FINAL REPORT

Evaluation of Criteria to Declare Drought (Study 2)
Review of Dates for Summer & Winter Operation (Study 3)

Studies 2 and 3 for Renewal of Osoyoos Lake Order of Approval

September 2, 2011 3088.0002.01

Prepared for:
INTERNATIONAL JOINT COMMISSION
International Osoyoos Lake Board of Control

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EXECUTIVE SUMMARY

Water levels on Osoyoos Lake are controlled by the Zosel Dam in Washington State, and are managed in accordance with Orders of the International Joint Commission (IJC). This report deals with Studies 2 and 3 from the Plan of Study designed to provide information to the IJC Commissioners to renew the Orders for Osoyoos Lake. Study 2 is an evaluation of the criteria used to declare drought and Study 3 is a review of the dates for switching between summer and winter operation. These studies will help the Commissioners determine the authorized water levels and the timing of those levels, whether summer or winter, drought or not. Both studies are presented together in this report due to the linkage in how the lake must be operated but each has a stand-alone conclusion.

Drought

An analysis of the 24 years of operations since the current Zosel Dam was completed shows that drought criteria were met nine times or 38% of the time. This is more frequent than most definitions of drought would indicate was appropriate. In eight of the nine years when the criteria were met, the Similkameen River criteria were met, while only for six and five times were either of the two Okanagan criteria met. A review of the last 80 years of record indicates that the Okanagan Basin in Canada did not appear to be experiencing an abnormally dry period during the time the dam was in place. However, for the Similkameen River at Nighthawk this was the driest period in that same period of record. The current drought criteria are hydrological criteria that reflect the available supply and do not reflect the use or demand for water downstream. They cannot react to the severity of impact of a drought situation where the water is used. Nevertheless, the current criteria do give an indication of the availability of water for the coming season and they do signal the need to store water.

Ten common drought indices were reviewed for their possible use as a drought criteria that might give a signal of the severity of a drought and allow for altered lake level operations based on the severity of the drought rather than the current drought-or-no-drought approach. Of these ten meteorological or agricultural indices, only the Standardized Precipitation Index (SPI) appears to provide an appropriate severity rating. However, the SPI tells you the severity of a drought at the beginning of a month based on the conditions in the previous month or months by which point it may be too late to capture spring snowmelt runoff. Furthermore, there is not sufficient data anywhere in the Basin to permit its calculation. No alternate criteria are recommended in this study.

Based on our review of the current approach we concluded that the all or nothing, drought or not, approach was not the optimum way to manage the reservoir. In addition, it was obvious that a better approach was needed to change levels from summer to winter and this was further explored in Study 3. The WEAP (Water Evaluation And Planning) hydrologic model from the Stockholm Environment Institute, which has been specifically designed for modeling the impacts

of water management policies, was used to develop scenarios to model these changes while also looking at better ways of operating the reservoir for the multiple objectives.

Summer and Winter Operation

Considerable trade-offs have to be made in operating a dam for multiple purposes. Water levels in Osoyoos Lake are desired high in summer to store water for irrigation and release for instream flow purposes downstream of the Zosel Dam. High levels are preferred by boaters and other recreational users to allow safe passage across the bars. But high levels cover the beaches and restrict useable areas. At high levels, waves from storms and boat wakes cause erosion that affects lakeside property and at higher levels, flooding is seen in some areas. In the winter, it is desired that the lake be drawn down to protect property from winter storms and ice damage. Drawdown may also help with aquatic vegetation control. All of these considerations must be balanced one against the other to determine an acceptable operating regime.

Currently Osoyoos Lake levels differ in summer and winter with minimum summer levels beginning April 1 and ending October 31. Study 3 was designed to examine practical alternatives to the present timing of changing lake levels and determine the advantages and disadvantages of switching to them.

The Zosel Dam is operated to meet the IJC Orders but is constrained by the available inflow, which is almost completely dictated by the releases from Okanagan Lake. The releases from Osoyoos Lake attempt to meet Fisheries Criteria and Instream Flow Criteria established in Washington State for the reach downstream of the Zosel dam. The lake level is generally drawn down in the fall to provide winter shoreline wave and ice damage protection and the stored water is used to provide flows for fish downstream of the dam throughout the winter. By April 1, the lake level must be at or above 911.0 feet. Raising the lake from its winter level to a minimum of 911 feet by April 1 is not consistent with the hydrology of the watersheds where spring freshet on the Okanagan system typically commences in late April and peaks in June.

Analysis shows that since 1987 there have been numerous years where outflows could not meet the Fisheries Criteria or Instream Flow Criteria. Years 2000 to 2010 were particularly problematic with releases from Zosel Dam frequently dropping to 100 cfs.

Five scenarios were developed and run through the WEAP model to evaluate alternative management options for lake levels and releases through Zosel Dam. All were compared to the base case and evaluated with respect to management of lake levels, achievement of downstream Fisheries Criteria, stakeholder acceptance, and impact on biological resources. Ramping rates were also discussed and it was concluded that there is a need to consider the implementation of ramping rate guidelines in future operations.

Based on the analysis of the scenarios, a management model is proposed for consideration. In this scheme, the drought declaration would be eliminated and a single, flexible management regime applied for both normal and drought years. A target lake level of 910 feet for the winter and 912 feet for the summer with a range of acceptable levels of +/- 0.5 feet. An eight-week window in the spring and fall would permit gradual raising and lowering of the lake levels with the spring period set for March 15 to May 15, and the fall lowering October 1 to December 1.

ACKNOWLEDGEMENTS

The authors would like to thank the members of the Osoyoos Board of Control and staff of the International Joint Commission for their guidance and assistance. We would also like to thank the many agencies, organizations and individuals who provided information and made suggestions that contributed to this report.

1.0 INTRODUCTION

1.1 BACKGROUND

Osoyoos Lake straddles the Canada-US border between British Columbia and the State of Washington (Figure 1). Except during extreme high flows, water levels in the lake and outflows from the lake are controlled by Zosel Dam, situated on the Okanogan River just downstream from the lake. The present dam is owned by the State of Washington Department of Ecology and is operated to the satisfaction of both countries under Orders of Approval (Orders) issued by the International Joint Commission (IJC or Commission) under the authority of the Boundary Waters Treaty of 1909. These Orders prescribe the allowable levels of Osoyoos Lake and the timing of the various levels as well as authorizing the construction of the dam.

The original dam was built in 1927 to form a millpond from which logs could be transported to the Zosel family sawmill. By the late 1970s, the dam was in a deteriorated condition and was overstressed during high water level conditions. In 1980, the State of Washington applied to the IJC for approval to reconstruct the dam.

In 1982, the current Orders were written for the replacement of the dam. The Orders specified a range of lake levels that should be maintained throughout the year and a flow conveyance capacity that should be maintained in the river channel between the lake and the dam. A Supplementary Order, written in 1985, allowed a change in the dam location and a change in the construction schedule for rebuilding the dam. Construction started in 1986 and was officially completed in1988.

Zosel Dam has four spillway gates with a capacity of 3,000 cubic feet per second (cfs) and two fish ladders (Ecology, 1990). The dam is operated by the Oroville Tonasket Irrigation District under contract with the Washington State Department of Ecology which has the direct responsibility over the dam. The IJC appoints a six member (three from US and three from Canada) International Osoyoos Lake Board of Control to oversee the implementation of the provisions of the Orders of Approval.

The 1982 and 1985 Orders of Approval terminate on February 22, 2013, 25 years after the new dam was completed unless renewed by the Commission. Washington State's former Governor Locke advised the IJC in a letter dated September 8, 2004 that the State intends to apply for renewal, and when it does, the IJC will need to decide whether and how the Orders should be modified. To make informed decisions, the IJC Commissioners need to be fully aware of all the interests, issues and demands that could affect dam operations, Osoyoos Lake water levels and Okanogan River flows. This is particularly important because since the 1982 and 1985 Orders were written, major changes have taken place in the valley such as increased population growth and settlement, changed agricultural practices such as orchard conversion to vineyards, agricultural expansion and climate changes.

Accordingly, the IJC commissioned a Plan of Study (Glenfir Resources 2006) that has now been completed. It set out a series of eight studies designed to provide information to the IJC Commissioners to renew the Orders for Osoyoos Lake, and described how those studies should be carried out.

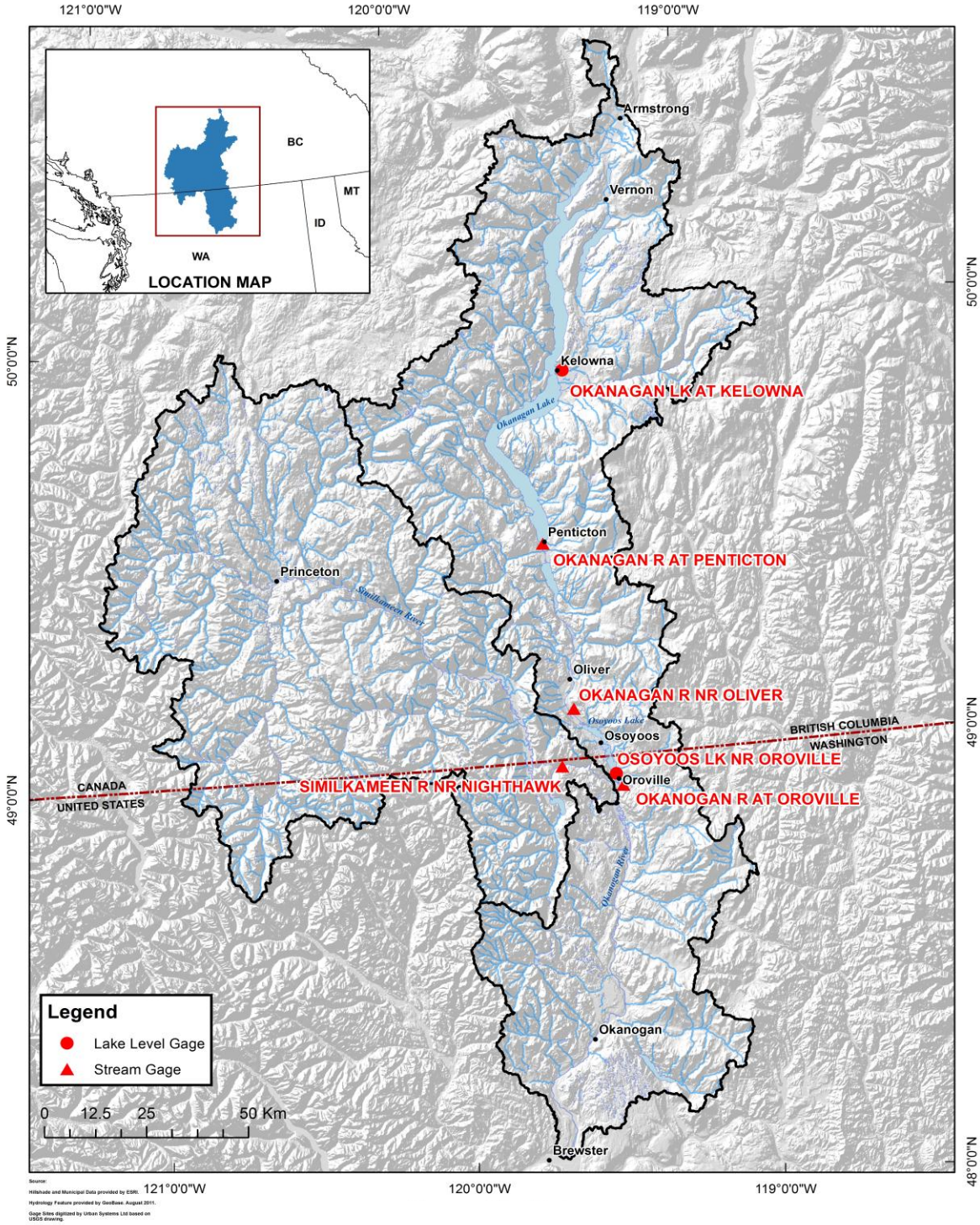


Figure 1: Okanagan River Watershed

1.2 PROJECT UNDERSTANDING

The International Joint Commission has contracted Urban Systems Ltd. to conduct the remaining two studies (numbered 2 and 3) as described in the Plan of Study. Study 2 is an evaluation of the criteria used to declare drought and study 3 is a review of the dates for switching between summer and winter operation. Studies 2 and 3 go directly to the essence of the Orders. They will help determine the authorized water levels and the timing of those levels, whether summer or winter, drought or not. The Plan of Study recommended that these studies be conducted in close collaboration with the International Osoyoos Lake Board of Control (Board) and this has been done. Both studies are presented together in this report due to the linkage in how the reservoir must be operated but each has a stand-alone conclusion in this report.

1.3 STUDY 2 OBJECTIVES

In the existing Orders of Approval, drought conditions are declared when any one of three criteria is met: low freshet flow in the Similkameen, low freshet inflow to Okanagan Lake, or low early-summer water levels in Okanagan Lake. Drought conditions are terminated when updated forecasts or actual conditions indicate none of these criteria are met. All of these criteria appear relevant to the various uses of water in Osoyoos Lake. Currently a drought is declared regardless of whether only one or all three of the criteria are met and regardless of the degree to which those criteria are satisfied. For example, a slight water shortage in the Similkameen with sufficient water in the Okanagan is treated as a drought – no differently than if both the Okanagan and the Similkameen were extremely dry.

The purpose of Study 2 is to explore alternatives to the all or nothing approach to drought declaration. Methods are sought for rating the severity of each drought and then using the severity rating to prescribe the levels of storage water needed over time. The original scope of work specified the following key questions to be answered and tasks to be accomplished.

