) also demonstrated that we used similar values appropriate for the area.

Tables 7 and 9 show the theoretical irrigation requirements for the different crops grown in the region are lower than the actual water right application rate of 4 acre-feet per acre. This amounts to approximately 11,900 acre-feet (14.68 million m^3) of demand compared to 16,400 acre-feet (20.23 million m^3) of use in the WA and approximately 8,400 acre-feet (10.36 million m^3) of demand compared to 12,600 acre-feet (15.54 million m^3) of use in BC. Therefore, even if crop requirements change in future due to factors like climate change, there is room for the current water rights to meet increased irrigation needs. If conservation practices are encouraged, this could be a source of water savings that can be applied to other demands like fisheries and instream flow requirements. Another point to note is that irrigation requirements are 35% less than water rights in BC and 25% less than water rights in WA. This difference can be attributed to a higher percentage of low water consumption crops like grapes cultivated in BC. A shift to cultivation of such crops might automatically occur or could be encouraged in the event of expected decrease in water availability.

3.3 Instream flow and fisheries requirements

The Zosel Dam Operating Procedures Plan (Ecology, 1990) is an agreement reached between Ecology, WA Department of Fisheries, and WA Department of Wildlife. The plan was created in cooperation with other agencies including the Board of Control and the BC Ministry of Environment. The operating plan includes criteria for fishery flows, trans-border flows, and instream flows. Fishery criteria include the recommended flow for the passage of migrating fish at Zosel Dam. To the extent possible, a discharge of 331 cfs (9.37 m^3/s), which is equivalent to 80% of the average October flow (1987-2009) at Oroville, WA, is to be maintained between October 1 and April 15 to allow egg/fry survival of Chinook salmon (*O. tshawytscha*) (Table 10, Column 2). For Steelhead spawning, incubation, and emergence, a discharge of 459 cfs (13.0 m^3/s), which is equivalent to 80% of the average March flow (1987-2009), is required between March 1 and June 15. In April, in order to flush migrating sockeye salmon smolts out of Osoyoos Lake and downstream through Zosel Dam, the BC Ministry of Environment releases up to an additional 2,850 acre-feet (3.5 million m^3) from Okanagan Lake to the extent possible. For resident fisheries, a discharge of 200 cfs (5.66 m^3/s) from June 15 to August 1 should be maintained to the extent possible (Ecology, 1990). The criteria are summarized in Table 10 (Column 2). The calculations of average October and March flows were done using data for time frame 1988-2007. Personal communications with John Arterburn, Colville Confederated Tribes established that the fisheries criteria in Table 10 seem to be reasonable optimal fish requirements.

The Washington Administrative Code (WAC, 1988) established instream flow requirements at Oroville, WA in agreement with the Water Resources Act of 1971. The monitoring station for Upper Okanogan River is USGS gauge #12439500. The minimum instream flows provide the necessary flow for the protection of wildlife, fish, scenic, and other environmental values, and navigational values (Chapter 173-549-020 WAC, 1988). It was assumed that instream flows further downstream on the Okanogan would be met with flows from the Similkameen River rather than the Osoyoos Lake reach due to the size difference between the two streams. These flows range from 320 cfs (9.1 m^3/s) from December through March to 500 cfs (14.2 m^3/s) in June. The criteria are summarized in Table 10 (Column 3).

These requirements were convert to acre-feet (million m^3) in column 5 are by far the largest demand component. It is about 10 times higher in magnitude than the residential/commercial/ municipal and agricultural demands considered.

Table 10. Summary of Instream and fisheries flows flow criteria for the Okanogan river downstream from related to Osoyoos Lake and Zosel Dam.

1	**2**	**3**	**4 [max(2,3)]**	**5**
Month	**Fisheries criteria at Oroville, WA, 1990, cfs (cms)**	**Instream Flow criteria at Oroville, WA, 1971, cfs (cms)**	**Maximum of criteria in Columns 1 and 2, cfs (cms)**	**Maximum Criteria, acre-feet (million m^3)**
Jan	331 (9.4)	320 (9.1)	331 (9.4)	20,500 (25.3)
Feb	331 (9.4)	320 (9.1)	331 (9.4)	18,500 (22.8)
Mar	459 (13.0)	320 (9.1)	459 (13.0)	29,600 (36.5)
Apr	459 (13.0)	330 (9.3)	459 (13.0)	28,700 (35.4)
May	459 (13.0)	350 (9.9)	459 (13.0)	29,600 (36.5)
Jun	459 (13.0)	500 (14.2)	500 (14.2)	29,700 (36.6)
Jul	200 (5.7)	420 (11.9)	420 (11.9)	25,800 (31.8)
Aug	200 (5.7)	320 (9.1)	320 (9.1)	19,700 (24.3)
Sep	200 (5.7)	300 (8.5)	300 (8.5)	17,800 (22.0)
Oct	331 (9.4)	330 (9.3)	331 (9.4)	20,500 (25.3)
Nov	331 (9.4)	370 (10.5)	370 (10.5)	22,000 (27.1)
Dec	331 (9.4)	320 (9.1)	331 (9.4)	19,700 (24.3)
Total	**-**	**-**	**-**	**282,100 (347.9)**

3.4 Summary and discussion of total demand

The residential, commercial, and municipal demands are base on the per capital usage of the current population and the projected low and high population in 2040 which are very small comparing to agricultural demand and instream/fisheries flow requirement (Table 11, Column 2, 3, and 4). For the agricultural demand, the different crops, for example, apple, alfalfa, pear, cherry, peach, and grape grown in the Oroville, WA and Osoyoos, BC required about 20,280 acre-feet (20.01 million m^3) of water annually (including 10% transmission losses) (Table 11, Column 5). However, the conservative approach for the agricultural demand is to assume the entire actual water right of 4 feet/acre is used for Oroville, WA and Osoyoos, BC which required 29,000 acre-feet (35.77 million m^3) annually (Table 11, Column 6). The maximum criteria of the instream and fisheries flow is the largest requirement from Osoyoos Lake and these account more than 90% of the total demand.

The total demand for four scenarios is calculated as the sum of residential/commercial/ municipal, agricultural and instream flow/fisheries requirements. The total demand for various scenarios is shown in Table 12 and Figure 9. Scenario 1 and 2 include the current population demand, agricultural demand and instream/fisheries requirement, however, scenario 2 used the more conservative agricultural demand approach (Table 3). For year 2040s total demand, the sum of low (scenario 3) or high (scenario 4) population growth, conservative agricultural demand and fisheries/instream flow requirements. It should be noted that since the fisheries/instream flow requirements have been assumed the future to be the same as the current requirement and since these account for more than 90% of the demand there is no major variation in the total demand in each of the scenarios. The concern to accommodate the instream/fisheries flow criteria should be addressed in the renew Order.

Table 11. Summary of the residential/commercial/ municipal, agricultural and instream/fisheries flow total demand.