Key Questions	Tasks
1. What methods are in use in other relevant places to define different levels of drought severity?	1. Research and report on the methods used to manage droughts in other areas. 2. Based on the research conducted, describe methods for drought declaration that take into account drought severity.
2. Which, if any, of these methods could be applied to the Osoyoos Lake water regulation program? ▪ Explicitly state the rationale for any criteria considered and, if appropriate, the location where the criteria is relevant (e.g., between the dam and the Similkameen confluence). ▪ Include an evaluation of having no "drought criteria" at all. In other words, what would be the effect of having a single range of elevation targets for all years?	3. Discuss and prioritize methods most suitable for the conditions experienced in the Okanagan. Provide reasons for the choices.
3. What advantages and disadvantages would the methods have in comparison with the present method?	
4. How would the recommended methods have performed under the conditions experienced in the Okanagan/Similkameen basin over the period of record?	4. Use retroactive analysis techniques to determine the outcome had the method of choice been used over the period of record. Report results. 5. Consult with the Osoyoos Lake Board of Control, the Okanagan Basin Water Board and other frontline water managers and decisions makers experienced with the Osoyoos Lake situation to get their advice on the pros and cons of the recommended method(s).
5. How acceptable would a revised system be to the stakeholders?	

1.4 STUDY 3 OBJECTIVES

Osoyoos Lake levels are regulated differently in the winter than the summer. Summer operating conditions begin April 1 and end October 31. These dates conform to the irrigation season but not to the natural hydrograph which would peak between mid-May and mid-June and begin to subside soon after. This lack of synchrony with the natural cycle has been criticized because it fails to accommodate spring freshets and because it may impact natural biological processes. This study is designed to examine practical alternatives to the present timing of lake levels and

outflows and determine the advantages and disadvantages of switching to them. The study should address the following key questions and tasks.

Key Questions	Tasks
1. In a drought, normal or wet year, what are the pros and cons of changing the starting or ending dates of the summer and winter schedules? ▪ Consider the impacts on flood risk, biological processes, and other interests.	1. Reconstruct the hydrographs (lake levels over time) that occurred for each year since 1982. 2. Construct other alternative hydrographs that could have been used if seasonal timing was altered.
2. In a drought, normal or wet year, what are the pros and cons of switching between summer and winter schedules (or vice versa) progressively by establishing target levels? ▪ Again, consider the impacts on flood risk, biological processes, and other interests.	3. Determine and record the pros and cons of each of the hydrographs from the point of view of ▪ Flood control; ▪ Irrigation and domestic water use; ▪ Ecosystem benefits. 4. Evaluate and prioritize the various timing regime alternatives.
5. When changing lake levels and river flows, what is the optimal rate of change (ramping rate)? Why?	
6. What level of stakeholder acceptance would be associated with the alternatives recommended?	

2.0 CURRENT OPERATONS

2.1 IJC ORDERS

The Zosel Dam was constructed in accordance with an Amendment Order granted by the IJC in 1985, amending some of the conditions of the 1982 Order which originally authorized a dam in a different location. There is no information about the need for the dam or the original purpose of the dam except as stated in the IJC Amendment Order of 1985:

> WHEREAS, as stated in the Commission's Order of Approval of December 9, 1982, there continues to be an urgent need to replace Zosel Dam, the replacement works proposed by the Applicant would facilitate control of the water levels of Osoyoos Lake for the benefit of agriculture, tourism and other interests, and the replacement works would not create flood levels any more extreme than would have occurred if Zosel Dam had remained in place and been maintained and operated in accordance with the 1946 Order of Approval.

From this, it seems apparent that the dam is to be operated for "agriculture, tourism and other interests" and is not to create flood levels any more extreme than would have occurred if the old dam had been able to operate. The 1985 Amendment Order also states:

> WHEREAS the Commission's present Supplementary Order of Approval does not change the requirements for the new works which relate to the level of Osoyoos Lake and which were established in the Commission's 1982 Order of Approval;

The Preamble to the1982 Order stated that the Province of BC and the applicant, State of Washington, were working together on a cooperation plan that provides for emergency storage in Osoyoos Lake during watershort years and "…that this emergency storage would be used for fisheries protection, domestic use and irrigation in both countries." It further stated that while the Province endorsed the application, "the Province does not consider the cooperation plan to be part of the application; and that the cooperation plan does not guarantee any transboundary flow but outlines procedures and flows which will be satisfied as far as practicable".

It was clear that fisheries protection, domestic use and irrigation, and tourism in both countries were the intended uses of the storage created by the dam. Further, the drought provisions were originally thought to be "emergency" provisions.

Normal operations for the dam are given in Section 7 of the 1982 Order as follows:

> Upon completion of construction the Applicant, in consultation with the Board of Control appointed under Condition 14, shall operate the works so as to maintain the levels of Osoyoos Lake between elevation 911.0 and 911.5 feet USCGS to the extent possible

from 1 April to 31 October each year except under drought conditions in the Okanogan Valley (in Canada Okanagan Valley), as defined in Condition 8 and also during the appreciable backwater conditions and excessive inflows described in Condition 9. Furthermore, the Applicant shall operate the works so as to maintain the levels of Osoyoos Lake between elevation 909.0 and 911.5 feet USCGS from 1 November to 31 March each year.

The requirements for the new works which relate to the level of Osoyoos Lake during drought years are contained in section 8 of the 1982 Order as follows:

During a year of drought as determined by the Board of Control accordance with the criteria set forth below, the levels of Osoyoos Lake may be raised to 913.0 feet USCGS and may be drawn down to 910.5 feet USCGS during the period 1 April to 31 October. The criteria are:

(a) the volume of flow in the Similkameen River at Nighthawk, Washington for the period April through July as calculated or forecasted by United States authorities is less than 1.0 million acrefeet or

(b) the net inflow to Okanagan Lake for the period April through July as calculated or forecasted by Canadian authorities is less than 195,000 acrefeet or

(c) the level of Okanagan Lake fails to or is forecasted by Canadian authorities to fail to reach during June or July elevation 1122.8 feet Canadian Geodetic Survey Datum.

Drought year operations shall be terminated when in the opinion of the Board of Control none of the three criteria defining a drought year exist. The level of Osoyoos Lake shall then be maintained in accordance with Condition 7.

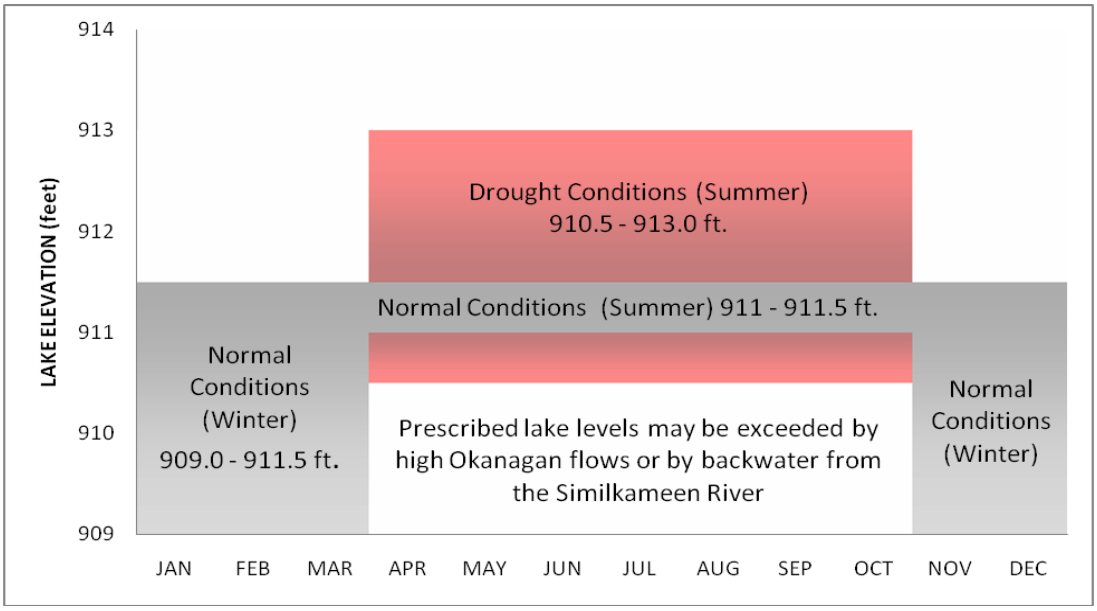


Figure 2: Normal and Drought Operation

In Figure 2, it can easily be seen that for normal conditions, the level of Osoyoos Lake can be any level from 909 feet to 911.5 feet during the winter but must be held between 911 and 911.5 feet from April 1 to October 31. If a drought is declared, however, the level can rise in summer to elevation 913 and may be drawn down to 910.5 feet, giving access to 2.5 feet of storage.
In the existing Orders of Approval, drought conditions are declared when any one of three criteria is met and drought conditions are terminated when none of these criteria are met.

2.2 OPERATIONS UNDER THE 1982 & 1985 ORDERS

Construction of Zosel Dam started early in 1986 and was essentially completed by the summer of 1987. It has operated under the IJC Orders continuously since that time. In Study 1, an Assessment of the Most Suitable Water Levels for Osoyoos Lake (Barber et al 2010a), a table showed values for each of the drought for each year of operation since 1987 (Table 2, page 9). That table is reproduced here as Table 1.

Firstly, it is important to remember that drought criteria are forecasted usually starting in February and updated monthly until April 1 of each year when the Board of Control must make a decision on whether or not to declare a drought. The data reported in Table 1 are the actual measured values and can differ from the estimates due to changed weather conditions after the drought was declared. It can be seen that in 3 of the 4 cases where drought was declared, the actual water available exceeded the early season forecasts and none of the criteria were met and therefore the Board of Control rescinded the drought declaration. In 1987, criteria 8(b) was met and the drought was still rescinded but this is believed to be an error on the part of the Board of Control[1]. The ability to rescind the drought declaration due to changed conditions was reported by some Board of Control members as being an important safety valve.

[1] Dan Millar, Canadian Secretary to the International Osoyoos Lake Board of Control, email dated August 24, 2011.

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

Table 1: Drought Declaration 1987-2010

In every instance of the 8 years where drought levels were permitted throughout the year, criteria 8(a) the Similkameen River forecast was met. Criteria 8(b), low April through July inflow to Okanagan Lake, was met in 5 of the years when drought was declared and also in 1987 when drought was declared and then rescinded as mentioned above. Criteria 8(c), low Okanagan Lake level, was met in the same 5 years that 8(b) was met.

The first thing to notice is that for the 24 full years of operation since the dam was completed, drought was declared 12 times or 50% of the years were declared to be drought years. For four of those years, drought was rescinded but even so, under the 8(a), (b) or (c) criteria, drought criteria were met 9 times or 38% of the time. Drought is often defined as an event that occurs less than 20% of the time. In fact, some relief agencies define drought as an event that occurs at a much lower frequency than that. This leads to the following questions analyzed in this report.

1. **Was the dam completed at the beginning of an abnormally dry period?**
2. **And if not, do the current drought criteria lead to a declaration of drought more often than necessary?**

BC Government staff have provided information on the annual net inflow volume to Okanagan Lake for the years 1921 through 2010. The inflows are calculated from change in storage plus the measured outflow. Monthly data is also available. The drought criteria for Okanagan Lake is 8(b) "the net inflow to Okanagan Lake for the period April through July as calculated or forecasted by Canadian authorities is less than 195,000 acrefeet". The April through July period for the entire record is presented in Figure 3. From this graph, it is easy to see the 1929 through 1931 drought of record as well as some low inflow years after the dam was completed such as 1991, 2003 and 2009.

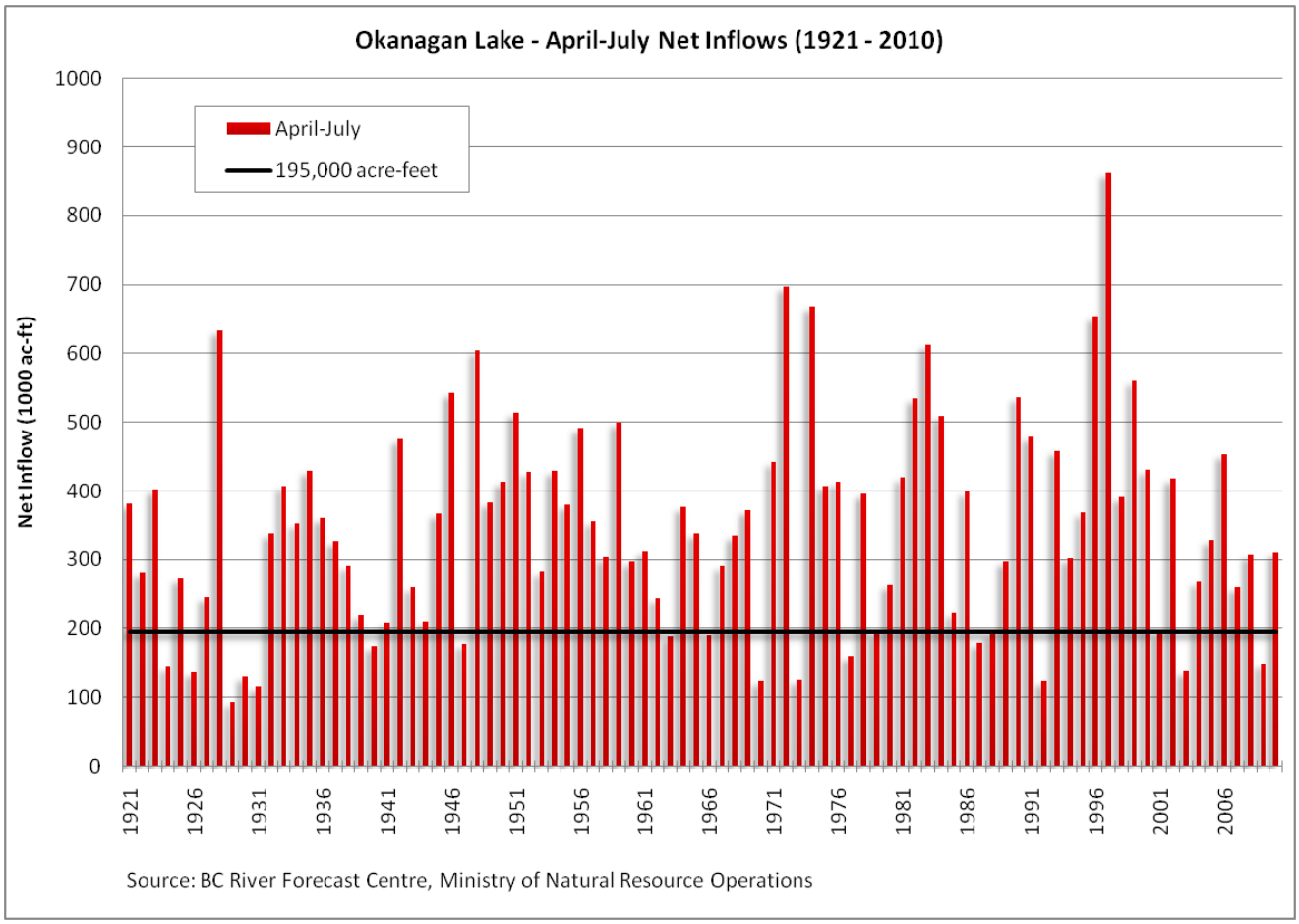


Figure 3: Okanagan April-July Inflows 1921-2010

Turning now to the period in which the current Zosel Dam has been operated, 1987 to 2010, the April through July inflows are presented in Figure 4 in ranked order from highest to lowest. Here the six years where criteria 8(b) was not met can be clearly seen.

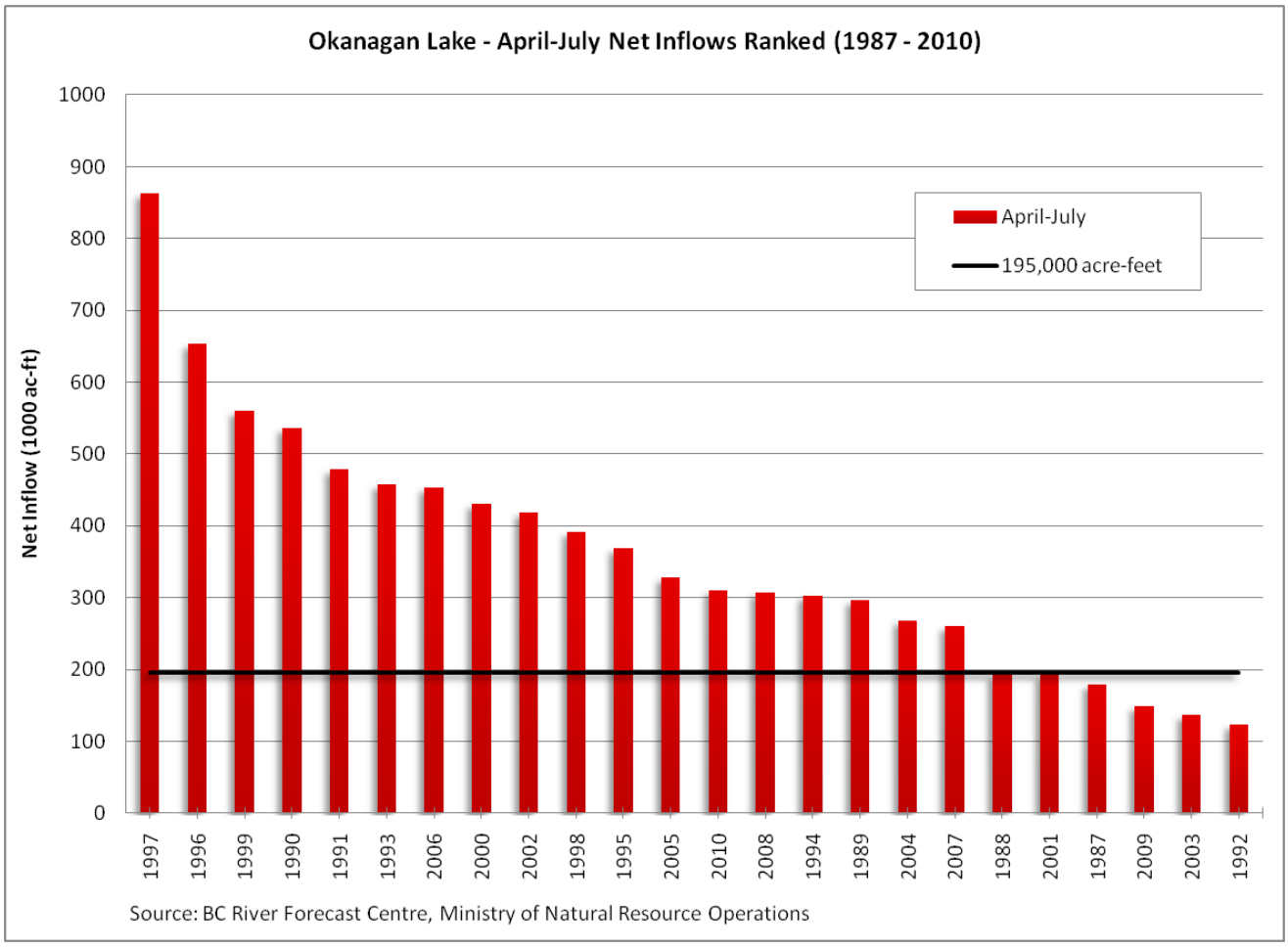


Figure 4: Ranked April-July Okanagan Lake Net Inflows (1987-2010)

Looking at the Okanagan system alone, drought is indicated under the Okanagan criteria 8(b) six times and 8(c) five times. Over the 24 years, this represents 25% of the time and about 21% of the time respectively and is more in line with what might be expected under most definitions of drought.

Thirty-year normal periods have been computed for both the annual inflows as well as the April through July period and the mean and the median for the period of record. They are shown here in Table 2.

The 30-year "normal" for the period 1981-2010 is 433,813 ac-ft and is certainly influenced by the huge runoff year of 1997. However, it is lower than the 1971 -2000 normal of 473,213 ac-ft but greater than the 1961-1990 normal of 387,359 ac-ft. This is of course, for total annual inflow. Because the bulk of the inflow is from the snowmelt period, the inflow for the April through July period is nearly as large as the annual inflow. Both are shown in the Figure 5.

Period	Entire Year (Ac-ft)	April through July (Ac-ft)
Mean	386,734	347,236
Median	395,571	338,927
Norm 1921-1950	334,146	312,611
Norm 1931-1960	397,249	354,606
Norm 1941-1970	389,223	346,499
Norm 1951-1980	392,223	350,552
Norm 1961-1990	387,359	347,877
Norm 1971-2000	473,213	409,896
Norm 1981-2010	433,813	378,522

Table 2: Okanagan Lake Inflow Normals 1921-2010

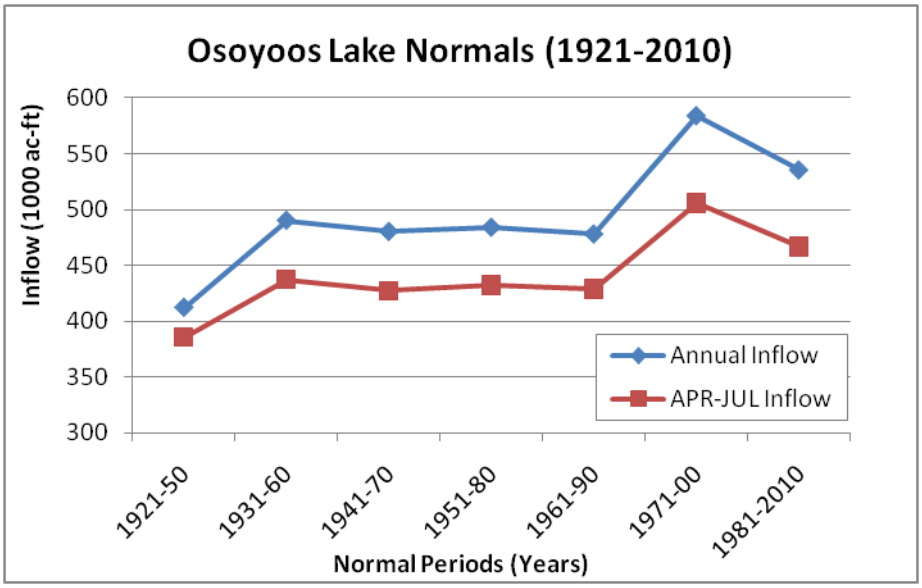


Figure 5: Okanagan Lake April-July Inflow Normals 1921-2010

It can be concluded that, for the Okanagan system at least, the 1981-2010 period was not an exceptionally dry period and in fact appears to be slightly wetter than all preceding normal periods since 1931, except the immediately preceding normal period of 1971-2000.

Looking further at the Similkameen River, the drought criteria 8(a) requires that the forecast volume for the April through July period measured at Nighthawk Washington be less than 1.0 million acre-feet. Figure 6 shows the April through July discharge for the Similkameen River at Nighthawk for the period of record (1929 to 2010). The horizontal black line shows the drought criteria of one million acre-feet. Over the 82 years of record, the one million acre foot criteria would have indicated drought 20 times or 24% of the time. However, as has been discussed, during the 24 years of Zosel Dam operations, the drought criteria 8(a) was met 8 times or 33%

of the time, which is more often than the frequency of drought occurrence in the long-term record.

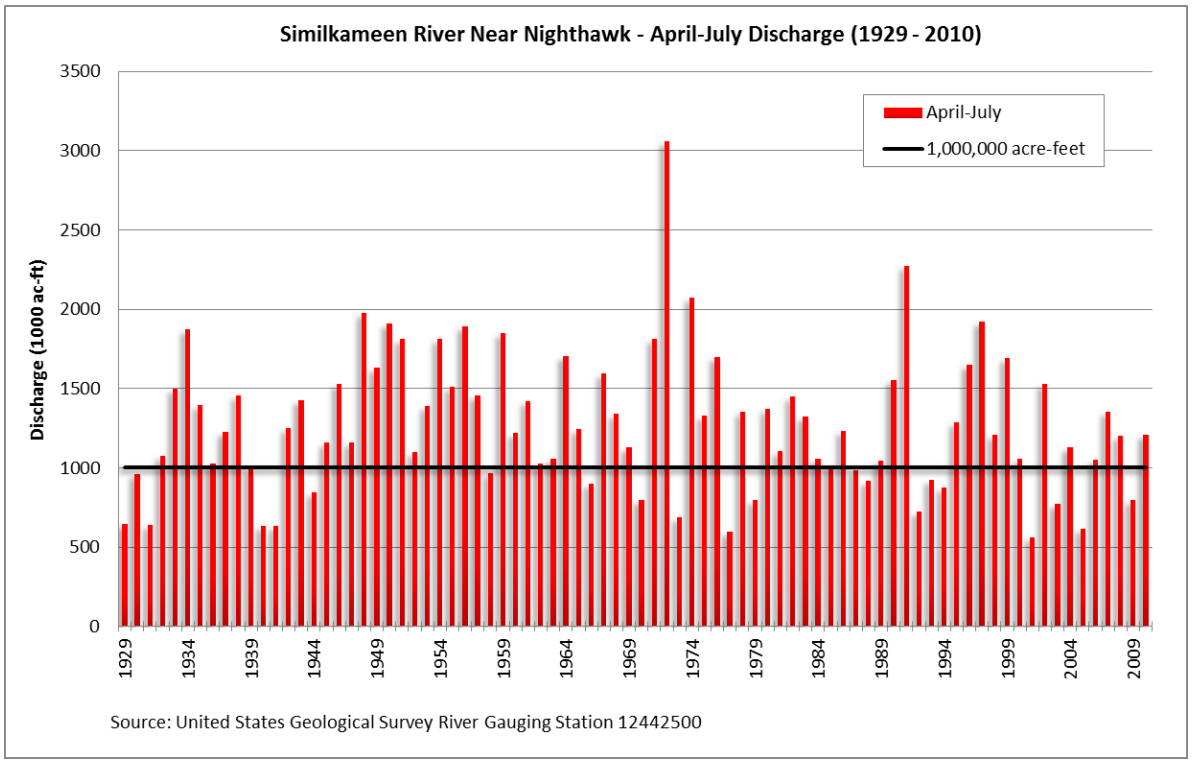


Figure 6: Similkameen River April-July Discharge 1929-2010

Again, the 30-year normals were examined to see if this last normal period was drier than the preceding periods. Figure 7 shows the normals.

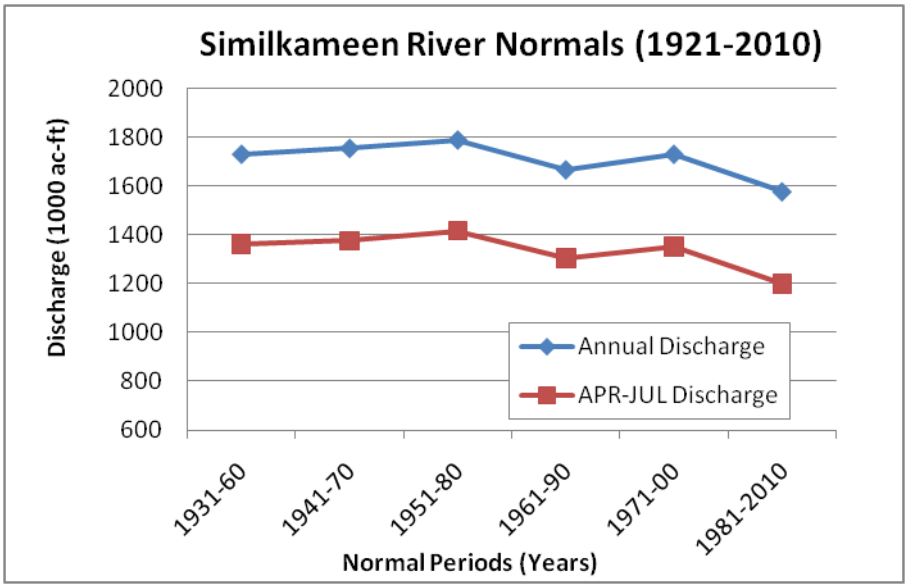


Figure 7: Similkameen River April-July Discharge Normals 1931-2010

Certainly this period appears to be slightly drier than the preceding periods over the 80 years of record with the greatest difference in normals being about 18%. So perhaps the Similkameen basin was experiencing slightly drier conditions in the time after the dam was constructed.