1	2	3	4	5	6	7
Month	**Current population demand (acre-feet)**	**2040 demand; low growth rate (acre-feet)**	**2040 demand; high growth rate (acre-feet)**	**WA and BC agricultural demand (acre-feet)**	**WA and BC Agricultural 4 ft/acre water right demand (acre-feet)**	**Instream/ fisheries; maximum criteria (acre-feet)**
Jan	76	104	180	0	0	20,500
Feb	76	104	180	0	0	18,500
Mar	76	104	180	0	0	29,600
Apr	76	104	180	120	180	28,700
May	91	125	216	2,260	3,220	29,600
Jun	228	313	539	4,830	6,890	29,700
Jul	228	313	539	6,020	8,620	25,800
Aug	228	313	539	4,170	5,970	19,700
Sep	197	271	467	2,620	3,760	17,800
Oct	91	125	216	260	360	20,500
Nov	76	104	180	0	0	22,000
Dec	76	104	180	0	0	19,700
Total	**1,519**	**2,087**	**3,594**	**20,280**	**29,000**	**282,100**

Table 12. Summary of total demand for the four scenarios considered (acre-feet).

1	2	3	4	5
Month	**Scenario 1 (Current demand)**	**Scenario 2 (Current demand)**	**Scenario 3 (2040 demand)**	**Scenario 4 (2040 demand)**
Jan	20,600	20,600	20,600	20,700
Feb	18,600	18,600	18,600	18,700
Mar	29,700	29,700	29,700	29,800
Apr	28,900	29,000	29,000	29,100
May	32,000	32,900	32,900	33,000
Jun	34,800	36,800	36,900	37,100
Jul	32,000	34,600	34,700	35,000
Aug	24,100	25,900	26,000	26,200
Sep	20,600	21,800	21,800	22,000
Oct	20,900	21,000	21,000	21,100
Nov	22,100	22,100	22,100	22,200
Dec	19,800	19,800	19,800	19,900
Total	**303,900**	**312,600**	**313,200**	**314,700**

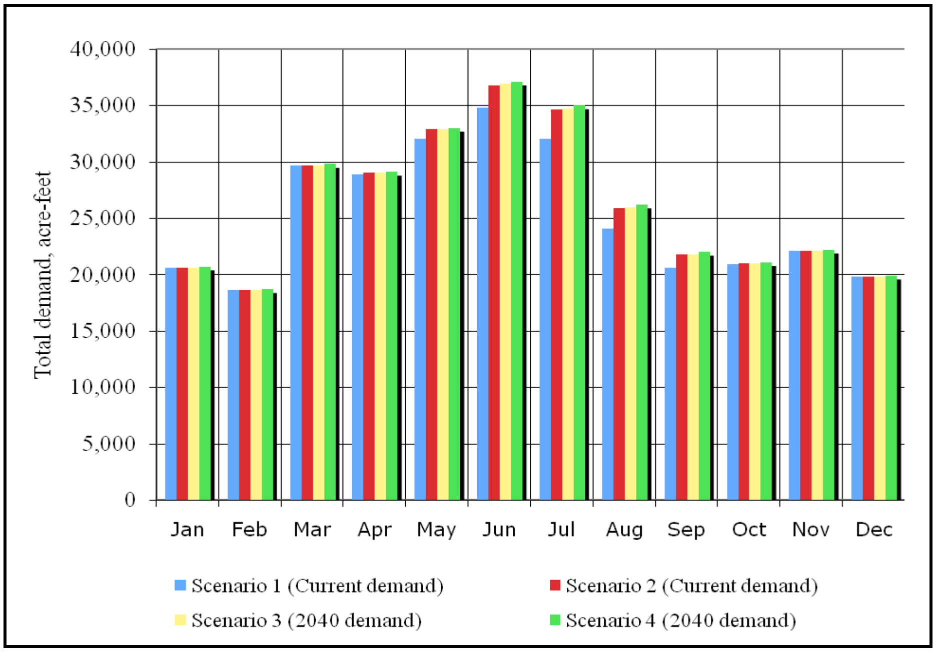

Figure 9. Total demand for the four scenarios considered (acre-feet).

4 Range of lake levels that can meet demand

In order to address this question, we examined the expected net inflow and expected total demand to see how much of the demand is not met. We then examined if storage in the lake could make up for the deficit. Net inflow includes trans-border flows from BC, precipitation and ungauged inflow between Oliver, BC and Oroville, WA. The effect of lake evaporation is also considered. Return flows from agricultural withdrawals are also a source of inflow, but we ignore it since we are unsure about magnitude of return flows, where the return flows actually materialize and given the fact that agricultural withdrawal is a small component of the net demand.

4.1 Trans-border flows from BC

Besides managing the lake levels at Zosel Dam specified in the IJC Order of 1982, the minimum trans-border flow targets in the Cooperation Plan will be met as far as possible by the Ministry of Environment during drought years. In 1980, Washington Department of Ecology and the BC Ministry of Environment entered into a non binding agreement entitled “British Columbia Washington State Cooperation Plan for Osoyoos Lake Levels and Trans-Border Flows” mentioned in Section 2.1. The plan included values for minimum trans-border flows that calculated according to the flows measured at Oliver, BC. In normal years and when a drought follows a normal year (first drought year), the minimum trans-border flows are 175 cfs (5.0 m^3/s) in January, rise incrementally to a peak of 340 cfs (9.6 m^3/s) in August, then decrease incrementally back down to 175 cfs (5.0 m^3/s) in November (Table 13, Column 2). These flows represent the five driest years between 1958-1977 and are similar to the flows specified in the Canada-British Columbia Okanagan Basin Agreement, 1974. In a second year drought (consecutive year droughts), the plan stated the flows will be cut back at all times with the condition that, as far as was practicable during the irrigation season, the flow would not be less than of 100 cfs (2.83 m^3/s) from April 1st through October 31st. For November 1st to March 30th, we assume the flow would be the same as the first drought year (Table 13, Column 4).

In order to compare minimum trans-border flows with historical discharges at Oliver we use the conversion of trans-border flow requirements into gauged flow requirement at Oliver, BC listed on page 11 of the British Columbia/Washington State cooperation plan for trans-border flows, 1980. This conversion was available for normal year requirements only (Table 13, Column 3). We used the same monthly scaling factor for drought year requirements to obtain corresponding gauge flows (Table 13, Column 5).