Turning again to the questions posed at the beginning of this section:

Was the dam completed at the beginning of an abnormally dry period? Looking at the last 80 years, the Okanagan Basin in Canada did not appear to be experiencing an abnormally dry period. However, for the Similkameen drainage above Nighthawk, the last 30 years were the driest period in that same period of record.

And if not, do the current drought criteria lead to a declaration of drought more often than necessary? Drought declaration based on either criteria 8(a) or 8(b) seemed to indicate a higher incidence of drought than the long-term record would support. However, the Similkameen River appears to have been experiencing drier conditions than it experienced in the time before the dam was built.

This analysis serves to illustrate the conundrum of using hydrologic indicators to indicate a "drought" condition. These criteria for declaring drought are "supply-side" criteria; they say that there is not going to be as much water this year and they trigger the declaration that allows more storage in Osoyoos Lake but they do not really say much about the actual conditions where the water is used. Section 3 of this report looks at drought and other indicators of drought. Some of these are more "demand-side" criteria and they look at the need for water and whether there are different criteria that could trigger the declaration that allows for more storage.

2.3 EFFECTIVENESS OF CURRENT OPERATIONS

Current operations were modeled to determine how effective the control mechanisms are to achieve compliance with the Orders, how the seasonal changes work and what the downstream effects are. The analyses for this study were conducted using software developed by the Stockholm Environment Institute. The WEAP (Water Evaluation And Planning) model is especially designed for modeling the impacts of water management policies. The general structure of the model, the key assumptions and the data used, are summarized in Appendix A.

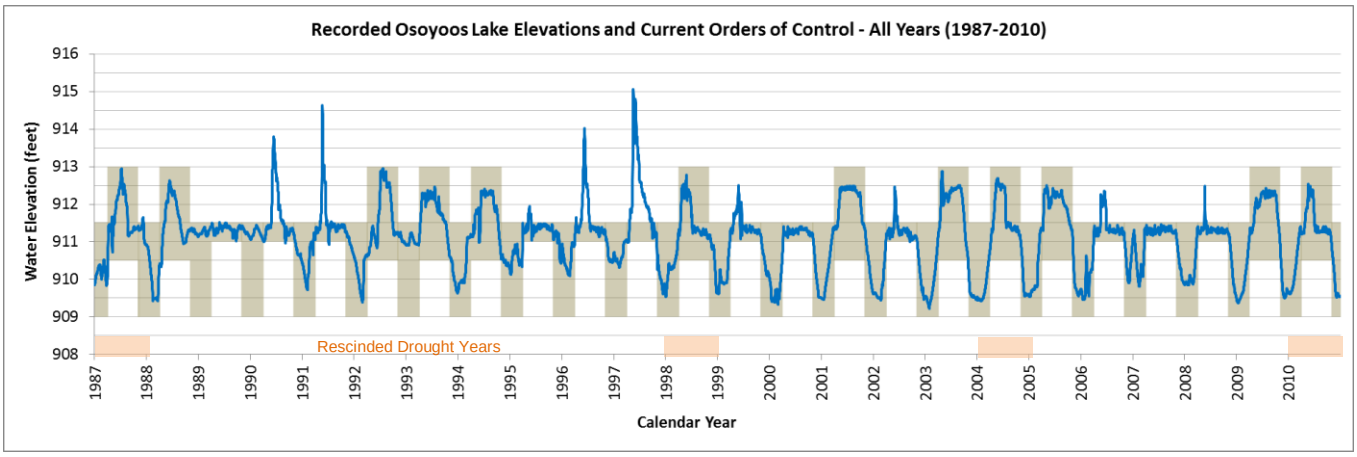


Figure 8: Comparison of Recorded Lake Elevations and Current Orders

The shaded grey area in Figure 8 represents the authorized levels under the Orders with the blue line representing the actual water levels attained. The 12 years where drought was declared are shown with the levels authorized to rise to elevation 913 feet. In the four years when drought was rescinded, marked with a pink bar beneath the year, the grey area still shows the authorized drought but it can be seen where the level is brought down to under 911.5 feet part way through the summer in response to the declaration being rescinded. It can also be seen that, except for a few very short duration events, lake levels in drought years since 1993 have generally not risen above 912.5 feet. This is in response to the informal agreements between the water managers in British Columbia and Washington State where the Washington Department of Ecology will try to limit Osoyoos Lake levels to no more than 912.5 feed during drought years provided the BC Ministry of Environment (as it was then) agreed to supply 2,850 acre-feet (the equivalent of the foregone half foot of storage on Osoyoos Lake) at a specified time (discussed further later).

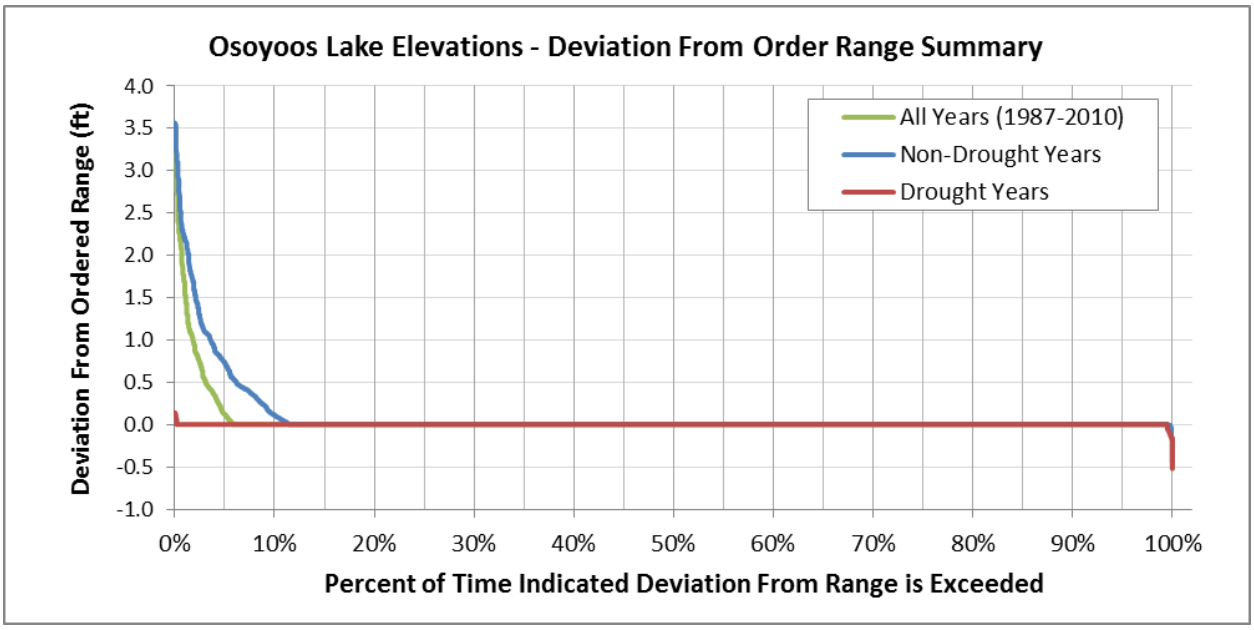


Figure 9: Osoyoos Lake Elevation Deviation From Current Orders Elevations

Figure 9 shows that deviation from the Orders is low. The instances where the lake levels went above the authorized range are generally due to the need to pass flood flows or when backwater from high stage in the Similkameen River impeded outflow from Zosel Dam.

Period	Time Above Range	Time Within Range	Time Below Range
All Years (1987-2010)	5.9%	93.7%	0.4%
Non-Drought	11.5%	88.1%	0.4%
Drought	0.2%	99.3%	0.5%

Table 3: Deviations from Authorized Range

Table 3 shows that 0.4% of the time during non-drought years and 0.5% during drought years, lake levels fell below the authorized range in the Orders. These were generally "cutting the corner" events after April 1 trying to ramp up to the authorized level or before October 31 trying to meet late season low flow targets while still keeping the Lake level above 911 feet. More analysis and discussion of seasonal changes will be given in Section 4.

3.0 DROUGHT

3.1 UNDERSTANDING DROUGHT

Drought is simply the result of an abnormal water deficiency. The National Drought Mitigation Center (NDMC) at the School of Natural Resources at the University of Nebraska-Lincoln describes drought as a deficiency of precipitation over an extended period of time resulting in a water shortage for some activity, group or environmental sector. Thus we see two factors here: first is lower precipitation than expected relative to some long-term "normal" and second is the impact that the resulting shortage has on the demand that people place on water for uses such as human consumption, agriculture, recreation or the human desire to maintain a particular instream flow. Research done by the NDMC in the 1980s found more than 150 definitions of drought. These were categorized into four basic approaches to measuring drought: meteorological, agricultural, hydrological and socioeconomic.

The first three deal with drought as a physical phenomenon. *Meteorological drought* is often measured as the number of days without rain or the monthly rainfall measured as a percentage of a 30-year "normal" for that month. *Agricultural drought* looks at the effects of a meteorological drought on crops and measures the soil moisture deficit for a particular crop at a particular time. *Hydrological drought* refers to deficiencies in surface and subsurface supplies and is measured as streamflow and reservoir levels. The last approach, *socioeconomic drought*, attempts to track the effects of drought on the economy and people's lives.

Droughts include low flow periods, but a low-flow event, even a continuous seasonal low-flow event, does not necessarily constitute a drought. While the above conceptual definitions of drought help people to understand the concept of drought and may be useful in establishing drought policy, operational definitions of drought are needed to identify the beginning, end, and degree of severity of drought.

3.2 DROUGHT INDICES

Mathematical indices are now generally used to decide on when to start implementing drought response measures. A drought index is generally a single number that expresses drought severity for a specific place for a specific time. It is generally a computation over time of a number of water supply inputs such as rainfall, snowpack, streamflow, etc. Below is a summary of a number of drought indices that are in use in the United States and other parts of the world.

1. Percent of Normal

Description: Using a single precipitation station, this index is calculated by dividing actual precipitation by normal precipitation—typically based on a 30-year mean—and multiplying by 100%. Normal precipitation is considered to be 100%.
Who uses it: Weather forecasters and TV weather people worldwide.
Pros: Effective for comparing a single region or season to normal for that region or season.
Cons: Easily misunderstood; the mathematical construct of "normal" does not necessarily correspond with what we expect normal weather to be.

2. Palmer Drought Severity Index (PDSI)

Overview: The PDSI is a soil moisture algorithm calibrated for relatively homogeneous regions. PDSI is calculated based on precipitation and temperature data, as well as the local available water content of the soil. Because it is based on moisture inflow (precipitation), outflow, and storage, it does not take into account the long-term trend.
Who uses it: Many US government agencies and states rely on the Palmer to trigger drought relief programs.
Pros: PDSI is the first comprehensive drought index developed in the United States.
Cons: The PDSI was not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Palmer values may lag emerging droughts by several months. It is less well suited for mountainous land or areas of frequent climatic extremes and it is complex with a built-in time scale that can be misleading. Computation of the PDSI is complex and it requires a substantial input of meteorological data, which often is not available where networks are scarce.

3. Crop Moisture Index (CMI)

Description: The CMI uses a meteorological approach to monitor week-to-week crop conditions. Developed from procedures within the calculation of the PDSI, the CMI was designed to evaluate short-term moisture conditions across major crop-producing regions. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week.
Who uses it: The US Department of Agriculture produces Weekly maps of the CMI for its Weekly Weather and Crop Bulletin.
Pros: Identifies potential agricultural droughts.
Cons: The CMI is not a good long-term drought monitoring tool. It also inadequately represents the beginning and end of a drought period.

4. Surface Water Supply Index (SWSI)

Description: The SWSI was designed to complement the Palmer Index in the state of Colorado. It is calculated by river basin, based on snowpack, streamflow, precipitation, and reservoir storage.
Who uses it: State of Colorado.
Pros: Represents water supply conditions unique to each basin. Accounts for mountain snowpack as a key element of water supply.
Cons: The index is unique to each basin, which limits interbasin comparisons. Changing a data collection station requires that new algorithms be calculated.

5. **Standardized Precipitation Index (SPI)**

Overview: The SPI is an index based on the probability of precipitation for a desired period. A long-term precipitation record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way.
Who uses it: The SPI has been used operationally to monitor drought conditions throughout the United States. Also widely used in India. The World Meteorological Organization adopted SPI in 2009 as a global standard to measure meteorological droughts.
Pros: The SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Palmer.
Cons: Values based on preliminary data may change. Computation is still complex and the procedure requires long-term records – at least 20–30 years (optimally 50–60 years) of monthly rainfall data is needed to calculate the SPI.

6. **Reclamation Drought Index (RDI**)

Description: RDI is calculated at the river basin level, incorporating temperature as well as precipitation, snowpack, streamflow, and reservoir levels as input.
Who uses it: Developed by the Bureau of Reclamation to trigger drought relief; used by the State of Oklahoma as part of their drought plan.
Pros: By including a temperature component, it also accounts for evaporation.
Cons: Because the index is unique to each river basin, inter-basin comparisons are limited.

7. **Deciles**

Description: Groups monthly precipitation occurrences into deciles so that, by definition, "much lower than normal" weather cannot occur more often than 20% of the time.
Who uses it: Used in Australia to trigger drought relief funding.
Pros: Provides an accurate statistical assessment of precipitation.
Cons: Meaningful results require a long climatic data record.

8. **Effective Drought Index (EDI)**

Description: The effective precipitation is the summed value of daily precipitation with a time-dependent reduction function. The deviation of effective precipitation (DEP) shows the deficiency or surplus of water resources for a particular date and place. The standardized value of the DEP denotes the standard deviation of each day's DEP. The effective deficit or surplus, the EDI, expresses the standardized deficit or surplus of stored water quantity. The EDI enables one location's drought severity to be compared to another location's, regardless of climatic differences.
Who uses it: Korea
Pros: Uses daily precipitation. The only data needed for the calculation of the drought indices series is daily precipitation values.
Cons: Not widely used.