Table 13. Summary of Trans-Border Flow Criteria

1	2	3	4	5
Month	**Minimum Trans-Border Flows (Normal or 1st Drought Year) cfs(cms)**	**Gauged Flows at Oliver, BC that meets Column 2 Flows cfs(cms)**	**Minimum Trans-Border Flows (2nd or 3rd Drought Year) cfs(cms)**	**Gauged Flows at Oliver, BC that meets Column 4 Flows cfs(cms)**
Jan	175(5.0)	113(3.2)	175(5.0)	113(3.2)
Feb	200(5.7)	167(4.7)	200(5.7)	167(4.7)
Mar	200(5.7)	224(6.3)	200(5.7)	224(6.3)
Apr	200(5.7)	186(5.3)	100(2.8)	93(2.6)
May	250(7.1)	231(6.5)	100(2.8)	92(2.6)
Jun	250(7.1)	232(6.6)	100(2.8)	93(2.6)
Jul	250(7.1)	288(8.2)	100(2.8)	115(3.3)
Aug	340(9.6)	372(10.5)	100(2.8)	109(3.1)
Sep	320(9.1)	321(9.1)	100(2.8)	100(2.8)
Oct	300(8.5)	267(7.6)	100(2.8)	89(2.5)
Nov	175(5.0)	135(3.8)	175(5.0)	135(3.8)
Dec	175(5.0)	145(4.1)	175(5.0)	145(4.1)

4.2 Historical inflow from the Okanagan River into Osoyoos Lake

We used the discharge record measurements from the Oliver, BC gauge for years 1987 to 2009 to compare actual historical inflows from the Okanagan River into Osoyoos Lake with the minimum trans-border flows detailed in section 4.1. The comparison is done for normal years and drought years as classified in Section 2.2. For the years 1988, 1992, 1993, 1994, 2001, 2003, 2005, and 2009 are classified as drought years according to the IJC Order of Approval specification. The flows for the years with abnormally high flows when elevations went beyond 913 feet (1990, 1996, and 1997) and years when the drought declaration was rescinded (1987, 1998, and 2004) are included in the normal year.

In normal years, historical average inflow was higher than the minimum trans-border flows at Oliver (Figure 9, Table 14). The average drought year discharge at Oliver, BC was also more than the drought year trans-border flows (Figure 10, Table 15), and this probably helped the WA meet a significant portion of the demand during 1987-2009.

Table 14. Minimum trans-border and historical discharge at Oliver, BC for normal years, 1987-2009.

1	2	3	4	5
Month	**Historical Maximum Flow (cfs)**	**Historical Average Flow (cfs)**	**Historical Minimum Flow (cfs)**	**Minimum trans-border flow (British Columbia Washington State, 1980) (cfs)**
Jan	932	402	160	113
Feb	1221	611	186	167
Mar	1758	755	161	224
Apr	2088	910	274	186
May	2832	1439	384	231
Jun	3099	1513	238	232
Jul	2715	1082	294	288
Aug	2665	885	281	372
Sep	2232	708	367	321
Oct	689	414	344	267
Nov	883	284	199	135
Dec	708	335	187	145

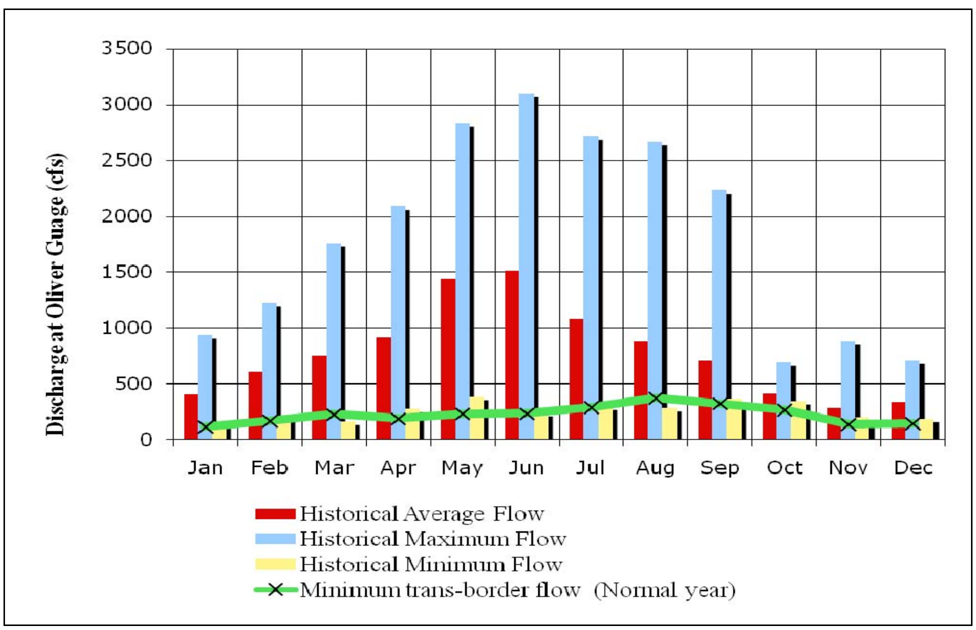

Figure 10. Minimum trans-border and historical discharge at Oliver, BC for normal years, 1987-2009.

Table 15. Minimum trans-border and historical discharge Historical and agreement based inflows at Oliver, BC for drought years, 1987-2009.

1	2	3	4	5
Month	**Historical Maximum Flow (cfs)**	**Historical Average Flow (cfs)**	**Historical Minimum Flow (cfs)**	**Minimum trans-border flow (2nd or 3rd drought years) (cfs)**
Jan	851	354	163	0
Feb	1020	308	149	0
Mar	930	384	162	0
Apr	1298	469	220	93
May	1332	604	267	92
Jun	916	462	286	93
Jul	1615	644	221	115
Aug	2092	569	203	109
Sep	976	446	205	100
Oct	406	330	194	89
Nov	268	221	185	0
Dec	263	204	175	0

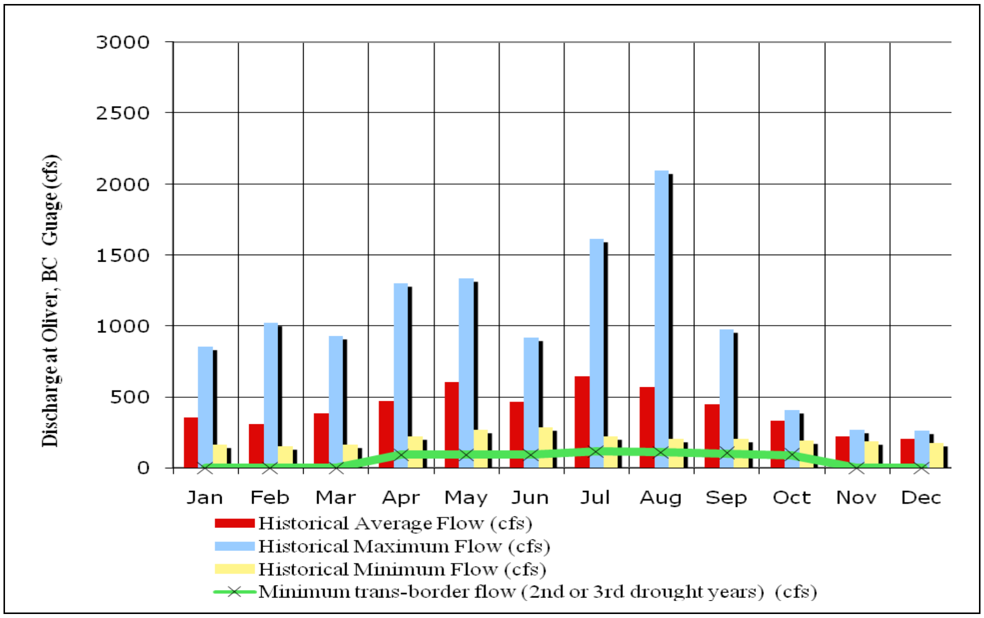

Figure 11. Minimum trans-border and historical discharge Historical and minimum trans-border discharge at Oliver, BC for drought years, 1987-2009.