9. **Streamflow Drought Index (SDI):**

Description: Based on cumulative streamflow volumes for overlapping periods of 3, 6, 9 and 12 months within each hydrological year.
Who uses it: Greece
Pros: Simple and effective
Cons: Not widely used.

10. Reconnaissance Drought Index (RDI)

Description: Uses precipitation and evapotranspiration to calculate the index. The RDI generally responds in a similar fashion to the SPI (and to a lesser extent to the Deciles), but it is more sensitive and suitable in cases of changing environmental conditions.
Who uses it: Greece.
Pros*:* May be calculated on a monthly, seasonal or annual basis.
Cons: Requires a suitable precipitation gauge network and a network for monitoring evapotranspiration.

3.3 CHOOSING DROUGHT INDICES

Drought is characterized by severity, time of onset, areal extent, duration, and frequency of occurrence. All of the indices described above are attempts to quantify the concept of severity for a particular place and a specific set of conditions. To be effective, a drought index should have the following characteristics:

1. Be easily understood and carry some physical meaning
2. Sensitive to a wide range of conditions
3. Identify drought soon after its occurrence
4. Based on data that are readily available.

Lack of sufficient and appropriate data generally restricts the choice of models that can be used to calculate a drought index, especially in Canada. Evaporation or evapotranspiration, temperature and soil moisture data are generally not available in the Canadian parts of the Okanagan basin. Streamflow data and precipitation data are readily available for some parts of the basin, however.

The index of the 10 discussed above that has the best potential of providing some indication of drought severity is the Standardized Precipitation Index (SPI). SPI is the most commonly used index worldwide. It has wide acceptance and its use is being promoted by the United Nations (GAR 2011). A drought event begins any time when the SPI is continuously negative and ends when the SPI becomes positive. Early detection of the onset of drought, and a measure of its intensity through the use of the SPI is used for drought relief by management agencies.

The National Oceanic and Atmospheric Administration(NOAA), National Climatic Data Center (NCDC) http://lwf.ncdc.noaa.gov/climate-monitoring/index.php calculates values of SPI and the Palmer Drought Severity Index across the United States and, where the data is available, in Canada and Mexico as part of their North American Drought Monitor. Palmer data is not available for Canada but SPI values are computed. The data is mapped and updated regularly (refer to Figure 10). Canada is not included in the contour maps because of the limited number of climatological stations currently available but Canadian data is provided.

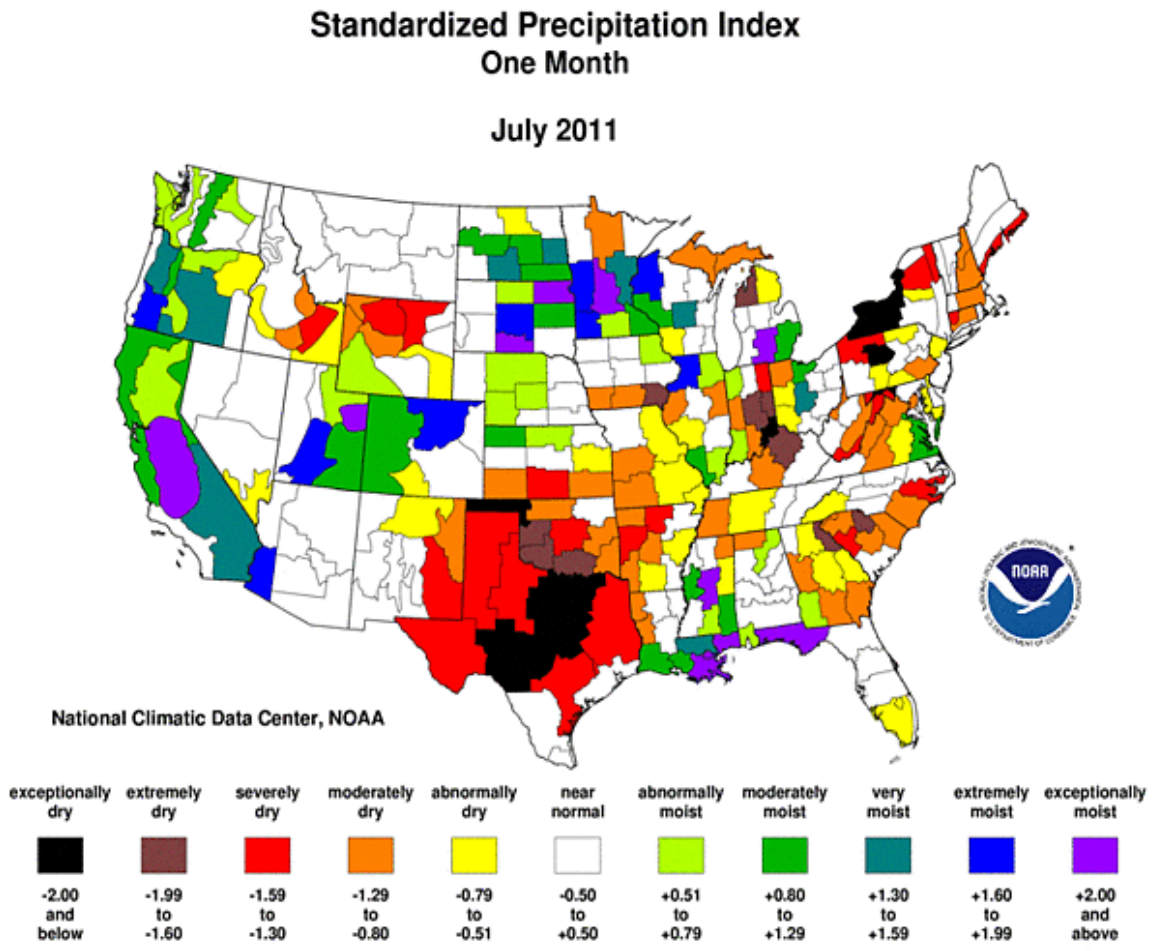


Figure 10: Sample NOAA NCDC SPI Map

The SPI files contain the monthly Standardized Precipitation Index (SPI) values for seven timeframes for each year and month in the period of record. The period of record may vary from station to station. The standardizing period for the SPI is 1951-2001. Positive values of the SPI indicate wet conditions and negative values dry conditions, with more extreme values indicating more extreme anomalies. The seven timeframes are: current month (short-term conditions), most recent two months, most recent three months, most recent six months, most recent nine months, most recent 12 months, and most recent 24 months (long-term conditions).

SPI values are computed for Kelowna (1968-2004) and Penticton (1942-2011). However, they are calculated from data collected at the airports near those cities. The weather stations are now operated by NAV Canada and the requirements to operate the weather stations are aviation requirements. It is uncertain how appropriate the SPI values computed from these data might be with respect to the agricultural or hydrologic uses for which we might want to use them. US weather stations at Tonasket and Colville appear not to have sufficient records to compute

SPI values and stations in Washington with sufficient records appear to be too far away to represent conditions in the US where the water from Osoyoos Lake may be used.

SPI values are computed at the end of each month for a specific place and they can give an indication of the conditions for that month or for the combined value for that month and the month before or for each of the seven time periods listed above. Thus by March, say, you could get a sense of how dry conditions are for that spring or had been over the previous winter. This would be an assessment of water needs. However, it would not tell us how much water is waiting in the mountains in the form of snow. As the summer progresses, SPI would give an indication of the severity of the drought in the place where it was calculated but by the time the July SPI value is calculated, the freshet is over and the best time to capture water into storage is over. No drought severity measure will be timely enough to assist with management of a reservoir dependent on mountain snowmelt for filling.

Further, Study 1 states that 90% of the demand for water from Osoyoos Lake is to meet the instream flow needs downstream of Zosel Dam. These are entirely dependent on inflows to Osoyoos Lake and reservoir storage.

3.4 DROUGHT CONCLUSIONS

The current approach for determining drought is working within its limitations. However, it may be signaling drought more often than would be considered drought by most common definitions of drought. The current criteria are streamflow criteria that reflect the available supply and do not reflect the use or demand for water downstream. They cannot react to the severity of impact of a drought situation where the water is used. Nevertheless, the current criteria do give an indication of the availability of water for the coming season and they do signal the need to store water.

The NOAA National Climatic Data Center cautions that streamflow measurements are useful indicators of droughts as well as floods but they must be used with caution. For streams that are regulated, the streamflow may reflect the upstream management decisions which may not reflect true drought conditions. While the Similkameen River is mostly unregulated, the inflow to Okanagan Lake upstream of Osoyoos Lake is heavily regulated by dams on tributary streams and, through the Cooperation Agreement and the good working relationship among the staff in British Columbia, Washington State and the Oroville-Tonasket Irrigation District, it is regulated for the benefit of Osoyoos Lake as well as the lakes further upstream on the Okanagan River. The inflow to Okanagan Lake can be used as an indicator of water available, but because it is regulated before reaching Osoyoos Lake, its value as a drought index is reduced. Nevertheless, the daily record of streamflow coming into Osoyoos Lake (driven by releases from Okanagan Lake) is a valuable management tool for Zosel Dam. Work is underway at the United Nations to develop a composite hydrological drought index that takes into account factors

including stream-flow, precipitation, reservoir levels, snow pack, and groundwater levels (GAR 2011) but such a model is not currently available.

Indices based on precipitation alone do not take into account specific drought impacts which will vary based on the vulnerability of the crops, environment or society of any particular region. The SPI and other indices are only tools to help decision makers understand events that are taking place. It is good to have one or more of these tools, but the decision makers have to become familiar with how to apply these tools and understand their strengths and limitations in local situations.

We began to realize that the all or nothing, drought or not, approach was not the optimum way to manage the lake elevations. What is needed is the management flexibility to capture the optimum amount of inflow to meet the in-lake and downstream flow criteria.

Further, it was also obvious that a better approach was needed to changing levels from summer to winter and this is discussed in the next section. Scenarios are developed to model these changes while also looking at better ways of operating the lake elevations for the multiple objectives.

4.0 SUMMER AND WINTER OPERATION

4.1 ANALYSIS OF CURRENT OPERATIONS

Considerable tradeoffs have to be made in operating a dam for multiple purposes. Water levels in Osoyoos Lake are desired high in summer to store water for irrigation and release for instream flow purposes downstream of the Zosel Dam. High levels are preferred by boaters and other recreational users to allow safe passage across the bars and to prevent propellers from striking bottom in some areas. But the levels cannot be too high: High levels cover the beaches and restrict areas for sunbathing and playing. At high levels, waves from storms and boat wakes cause erosion that affects lakeside property. At higher levels, flooding is seen in some areas and the high water table leaves some grassy areas soggy restricting use. Standing water can be a mosquito breeding area. In the winter, it is desired that the lake be drawn down to protect property from winter storms and ice damage. Drawdown may also help with aquatic vegetation control. All of these considerations must be balanced one against the other to determine an acceptable operating regime.

Currently Osoyoos Lake levels are regulated differently in the winter than the summer. Summer operating conditions begin April 1 and end October 31. These dates conform to the irrigation season but not to the natural hydrograph. This lack of synchrony with the natural cycle has been criticized because it fails to accommodate spring freshets and because it may impact natural biological processes. Study 3 was designed to examine practical alternatives to the present timing of lake levels and outflows and determine the advantages and disadvantages of switching to them.

The current Orders require that the lake levels be maintained between 911.0 and 911.5 feet from April 1 to October 31 (summer levels), and between 909.0 and 911.5 feet from November 1 to March 31. Exceptions are provided for recognizing the impacts of backwater from the Similkameen and excessive inflows. The Orders also recognize the impacts from drought conditions when the summer lake level may be raised to 913.0 feet and drawn down to 910.5 feet (Figure 2).

By April 1, the lake level must be at or above 911.0. This generally requires a rapid increase in lake levels to be in compliance with the Orders as indicated in Figure 2. While the operator could have held the lake level above 911.0 all year, the level is drawn down in winter for shoreline wave and ice damage protection and the stored water is generally used to provide flows for fish downstream of the dam throughout the winter. The April 1 date for raising the lake from its winter level to a minimum of 911 feet is not consistent with the hydrology of the watersheds where spring freshet on the Okanagan system typically commences in late April and peaks in June.

Inflows

To begin with, dam operations depend on the inflows. In the case of the Zosel Dam, those inflows are almost completely regulated by the releases from Okanagan Lake. The inflows to Osoyoos Lake are often referred to as the "trans-border flows". The 1980 Cooperation Plan between British Columbia Ministry of Environment and Washington State Department of Ecology recommended that during normal and first year droughts the Ministry of Environment will attempt to operate the minimum trans-border flow range from 175 cfs in January to a peak of 340 cfs in August and back down to 175 cfs in November. These flows are based on the Okanagan River near Oliver gauge. These inflows were presented in Study 1, Table 13 (Barber et al 2010a) which has been reproduced as Table 4.

1	2	3	4	5
Month	**Minimum Trans-Border Flows (Normal or 1st Drought Year) cfs(cms)**	**Gauged Flows at Oliver, BC that meet 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)

Table 4: Trans-border Flows

Further in a series of informal agreements between the water managers in British Columbia and Washington State, the Washington Department of Ecology will try to limit Osoyoos Lake levels to no more than 912.5 feet during drought years provided the BC Ministry of Environment (as it was then) agrees to supply 2,850 acre-feet (the equivalent of the foregone half foot of storage on Osoyoos Lake) from Okanagan Lake in April or May when flows are needed to flush migrating sockeye smolts out of Osoyoos Lake and downstream through Zosel Dam.

Downstream Flows and Fisheries Requirements

In addition to the Orders of Approval, operations at Zosel Dam are also guided by current regulations and agreements related to fishery flows, and instream flows including: (1) the Zosel Dam Operating Procedures Plan Fisheries Criteria (Ecology 1990, p.64) and (2) The Washington Administrative Code (WAC 1988) that established instream flow requirements for the upper Okanagon River in agreement with the Washington State Water Resources Act of 1971. Operations at Zosel Dam attempt to meet the downstream flow agreements. Minimum flows for the reach downstream of the dam to the confluence with the Similkameen River are given in Table 5 which is adapted from Study 1, Table 10 (Barber et al 2010a).