4.3 Net other inflow

Other inflows into Osoyoos Lake include precipitation onto the lake and ungauged inflows between Oliver and Oroville. These numbers are taken from the Cooperation Plan for Osoyoos Lake Levels and Trans-Border Flows (British Columbia Washington State, 1980) and total around 34,000 acre-feet (42 million m^3) per year (Table 16, Column 4). Although not an inflow, evaporative losses from the lake are also considered in calculating net other inflow. The numbers are also from Cooperation Plan and total around 9,000 acre-feet (12 million m^3) per year. Evaporation losses subtracted from the precipitation and ungauged inflows gives the net other inflows. Return flow from irrigation are also a source of inflow, but we ignore due to the uncertainty of the return flows.

Table 16. Net Other inflows into Osoyoos Lake.

1	2	3	4 (2+3)	5	6 (4-5)	7
Month	**Ungauged Inflow (cfs)**	**Precipitation (cfs)**	**Total (cfs)**	**Evaporaration (cfs)**	**Net Other Inflow (cfs)**	**Net Other Inflow (acre-feet)**
Jan	19	14	33	0	33	2,000
Feb	52	8	60	0	60	3,300
Mar	19	7	26	0	26	1,600
Apr	45	7	52	0	52	3,100
May	88	9	97	16	81	5,000
Jun	62	11	73	31	42	2,500
Jul	32	7	39	39	0	0
Aug	27	8	35	39	-4	-200
Sep	70	5	75	31	44	2,600
Oct	19	7	26	8	18	1,100
Nov	12	10	22	0	22	1,300
Dec	21	14	35	0	35	2,200

4.4 Total Inflow

The total inflow is calculated as the sum of inflow from the Okanagan River into Osoyoos Lake (as measured at the gauge in Oliver, BC) and the net other inflows. Table 17 and Table 18 show the total inflow for normal years and drought years respectively. Total minimum inflow that incorporates the minimum trans-border flow between WA and BC as well historical average inflow between 1987 and 2009 are calculated to the nearest 100^{th} acre-feet.

Table 17. Total agreement and historical inflow for normal years.

1	2	3	4	5 (2+4)	6 (3+4)
Month	**Minimum trans-border flow at Oliver Gauge (acre-feet)**	**Average Historical Discharge at Oliver Gauge (acre feet)**	**Net Other Inflow (acre-feet)**	**Total Minimum Inflow (acre feet)**	**Total Average Historical Inflow (acre feet)**
Jan	6,948	21,621	2,000	8,900	23,600
Feb	9,275	34,495	3,300	12,600	37,800
Mar	13,773	42,343	1,600	15,400	43,900
Apr	11,068	48,463	3,100	14,200	51,600
May	14,204	87,301	5,000	19,200	92,300
Jun	13,805	73,202	2,500	16,300	75,700
Jul	17,708	56,164	0	17,700	56,200
Aug	22,873	42,066	-200	22,700	41,900
Sep	19,101	35,721	2,600	21,700	38,300
Oct	16,417	24,518	1,100	17,500	25,600
Nov	8,033	14,206	1,300	9,300	15,500
Dec	8,916	16,999	2,200	11,100	19,200

Table 18. Total agreement and historical inflow for drought years.

1	2	3	4	5 (2+4)	6 (3+4)
Month	**Minimum trans-border flow at Oliver Gauge (acre-feet)**	**Average Historical Discharge at Oliver Gauge (acre feet)**	**Net Other Inflow (acre-feet)**	**Total Minimum Inflow (acre feet)**	**Total Average Historical Inflow (acre feet)**
Jan	0	21,760	2,000	2,000	23,800
Feb	0	17,090	3,300	3,300	20,400
Mar	0	23,595	1,600	1,600	25,200
Apr	5,534	27,919	3,100	8,600	31,000
May	5,681	37,161	5,000	10,700	42,200
Jun	5,522	27,504	2,500	8,000	30,000
Jul	7,083	39,626	0	7,100	39,600
Aug	6,727	34,996	-200	6,500	34,800
Sep	5,969	26,531	2,600	8,600	29,100
Oct	5,472	20,268	1,100	6,600	21,400
Nov	0	13,131	1,300	1,300	14,400
Dec	0	12,544	2,200	2,200	14,700

4.5 Total inflow versus demand comparison

Total inflow minus the demand gives the amount of surplus or deficit. We will explore the range of lake levels needed to manage any deficit. Tables 19 and 20 contain comparisons for normal and drought years respectively. Columns 2 and 3 in both tables come from Tables 17 and 18 in section 4.4 and Column 4 comes from Table 12 in section 3.4. The other columns are calculated as noted in the table headers. The demand scenario used for the example calculation in Tables 19 and 20 is Scenario 1 which is the current and lowest demand scenario. Figures 12 and 13 compare inflows with all demand scenarios.

Table 19 (Column 5) shows that inflow based on minimum trans-border flow was sufficient to meet only about one-half or less of the demand in most months in normal years during 1987-2009. Lake storages of 0.5 ft to 3 ft per month would be needed to make up this deficit and this is infeasible. But average inflow during normal years between 1987-2009 (Table 19, Column 3), was much higher than the inflow based on minimum trans-border flows and this probably helped the WA meet demand. Lake storage of 1 ft (to meet deficit in November) could help the WA to meet all its demands in a normal year if inflow magnitudes are similar to inflows that occurred between 1987-2009. In the event that inflows were reduced to the current minimum trans-border based values, it would be impossible to manage demand using lake storage even in normal flow years.

Table 20 (Column 5) shows that in drought years during 1987-2009, inflow based on minimum trans-border flow did not meet even $1/4^{th}$ the demand in most months. Lake storages of 2 to 5 ft per month would be required to address this deficit and this is infeasible. Again, average inflow in drought years during 1987-2009 were higher than minimum flow based on minimum trans-border flows and this may have helped WA meet more than 80% of the demand in most months. Although the range of storage levels needed to completely meet the deficit in drought years studied is infeasible even with historical inflows, storages of 1 to 2 feet per year could have helped meet about 90% of the demand. The results indicate that in the event inflows were to be reduced to the current minimum trans-border based values, it would be impossible to manage demand using lake storage and a large portion of demand would remain unmet having adverse impacts on fish and other wild life.

Table 19. Demand versus inflow comparison for normal years, 1987-2009.

1	2	3	4	5 [2/4]*100	6 [4-2] / Lake Area	7 [3/4]*100	8 [4-3] / Lake Area
Month	**Total Minimum Inflow (acre-feet)**	**Total Average Historical Inflow (acre-feet)**	**Total Current Demand (Scenario 1) (acre-feet)**	**% Demand Met by Agreement Inflow**	**Lake Storage to meet Agreement Deficit (ft)**	**% Demand Met by Historical Inflow**	**Lake Storage to meet Historical Deficit (ft)**
Jan	8,900	23,600	20,500	43%	2.0	115%	0.0
Feb	12,600	37,800	18,600	68%	1.0	203%	0.0
Mar	15,400	43,900	29,700	52%	2.5	148%	0.0
Apr	14,200	51,600	28,900	49%	2.5	179%	0.0
May	19,200	92,300	32,000	60%	2.0	288%	0.0
Jun	16,300	75,700	34,800	47%	3.0	218%	0.0
Jul	17,700	56,200	32,000	55%	2.5	176%	0.0
Aug	22,700	41,900	24,000	95%	0.0	175%	0.0
Sep	21,700	38,300	20,600	105%	0.0	186%	0.0
Oct	17,500	25,600	20,800	84%	0.5	123%	0.0
Nov	9,300	15,500	22,100	42%	2.0	70%	1.0
Dec	11,100	19,200	19,700	56%	1.5	97%	0.0

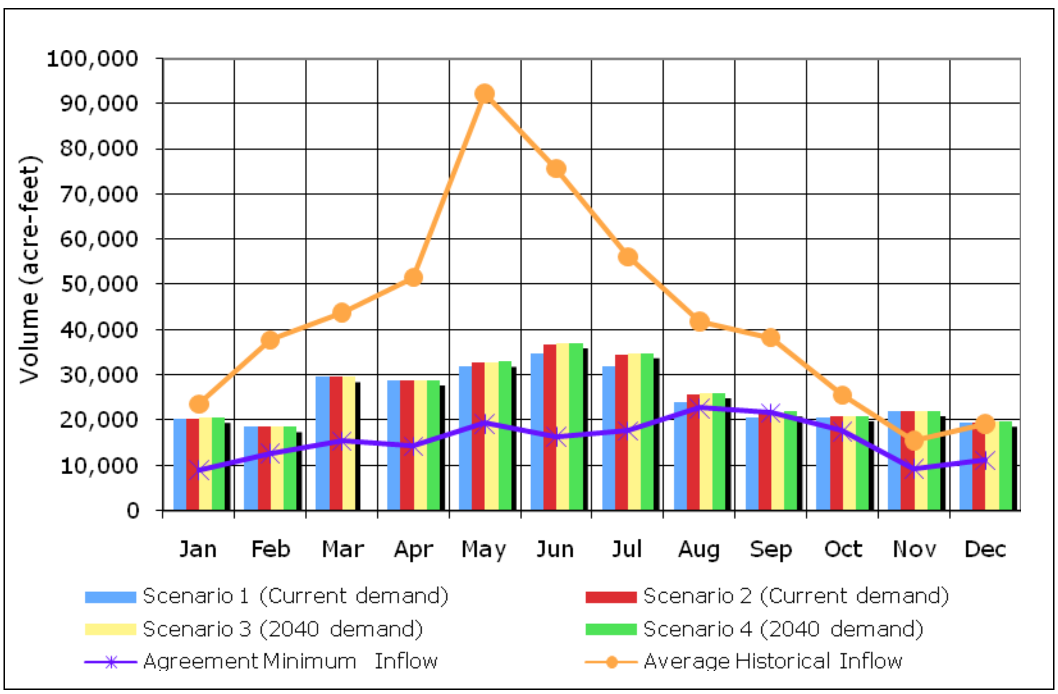

Figure 12. Demand versus inflow comparison for normal years, 1987-2009.

Table 20. Demand versus inflow comparison for drought years, 1987-2009.

1	2	3	4	5 [2/4]*100	6 [4-2] / Lake Area	7 [3/4]*100	8 [4-3] / Lake Area
Month	**Total Minimum Inflow (acre-feet)**	**Total Average Historical Inflow (acre-feet)**	**Total Current Demand (Scenario 1) (acre-feet)**	**% Demand Met by Agreement Inflow**	**Lake Storage to meet Agreement Deficit (ft)**	**% Demand Met by Historical Inflow**	**Lake Storage to meet Historical Deficit (ft)**
Jan	2,000	21,760	20,600	10%	3.0	106%	0.0
Feb	3,300	17,090	18,600	18%	2.5	92%	0.5
Mar	1,600	23,595	29,700	5%	5.0	79%	1.0
Apr	8,600	27,919	28,900	30%	3.5	97%	0.0
May	10,700	37,161	32,000	33%	3.5	116%	0.0
Jun	8,000	27,504	34,800	23%	4.5	79%	1.0
Jul	7,100	39,626	32,000	22%	4.5	124%	0.0
Aug	6,500	34,996	24,100	27%	3.0	146%	0.0
Sep	8,600	26,531	20,600	42%	2.0	129%	0.0
Oct	6,600	20,268	20,900	32%	2.5	97%	0.0
Nov	1,300	13,131	22,100	6%	3.5	59%	1.5
Dec	2,200	12,544	19,800	11%	3.0	64%	1.0