1	2	3
Month	**Fisheries Criteria (Ecology 1990) (cfs)**	**Instream Flow Criteria (WAC 1988) (cfs)**
January	331	320
February	331	320
March	459	320
April	459	330
May	459	350
June	459	500
July	200	420
August	200	320
September	200	300
October	331	330
November	331	370
December	331	320

Table 5: Downstream Flow Criteria

These flows were determined as essential to the well-being of fish populations downstream of Zosel Dam.

We began by using these instream flow rates in our model to project the behavior of downstream flows in drought years. Historic discharge flows from Zosel Dam, for years 1987 to 2010, were compared to desired downstream flows (Figure 11).

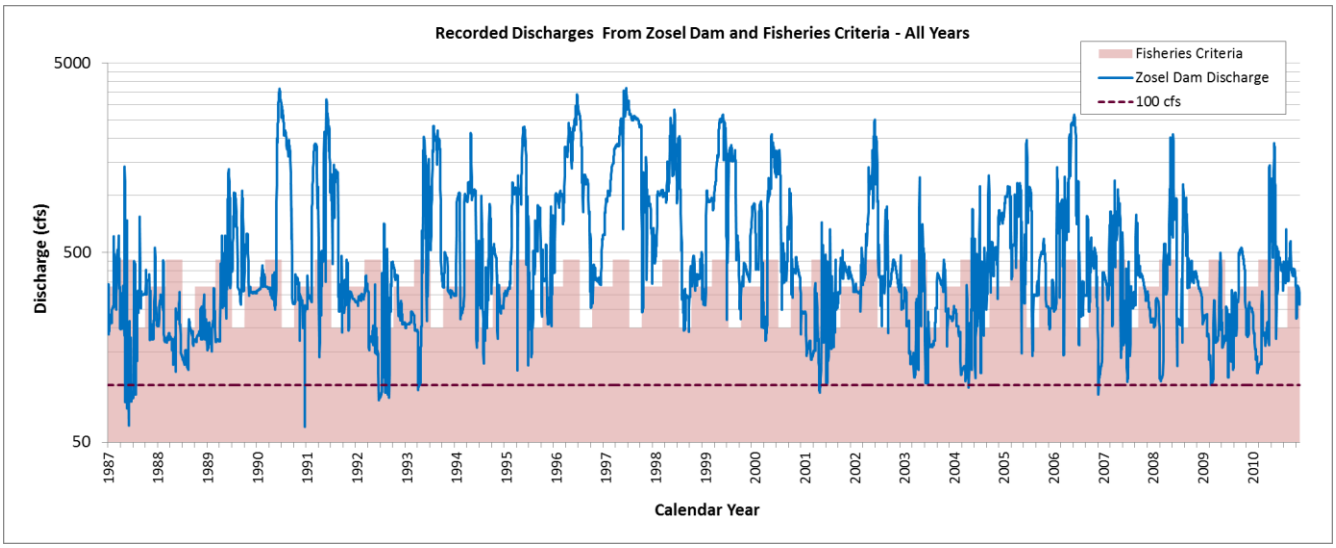


Figure 11: Historical Discharges and Downstream Fisheries Criteria

It is apparent that since 1987 there have been numerous years where outflows could not meet the Table 5 Fisheries Criteria or Instream Flow Criteria. Years 2001 to 2010 were particularly problematic with minimum flows frequently reaching 100 cfs.

To be in compliance with the Orders the operator may start to raise the level of the lake as early as February by reducing the outflows at the dam. The result is reduced flows in the river downstream of the dam, on occasion close to 100 cfs, which the operator indicates is his minimum tolerable flow[2], for extended periods of time. Table 5 shows the recommended flows for the period October through April are 331 cfs to allow Chinook egg/fry survival. In the fall, the operator begins by drawing the lake down to the authorized winter level, but he generally cannot keep a 331 cfs release through the winter with the reduced inflows. The requirement in the current Orders to meet the April 1 lake level in the range of 911-911.5 feet forces the operator to try to raise the levels when inflows are naturally low.

[2] The operator of Zosel Dam uses 100 cfs as the minimum release that is tolerable and he attempts not to allow releases smaller than this flow.

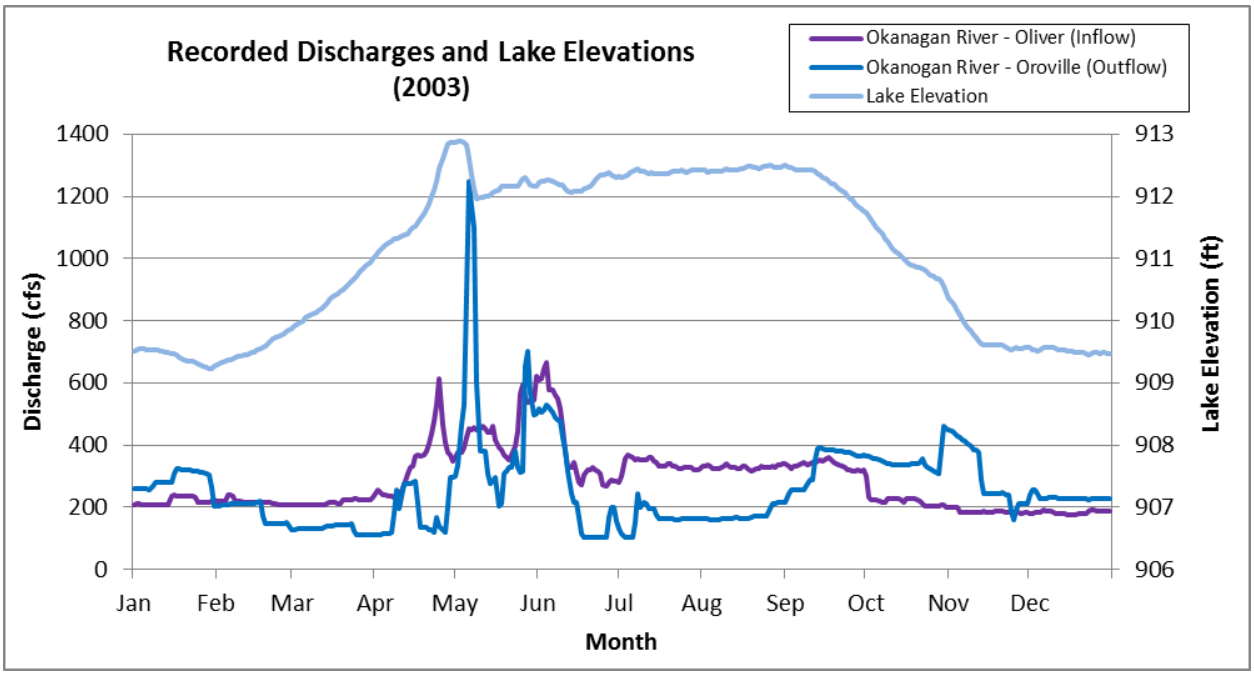


Figure 12: Osoyoos Lake 2003 Inflow, Outflow and Level

To illustrate this situation refer to Figure 12 that shows the inflows and outflows to the lake for 2003 and the associated lake level. The purple line in Figure 12 represents the inflow at the Okanagan River near Oliver gauge and the dark blue line is the outflow from the dam. In 2003, a drought year, the operator started to raise the lake level about February 15 by reducing the flows downstream reaching as low as 100 cfs by March 26. Releases were kept low until April 27 when they were increased to 1200 cfs in early May so as not to exceed the levels in the Orders. The inflows during the period February 15 – April 10 remained relatively constant in the 200 cfs range then increasing to approximately 600 cfs by April 25. In Figure 13 it can be seen that the lake levels bottomed out about the end of January near 909 feet and then, as a result of reduced outflows steadily increased until late April, topping out near 913 feet then dropping back to the 912.5 feet range by early May when the outflows were increased.

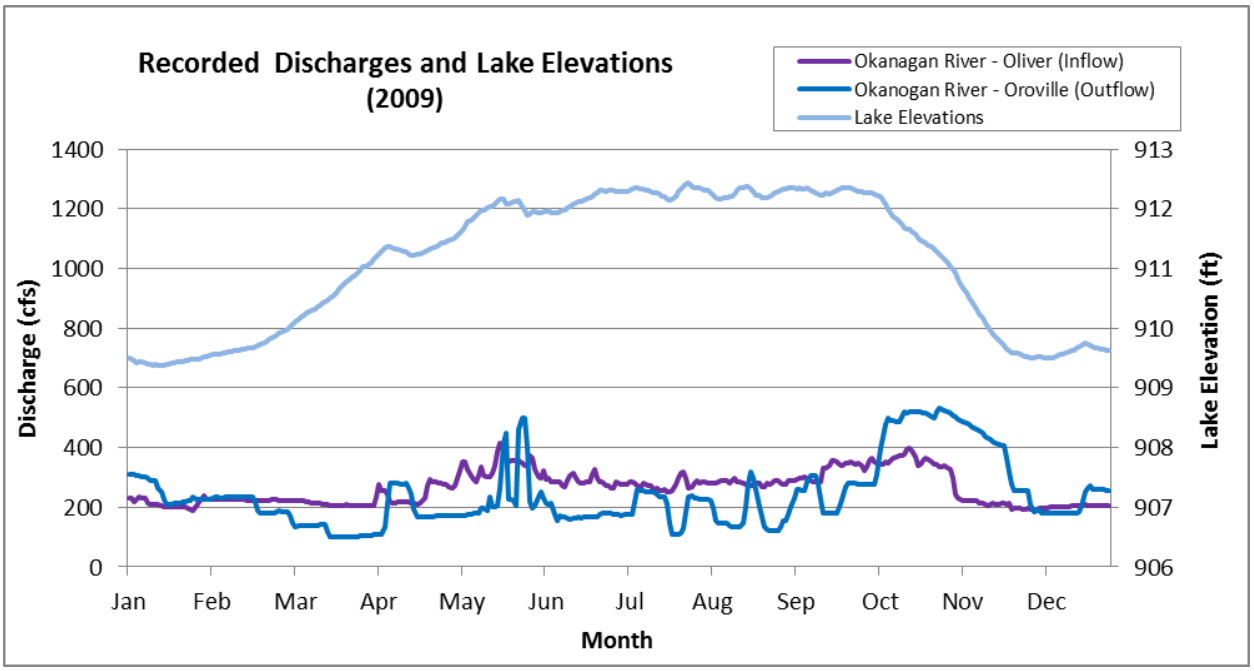


Figure 13: Osoyoos Lake 2009 Inflow, Outlow and Levels

Figure 13 presents similar results for 2009, which was also a drought year. These examples illustrate not only how difficult it is for the operator to meet the April 1 lake level, but also the impacts on instream flows downstream of the dam. To review all years from 1987 to 2010, please refer to Appendix B.

4.2 ALTERNATIVE LAKE LEVELS AND FLOWS

The WEAP model introduced in Section 2.3 to evaluate the current management regime was configured to run a number of management simulations for various target lake levels from which one could be chosen that best fits the requirements of stakeholders for desired lake levels and flows for downstream resources and agencies. The model was set to adjust outflows based on historical inflow data for both normal and drought years through the period 1987 to 2010, with the objective of meeting lake elevation targets defined for each scenario.

Five scenarios were developed numbered 1 to 5 plus the base case numbered 0 to evaluate alternative management options for lake levels and releases through Zosel Dam. In Scenarios 1 through 5, target elevations were set in the model. The model was then set to adjust outflows based on historical inflow data for both normal and drought years through the period 1987 to 2010, with the objective of meeting the lake elevation targets defined for each scenario. A limitation of the model is that it attempts to keep the lake level at the target value but because it is using daily time steps, the lake level can miss the target depending on how quickly the inflow is changing. The deviation generally stays within +/- 0.5 feet of the target but can be more in an extreme event as can be seen in the graphs of the different scenarios For example, during wet

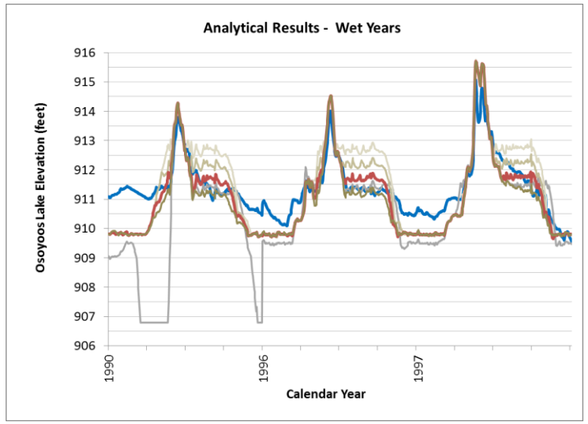
years, the lake elevations tend to peak approximately 0.5 – 0.7 feet higher than the historical peaks. This is not a function of the target operational range – but is rather a result of the relatively simplistic discharge adjustment algorithm. Please refer to Appendix A for more detail.

Table 6 summarizes the five scenarios numbered 1 to 5 plus the base case numbered 0 that were developed to evaluate alternative management options for lake levels and releases through Zosel Dam. A brief summary of each scenario is provided below:

Scenario	Drought Declaration	Inflows	Lake Level Summer (ft)	Lake Level Winter (ft)	Zosel Discharge (cfs)
0	Yes	1987-2010	current Orders	current Orders	≥ 100
1	Yes	1987-2010	current Orders	current Orders	≥ Fisheries Criteria *
2	No	1987-2010	913.0	910.0	≥ 100
3	No	1987-2010	912.5	910.0	≥ 100
4	No	1987-2010	912.0	910.0	≥ 100
5	No	1987-2010	911.5	910.0	≥ 100

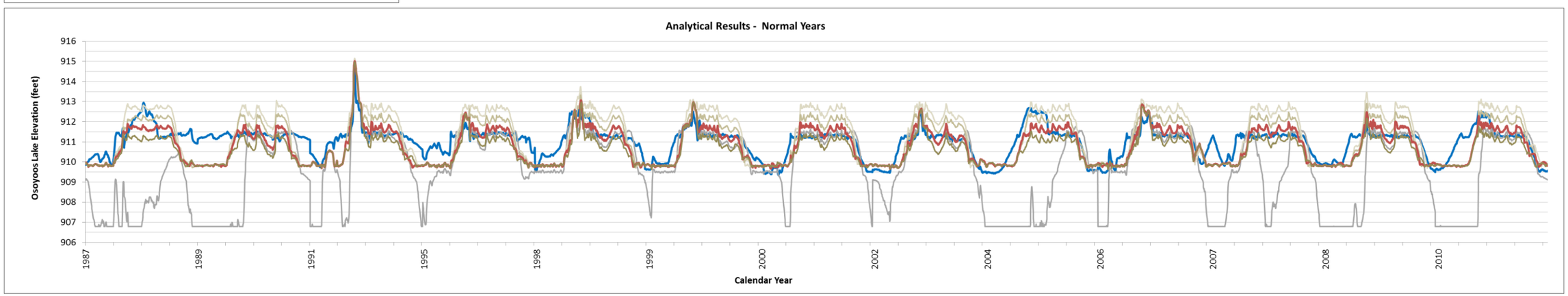
* refer to Table 5, Column 2

Table 6: Base Case and Five Alternate Management Scenarios



Analytical Scenarios:

- Scenario 0 (Historical)
- Scenario 1 (Discharges To Meet Fisheries Criteria)
- Scenario 2 (910.0 - 913.0)
- Scenario 3 (910.0 - 912.5)
- Scenario 4 (910.0 - 912.0)
- Scenario 5 (910.0 - 911.5)



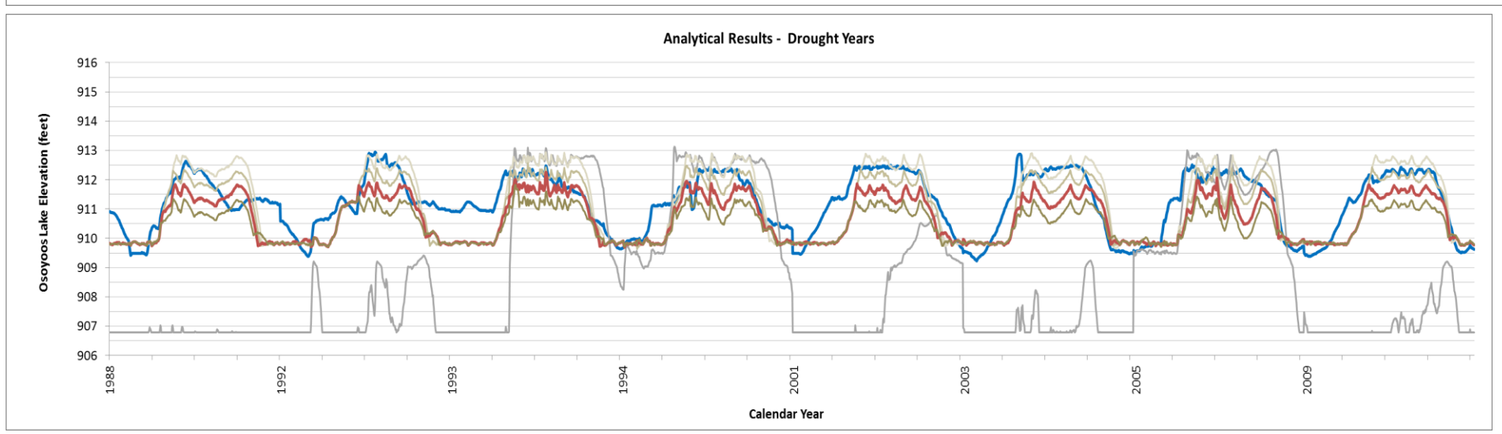


Figure 14: Base Case and Five Alternate Management Scenarios for Wet, Normal, and Drought Years

The scenarios are shown in Figure 14 and illustrate normal years, drought years and wet years.

Scenario 0 (blue line in Figure 14), is the base case for comparison. This is the historical data for lake levels and releases at Zosel Dam as recorded at the USGS gauges Osoyoos Lake near Oroville (Sta # 12439000) and Okanogan River at Oroville (Sta # 12439500). It reflects actual operations – drought declarations and current Orders.

Scenario 1 (dark grey line in Figure 14), assumes current conditions - drought declarations and the current Orders. Releases through the Zosel Dam, however, are based on the Fisheries Criteria as stated in Column 2, Table 4 (Study 1, Table 10, Column 2). This resulted in lowering the lake levels below 909.0 feet in all but four years of the study period, with the live storage completely drained seventeen of twenty-four years. Lake levels below 909.0 feet are considered unacceptable to the public, and expose some irrigation intakes. This scenario is **not recommended**.

Scenario 2 (light tan line, Figure 14), no drought declaration, 1987-2010 inflows, and summer target lake levels of 913.0 feet with winter levels 910.5 feet, with Zosel Dam minimum discharges ≥ 100 cfs. For normal years the summer levels would be in the 912.5-913.0 feet range with some years in the 915 feet range and winter levels of 910.0 feet. For wet years the summer levels would be in the 914 feet range with some years in the 915.5 feet range and winter levels of 910.0 feet. For drought years the summer levels would be in the 912.5-913.0 feet range and winter levels of 910.0 feet. Due to levels close to 913 feet for most years with the risk of levels as high as 915 feet in a normal year, this scenario is **not recommended**.

Scenario 3 (medium tan line in Figure 14), assumes no drought declaration, uses the 1987-2010 inflows and sets the target lake levels to 912.5 feet for the summer and 910.0 feet for the winter. The Zosel Dam minimum discharges are set to be ≥ 100 cfs. For normal and drought years the summer levels would be in the 912.0-912.5 feet range with the winter levels in the 910.0 feet range. For wet years the maximum lake level could be approximately 0.5 feet higher than under the current scheme with the winter levels remaining in the 910.0 feet range.

Scenario 4 (red line Figure 14), assumes no drought declaration, 1987-2010 inflows and sets the target lake levels one-half foot lower to 912.0 feet for the summer and 910.0 feet for the winter. The Zosel Dam minimum discharges are set to be ≥ 100 cfs. For normal and drought years the summer levels would be in the 911.5-912.0 feet range with the winter levels in the 910.0 feet range. For wet years, the maximum lake level could be approximately 0.5 to 0.7 feet higher than under the current scheme with the winter levels remaining in the 910.0 feet range. Please reference model limitations described earlier in this section, as well as Appendix A for more details.

Scenario 5 (dark tan line Figure 14), assumes no drought declaration, 1987-2010 inflows, and lake levels with summer target of 911.5 feet and winter levels of 910.0 feet. The Zosel Dam

minimum discharges are set to be ≥ 100 cfs. For normal years the summer level would be in the range of 911.0 to 911.5 feet and winter levels in the 910 feet range. For wet years the peak elevations would be in the 914.0 feet range and could be as high as 915.5 feet. For drought years the summer level would be in the 911.0-911.5 feet range and winter levels in the 910.0 feet range.

4.3 ALTERNATIVE SUMMER AND WINTER MANAGEMENT

As indicated in section 4.2, five alternate management scenarios were considered. A proposed management scheme based on Scenario 4 is offered for consideration. In this scheme, the drought declaration would be eliminated and a target level for all years, including a buffer zone of acceptable levels, is proposed. A six to eight week window in the spring and fall would permit gradual raising and lowering of the lake levels with the spring period set for March 15 to May 15, and the fall lowering to October 1 to December 1. This is illustrated in Figure 15 with a blue zone. For illustration purposes, it is superimposed over the current approved levels.

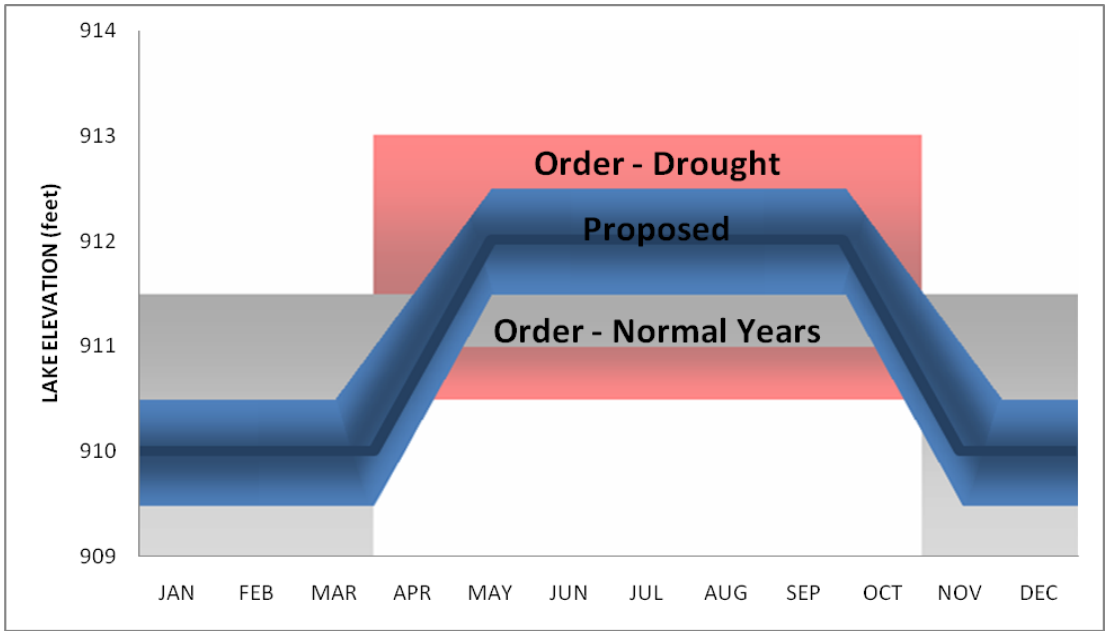


Figure 15: Osoyoos Lake Levels for Proposed Management Scenario, Current Orders in Background

It is proposed that a single, flexible management regime be applied for both normal and drought years. The lake level targets are 910 feet for the winter and 912 feet for the summer with an allowable range of +/- 0.5 feet. Under this regime, the levels may be increased above the winter range starting after March 15th and must be above the winter range by about April 20th. Minimum summer levels may be achieved by April 15th and must be achieved by May 15th. The rationale for the May 15th date for summer levels was to permit a better fit with the existing inflows to the system and also recognizing irrigation needs. Reduction of levels below 911.5

feet in the fall could start as early as October 1st and must be below 911.5 feet by November 1st. Winter levels may be achieved by about October 20th and must be achieved by December 1st. The lowering in the fall would correspond to the end of the normal irrigation season and better fit to the need for instream flows downstream.

Figure 16 illustrates the proposed management scenario for the period 1987-2010. Figure 17 illustrates the deviation with the proposed management scenario. For the period 1987-2010, the proposed management scenario would have maintained the lake levels within the 909.5-912.5 feet range for 83.1% of the time. Figures 19 to 21 illustrate a comparison between the current management scheme and the proposed Scenario 4. The results suggest that the proposed management scenario does a better job in meeting the instream flow criteria when they are less likely to be met.

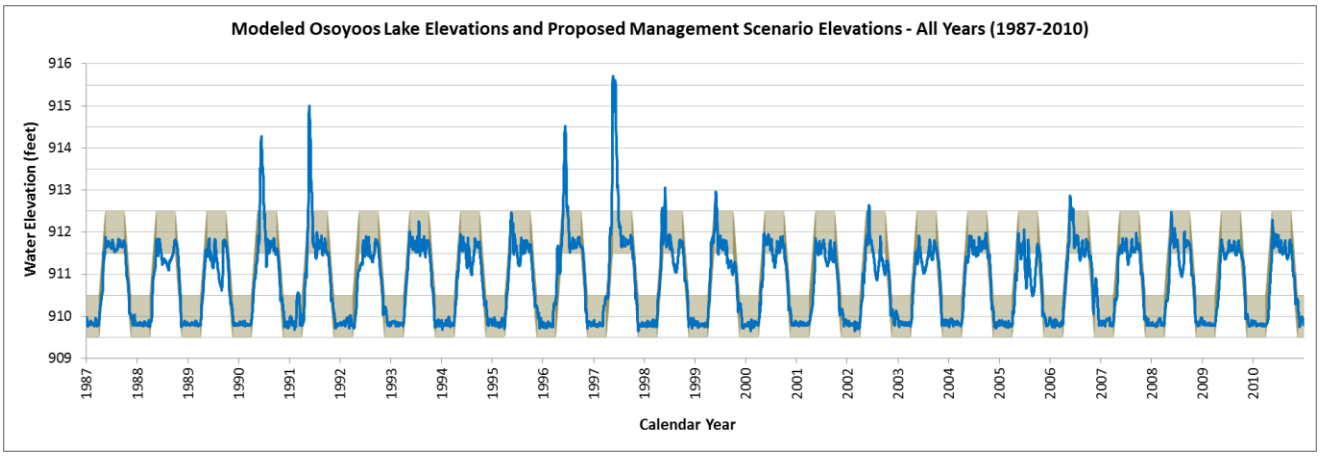


Figure 16: Comparison of Modeled Lake Elevations and Proposed Management Scenario