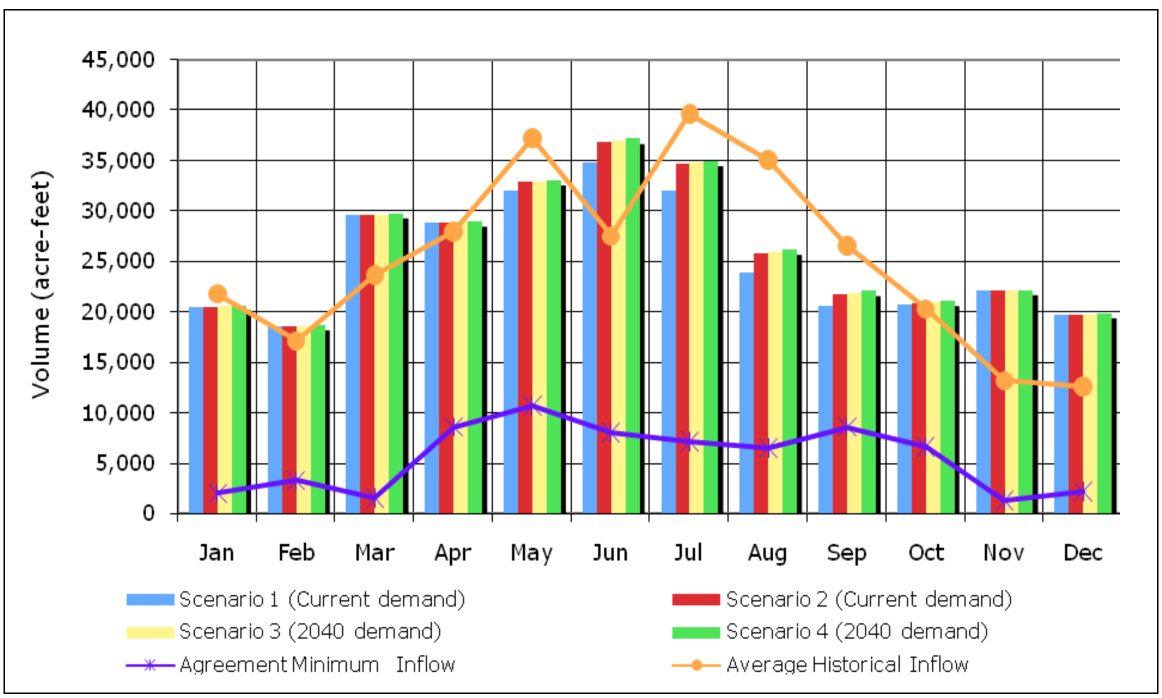

Figure 13. Demand versus inflow comparison for drought years, 1987-2009.

5 Elevation targets to be used in normal and dry years

One of the questions related to this study is whether the same set of elevation targets can be used to manage wet and dry years. Section 4.4 showed that average historical inflows in normal years between 1987-2009 were such that 1 foot of lake storage could be used in November to meet demands in a normal year. In drought years during 1987-2009, average historical flows met at least 80% of the total demand in all months except November and December. Assuming future drought year flow is similar, 1 foot of storage for use in November and December would help meet at least 80% of demand in all months. Therefore, wet and dry years could be managed under the same elevation targets by trading off the option of meeting 100% of the demand in drought years for meeting 80% of demand or higher. Fisheries and in stream flow would not be met in this situation.

The assumption here is that average inflows in future will be similar to past average inflows. This assumption may or may not be true and hence it would be good to have the flexibility to manage wet and drought years differently based on inflow amounts. Even if this assumption is true, it could be worthwhile to have this flexibility in order to meet more than 80% of the demand every month (as close to 100% as possible).

If inflows in future decrease as compared to historical values or are restricted to the current agreement based values it would be infeasible to manage demand using elevation targets. A significant portion of demand will not met in such a situation.

6 Stakeholders affected by lake levels

Table 21 lists different stake holders and lake levels that cause concern / inconvenience to them. This list was compiled using comments made by attendees at public meetings, which was recorded in Glenfir Resources (2006).

Table 21. Stake holders and lake levels of interest

Stakeholders	Unacceptable Lake Levels	Impact
Residents/Property Owners	> 912.5 feet in summer	Erosion issues
	< 912.0 feet in summer	Not optimal for boating
	> 909.0 feet in winter	Ice pressure causes damage to the shore line
	> 909.0 feet in winter	Does not help control milfoil
	Changes in lake levels	Causes inconvenience in terms of raising and lowering the docks.
Irrigators	< 910.5 feet in summer	Water right will be terminated
Campers	> 912.5 feet in summer	Floods camp sites and results in mosquito infestation
Boaters	< 912.0 feet in summer/winter	Can Lead to safety issues
Fisheries and ecological needs stakeholders	Flow not lake level	Generally concerned with flow magnitutes for fishes more than lake level itself
	Varies	Different species residing in the lake could have different elevation requirements as part of their life cycle. One optimal lake level for all species may not be practical
Regulators	< 913.0 feet in summer	If the Order prescribes lesser elevation, future uncertainties may not be met. Hence the option of keeping lake levels as high as possible with least detrimental impact to stakeholders, expecially during drought years is necessary.

The general consensus seems to be for lake levels of 912 or 912.5 ft in summer months. One of the problems associated with maintaining high lake level is wake erosion. Unconsolidated materials such as sands, gravels, and clays along the lake shoreline are susceptible to erosion via both natural and anthropogenic pathways. The impacts include loss of waterfront property as well as water quality impairment due to increased sediment loading and nutrient addition. Wave action is one of several aquatic forces that can facilitate shoreline erosion. The severity of the erosion depends on several factors including shoreline slope, vegetation and soil composition. A number of studies suggest that near-bank wave heights of approximately 0.4 to 0.5 feet mark the onset of bank sediment motion. Waves may be caused naturally or by boat wakes. Wake energy from boats is a function of hull size, boat speed, water depth and distance from shore. To alleviate boat wake impacts, many lakes or states are beginning to impose no-wake zones (low boat speeds) in near-shore regions. For example, in July of 2009, Wisconsin Governor Doyle signed into law a bill that created a 100 feet no-wake zone along all lake shores in the state. Other lakes have imposed even more restrictive criteria. Big Payette Lake in Idaho has a no wake zone within 300 feet of the shore (Ordinance #08-01).

The erosive power of waves is generally assumed to be proportional to the wave height raised to a power. As a result, small increases in height rapidly increase the erosion potential. Wave energy (E) calculations have been performed using:

$$E = \frac{\rho\, g^2\, H^2\, T^2}{16\, \pi} \qquad (1)$$

where ρ is the water density (kg/m^3), g is the gravity (m/s^2), H is the wave height (m), and T is the wave period (s).

Converting wave energy into shoreline erosion has proven to be very difficult. Glamore (2009) explains the problematic nature of computations due to: (1) the lack of standardized wave measurement criteria, (2) the different wave and shoreline monitoring techniques, (3) the diverse forms of boat wakes generated, and (4) the wide range of shoreline types encountered. In addition, separating boat wake erosion from other sources of erosion can be difficult due to incomplete data sets. Moreover, many existing studies have focused on river boat traffic with significant longitudinal currents rather than lake environments. As a result, Asplund (2000) concluded that the impact of boat wakes on shoreline erosion in lakes is currently not well understood.

Lake level can have a significant impact on erosion due to changes in near shore bathymetry (Figure 13). Waves breaking on the flatter slope (m_1) at lower lake levels generally produce less erosion than the same waves hitting the steeper slope (m_2) at higher water levels. In reality the process is much more complicated with soil properties, wave angle, vegetative cover, currents and other interrelated factors all contributing to the loss of property.

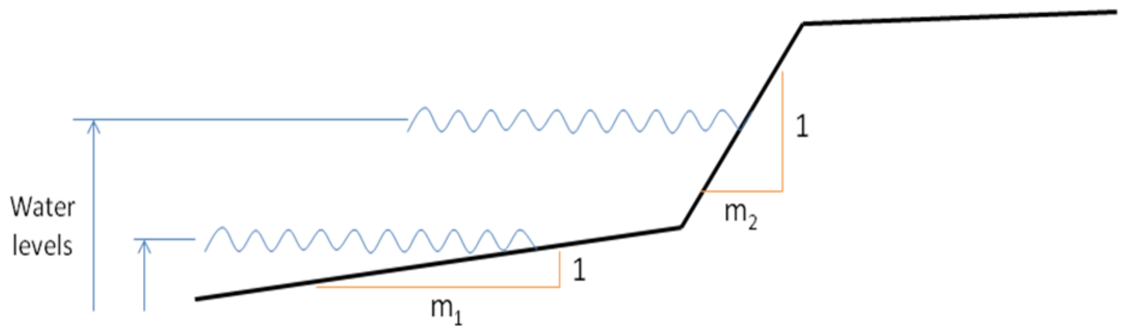

Figure 14. Schematic of water level impact on shoreline erosion, where the slope are m_1 and m_2 horizontal length to 1 vertical length.

A possible issue related to winter lake levels is the potential property damage associated with ice through a phenomenon sometimes referred to as “ice heaving” or “ice jacking”. Typical problems reported across northern climate zones include significant damage to retaining walls, docks, and boat lifts. Experts from various disciplines place high values on the force that will be brought to bear on structures as they are lifted (ice jacking), or subjected to wind-drag or thermal expansion (ice thrust). FERC (2002) recommends an ice loading of about 35 pounds of force per square inch (psi) for dam design although, according to the New Hampshire Department of Environmental Services (2006), in the extreme ice can exert 2,000 psi on anything in its path. Similarly, the US Army Corps has reported values up to 1,275 psi (USACE, 2002). Ice is often pushed ashore in blocks or sheets that pile up and erode the shoreline. An example of a characteristic problem is shown in Figure 14. Pyoekaeri (1981) concluded that the damages on small lakes were often less than larger lakes. In addition to the lateral force, as these ice berms form around the shorelines they may freeze around an object. Should lake levels fluctuate when the ice is frozen onto an object, that object will be moved accordingly up or down. Expansion, rather than wind induced ice drifts, are more emblematic of smaller lakes (Northwest Regional Planning Commission, 2001).

It is not clear as to whether or not this is a significant issue for Osoyoos Lake residents although it was mentioned by a few people in public meetings. A review of the literature did not reveal studies for the area. Nevertheless, lake drawdowns during winter are effective at transferring the location at which these forces are exerted away from the natural shoreline environment. As such, it may be prudent to lower winter lake levels as currently done.

Figure 15. Example of ice damage on Lake Lida in Minnesota
(Minnesota Department of Natural Resources, 2010)

7 Alternate sources of water

There have been some preliminary discussions regarding the availability of out-of-basin transfers of water to the Okanogan watershed. One option was referred to as the “Kruger Mountain” project which involved a 2-mile long tunnel from Shanker’s Bend area on the Similkameen River to a discharge point near the US/Canada boarder (Kauffman, 2007). While far from settled, a flow of approximately 200 cfs has been mentioned as a possible flow target. Anadromous fish species have never been able to migrate to the Canadian portion of the Similkameen Basin because of a natural falls barrier approximately 350 feet downstream of Enloe Dam (8.8 miles upstream of the Okanogan River confluence). While the new structure would be located upstream of Enloe Dam and thus not pose a threat to salmonid migration, given the challenges of meeting minimum instream flow requirements on the lower Okanogan River, it seems very unlikely that any direct diversion would be permitted without additional storage to accommodate summertime flows. Furthermore, there has been discussion regarding the construction of a hydroelectric and water storage facility at the Shanker’s Bend location with FERC granting the Public Utility District No. 1 of Okanogan County a preliminary permit to investigate the project feasibility.

Another possibility to consider is groundwater. The US Geological Survey (USGS) reported glacial deposits of sand and gravel as much as several hundred feet thick in the Okanogan River Valley in Okanogan County (Whitehead, 1994). Wells in the area that are less than 60 feet deep typically yield from less than 10 to 1,000 gallons per minute. An Ecology report by Garrigues and Carey (1999) concluded that these glacial and alluvial deposits are directly linked to surface water. It may be possible to take advantage of the time lag in between surface and groundwater diversion however without considerably more investigation it is not possible to assess any real significant contribution.

In short, for the next set of Orders, it appears that water management within the basin must be used to meet demands.

8 Conclusions

The first objective of this study addressed in Section 3 of the report was to assess total expected water demand in 2040 and compare it against current demand. Two scenarios of current demand resulted in a total demand between 303,900 acre-feet (374.8 million m^3) and 312,600 acre-feet (385.6 million m^3) per year. Two scenarios for future 2040 demand were considered which resulted in 2040 demands of 313,200 acre-feet (386.3 million m^3) and 314,700 acre-feet (388.2 million m^3) per year. Fisheries and instream flow requirements were the largest component of demand accounting for at least 90% of the demand. Since these requirements were considered constant and they accounted for at least 90% of the demand, we do not see much of a relative difference between current and 2040 water demand from Osoyoos Lake.

In studying agricultural demand, we noticed that irrigation requirements for the different crops grown in the area are lower than the currently actual water rights of about 4 acre-feet per acre (1.22 m per ha) (25% lower in WA and 35% lower in BC). Therefore, even if crop requirements change in the future due to factors like climate change, there is room for the current water rights to meet increased irrigation needs through conservation and efficiency practices. If conservation practices are encouraged, this could be a source of water savings that can be applied to other demands like fisheries and instream flow requirements. The difference between US and BC percentages (25% as compared to 35%) can attributed to a higher percentage of low water consumption crops like grapes cultivated in BC. A shift to cultivation of such crops might automatically occur or could be encouraged in the event of expected decrease in water availability in the future.

The second objective of the study was to assess the range of feasible lake levels that could be used to meet the future demand. This was addressed in Section 4 of this report. We examined inflows into the lake for 1987-2009 and compared them against the current and expected demand to identify any surpluses or deficits and study whether the any deficits could be managed using lake levels. Two sets of inflows were compared against demand:

a) Inflows based on minimum trans-border flows agreed upon as part of the Cooperative Plan between WA and BC, and
b) Actual historical inflows between 1987 and 2009.

If inflows were restricted to minimum flows that are based on the minimum trans-border flow, approximately 50% of the current demand would not be met in most months of a normal year and about 75% of the demand would not be met in a drought year. Addressing these deficits would require storages of 0.5 to 3 feet (0.15 to 0.91 meters) per month in normal years and 2 to 5 feet (0.61 to 1.52 meters) of storage per month in drought years. Thus the use of lake storage to manage demand is not a feasible solution for two reasons. First, water for storing is unavailable. Second, even if water were available from an alternative source, Osoyoos Lake does not have the capacity to handle the kind of storage levels needed to address the deficit.

However average historical inflows between 1987-2009 were higher than what was agreed upon in the Cooperation Plan. Therefore, there was not a situation in the past where 50% and 75% of the demand was not met. If we assume that past inflows are a good estimate of expected future inflows, the results in Table 19 indicates that in a normal year, inflow would be more than sufficient to meet demand except in the month of November. The deficit in the month of November could be managed with one foot of storage per year in the lake.

In drought years between 1987-2009, there were deficits in February, March, June, November and December. If these same deficits were to occur in the future drought years, they could be managed by an annual storage of about 5 feet (1.52 meters). Based on Figure 12, the excess inflow in May could be used to store 1.0 foot (0.3 meters) of water to meet the deficit in June and excess inflows in August and September could be used to store 2.5 feet (0.76 meters) of water to meet deficits in November and December. So there would be a need to manage the lake levels fluctuate about 2.5 feet. If summer lake levels were kept at 912 feet, this would result in the lake level dropping to 909.5 in winter. However, potential deficits in February and March might not be met unless the previous year was a normal/wet year and in anticipation of a drought in the following year, about 1.5 feet of water was stored late in the year. This would mean high winter elevations in the year water is stored which could be undesirable because it could result in winter ice damage to the shoreline and dam structure as well as prevent control of Eurasian Milfoil. Another option to consider is to reach an agreement among stakeholders that it would be acceptable to meet less than 100% of the demand in drought years. For example, if stakeholders agree that it was acceptable to meet about 80% of the demand in the months with a deficit, storage might only be needed to manage deficits in the months of November and December and about a foot of storage would handle the deficit. In this event, both normal years and drought years could be managed with a lake elevation fluctuation of about one foot.

The third objective was to assess whether the same set of elevation targets can be used in normal years and drought years. As mentioned in the previous paragraph, if stakeholders agree that it would be acceptable to meet 80% of the demand in some months in a drought year, it would be possible to use the same set of elevation targets for normal and drought years. Since average inflows for the period 1987-2009 are used to make this conclusion, there will be some years were inflow is below the average and the deficits would be higher than the average deficits reported in Table 19 and Table 20. This is less of a concern in normal years since the average inflows are much higher than demand in most months (Figure 11). But it might be necessary to have flexibility of changing lake levels based on actual inflows to address deviations from average. In general, the amount of inflow is the most important factor in Osoyoos Lake management since it is a much larger component than possible storage in the lake. Hence it might be worth considering the option of managing for inflows instead of managing lake elevation in terms of the dam operation. The success of such a management strategy would depend of the ability to get estimated inflow a few months ahead of time. Another aspect to consider is backflow into Osoyoos Lake from the Similkameen River in high runoff years causing lake levels to go above 913 feet. This is a rare occurrence (occurred three times in the last 24 years) and managing lake elevations will not help address the issue. Hence, it may not be feasible or necessary to incorporate this as criteria for managing the Osoyoos Lake.

The fourth objective of the study was to assess stakeholder interests in lake elevations. It appears that boaters like to have a lake elevation of 912 feet during the summer boating season and the winter levels are not of concern to them. Resort owners and vacationers are greatly impacted by reduced recreational potential due to the beaches cover with water when lake elevations exceed 912.5 feet. Campers like the lake elevation to be less than 912.5 feet in the camping season so as to avoid flooding of campsites and mosquito infestation. Residents/Property owners are concerned about erosion issues related to lake levels higher than 912.5 feet. They also seem to prefer a winter lake elevation of 909 feet so that ice damage to the shoreline is prevented and Eurasian Milfoil can be controlled. Irrigators are worried when the lake elevations drop below 910.5 feet in the summer, all of the water right from Osoyoos Lake that is issued after July 14, 1976 will be terminated (Ecology, 1990). Stakeholders concerned with fisheries and ecological demands downstream of the dam are probably less concerned about lake elevation than the discharge amounts from the dam. There are important species that reside in the lake and different species will have different elevation requirements. Some might require fluctuations in levels for their life cycle and others might not. Also, what is optimal for one species may be detrimental to others and it may not be practical to come up with one elevation criterion that fits all species. Dam operators will be concerned with simple and easy to manage elevation targets, and regulators will like the flexibility of having multiple dam operation options to cater to changing needs.

The fifth objective was to look at alternate sources of water. Although preliminary discussions on out-of-basin transfers and the potential of using ground water as an additional source have been discussed, for the next set of Orders it appears that water management within the basin must be used to meet demands.

There are some data gaps that will be useful to address. Climate change and the impacts this can have on future demand for water as well as future supply of water is important to know. Key findings of the Okanagan Water Supply and Demand Project, Phase 2 (2010) indicated that summer stream flows in Okanogan could reduce by one third by mid century. This preliminary result is not currently based on an ensemble of Emission Scenarios and Global Climate Models (GCM) and hence, in its current state, it does not handle the uncertainties associated with climate change well. Phase 3 of the Okanagan Water Supply and Demand Project is expected to address this limitation. The other climate studies we have referenced also do not consider a broad range of emission scenarios and GCMs to address uncertainties. The Osoyoos Lake Plan of Studies also includes a study on climate change (Study 6). Once these studies are complete and estimates of climate change impacts with associated uncertainties are known, future inflows will need to be reassessed to study what percentage of demand can be reasonably met and if different storage requirements will be necessary.

Instream flow requirements are available for Upper, Middle and Lower Okanogan River segments below the Zosel dam. However, currently Ecology only monitors the Middle and Lower Okanogan river segments for compliance (personal communication with Susan Beery, Ecology). The instream flow requirements are available as one set of targets. It would be worthwhile to quantify the exact implications of not meeting these targets and come up with an acceptable minimum target to be met in drought years in addition to the optimal target requirements. LGL Limited and Pacific Hydraulic Engineers and Scientists (2009) came up with such ranges of required targets (optimal, minimum and maximum) for fisheries flows. Currently, fisheries requirements are managed at the dam to allow a downstream flow of 300cfs to the extent possible every month (Personal Communication with John Arterburn, Colville Confederated Tribes). This is being done as a practical dam operation trade off and is perceived by stakeholders as having acceptable negative consequences. March flows are important in terms of fisheries requirements and flows of 300cfs have not been met a few times in the recent past year for this month. One reason for this could be because releases are restricted to fill up the lake. From the historical inflows and demands comparison, it seems like in an average year it would be okay to discharge the required instream/fisheries flows in March and fill up the lake for storage earlier or later in the year.

To summarize, it would be beneficial to negotiate minimum trans-border flows more in line with historical inflows so that a degree of certainty can be attached to how much of the projected demand can be expected to be met. This is especially important because if inflows were restricted to current minimum trans-border flow requirements, a large portion of the demand would not be met (50% to 75% in most months). Because of limited storage capacity, more than storage options it is the inflow amounts that are critical and it would be worthwhile to consider managing lake operations based on inflow rather than elevation targets or managing based on a combination of inflow and elevation targets. If the historical inflows analyzed in this study continue in the future, lake elevation fluctuations of one foot and 2.5 feet should address storage requirements in an average normal year and drought year respectively. So lake levels can generally be set to what is perceived as optimal by stakeholders with regulators having the flexibility of modifying it as required based on actual inflows and their deviation from historical averages.

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