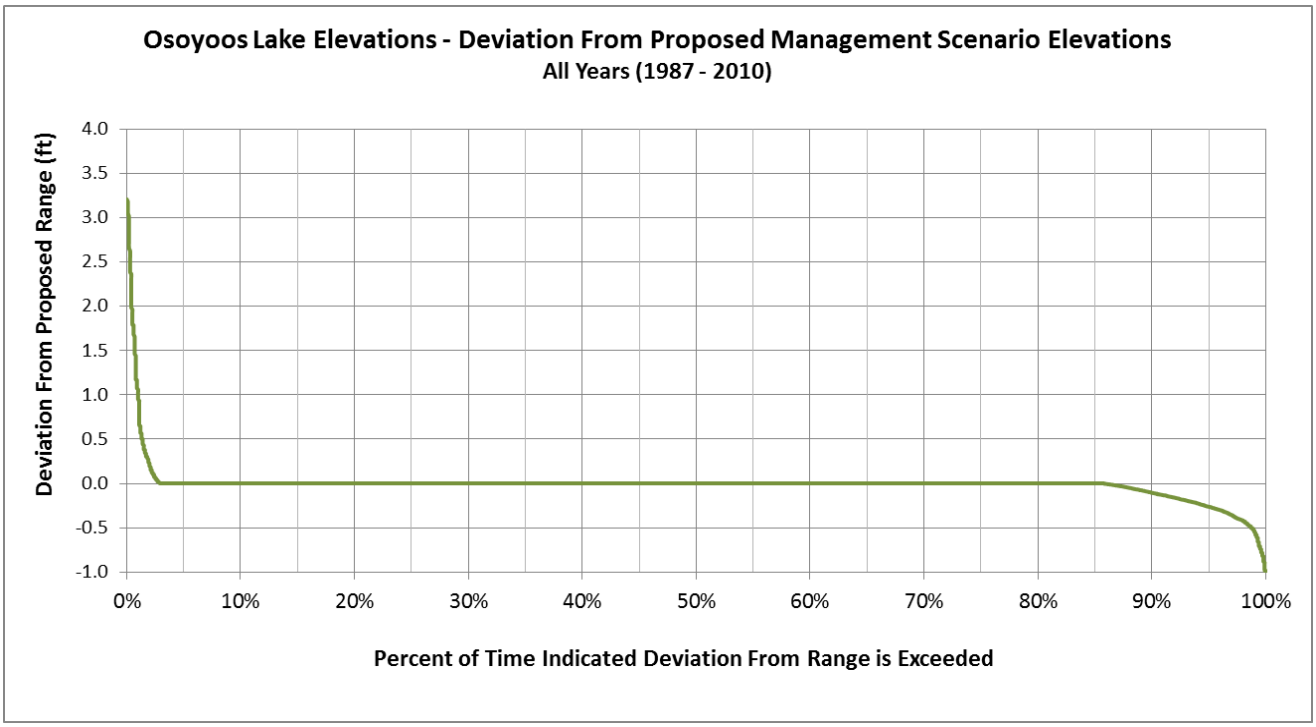


Figure 17: Osoyoos Lake Elevation Deviation From Proposed Management Scenario Elevations

Modeled discharges from Zosel Dam were then compared to these proposed Fisheries Criteria flows and results are shown in Figure 18.

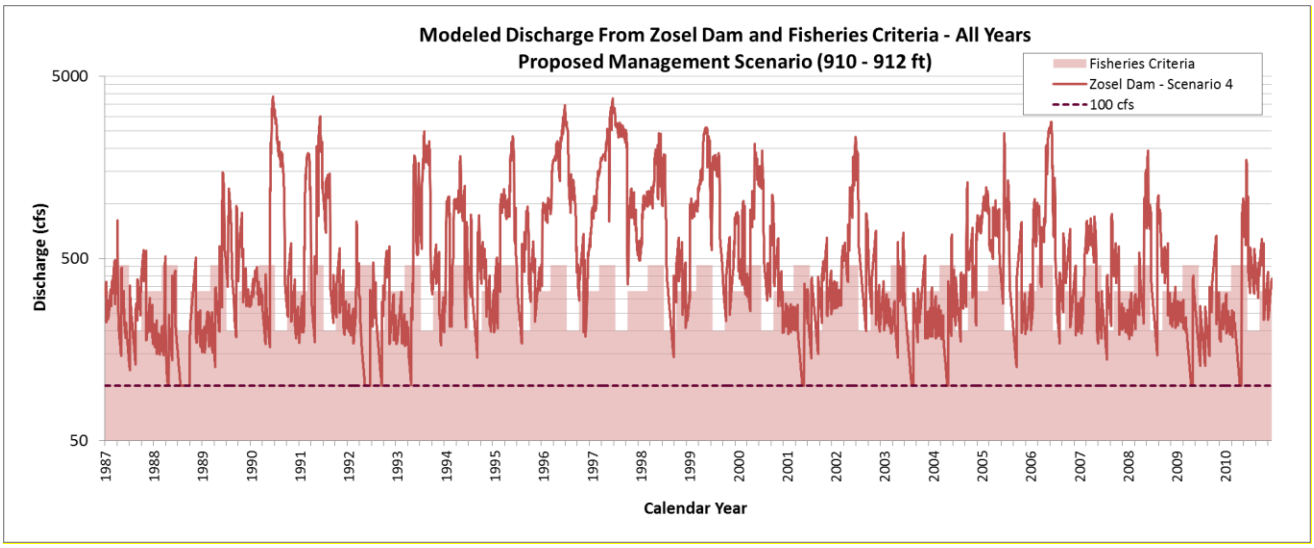


Figure 18: Modeled Discharges and Downstream Fisheries Criteria

We then compared the percent of time that a given percent of the Fisheries Criteria flows were met for both historic operations and for the proposed model for all years, non-drought years and drought years (Figures 19, 20, and 21).

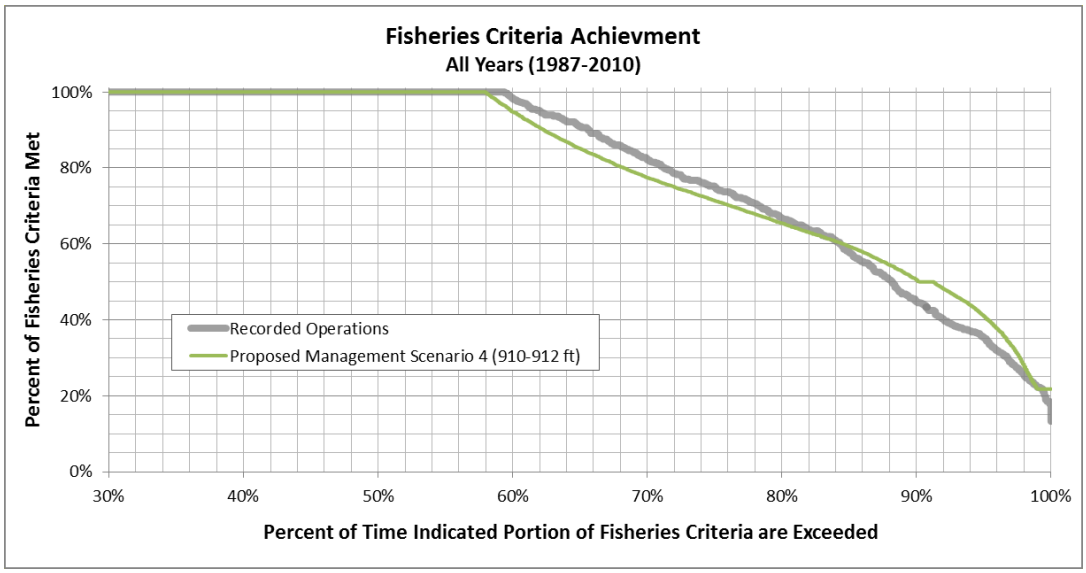


Figure 19: Coverage of Downstream Fisheries Criteria – All Years

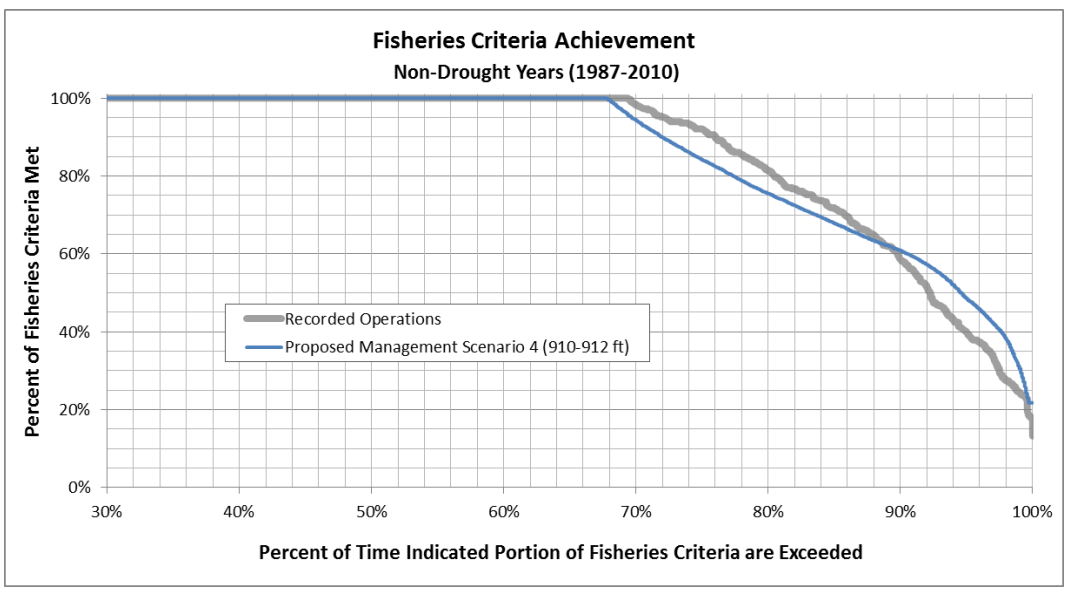


Figure 20: Coverage of Downstream Fisheries Criteria – Non Drought Years

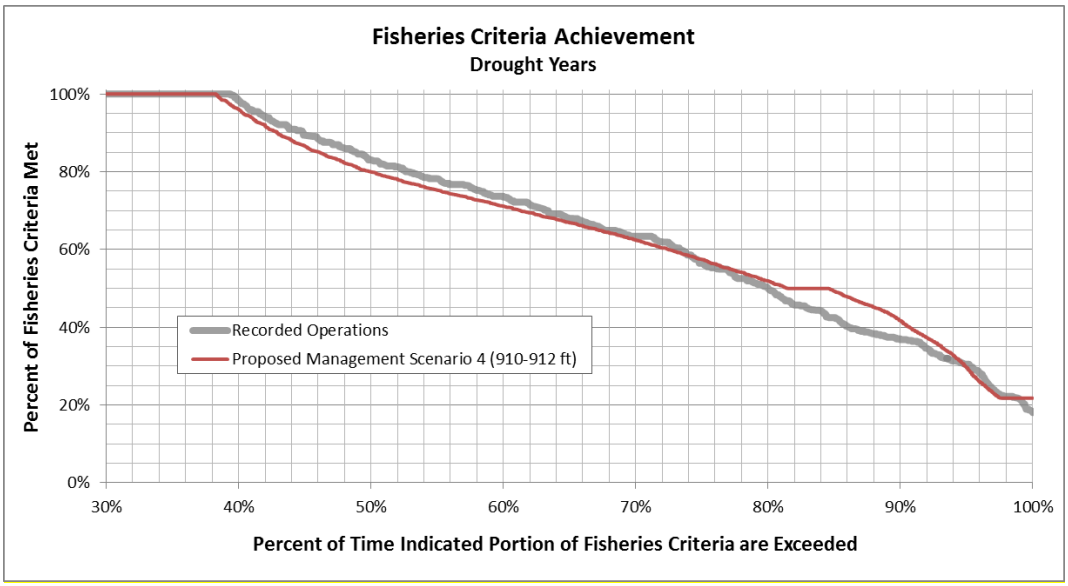


Figure 21: Coverage of Downstream Fisheries Criteria – Drought Years

These comparisons showed that using the model for drought and non-drought years we could generate an increase in releases during the time when the lowest percent of the fisheries criteria was being met. The implications for downstream fisheries are that in most conditions there would be increased flows for fish available at critical times.

The assessment of the proposed management scenario suggests that it would have the advantages of providing more flexibility to achieve target lake levels while providing better flows for fish in the late winter, as well as over the remainder of the year. It is understood that if the instream flows are met, there is adequate water for downstream irrigation needs. It was also noted that flows of 100 cfs would meet the downstream irrigation needs. For additional information on the comparison of the scenarios refer to Appendix B.

4.4 DISCUSSION OF RAMPING RATES

In about 1988, a Memorandum of Understanding (MOU) was created and entered into by the Washington State Department of Ecology, the Washington State Department of Fisheries, and the Washington State Department of Wildlife (Washington State, undated). The purpose of this MOU was to establish an understanding of ownership, operational constraints, fisheries considerations, and coordination procedures related to operation of Zosel Dam in Okanogan County. Although this MOU addressed various flow requirements for downstream aquatic resources there were no provisions considered or provided for ramping rates at Zosel Dam. In Study 3 the IJC requested that we examine various aspects of ramping rates and consider the need to address them in future renewal orders. It should be noted, that ramping guidelines are not a specified requirement of the operation of the three dams on the Okanagan River upstream of Osoyoos Lake.

Ramping Rate and Downstream Impacts

Ramping rates can be measured either in changes in flow, which is the volume of water passing a specific downstream river transect, or by changes in stage, which is recorded as the water surface elevation or gauge height. Flow fluctuation impacts on downstream biota are fairly well understood in the Pacific Northwest, central British Columbia and Washington State. Hydroelectric dams are common throughout this region and have been implicated in causing considerable impacts to downstream biota, often as a result of excessive ramping change.

For this discussion ramping rate is defined as the rate of change in water level in the reach downstream of Zosel Dam resulting from a change in the gate settings. In most cases it is the rate of change resulting in a declining water level that causes the greatest impact. These changes can cause water level fluctuations or unnatural changes in flow which occur over a period of minutes, hours or days. The downstream biological impacts associated with fish production and the well-being of other aquatic invertebrates can include immediate mortality, delayed mortality, temporary loss of habitat, reduced reproductive success, loss of food resources, and behavioral responses that could reduce survival or growth (Hunter, 1992).

Okanagan River Operations

Inflows to Osoyoos Lake which have a direct influence on operations at Zosel Dam are heavily influenced by upstream flow management of the Okanagan River. Operations of the Okanagan Lake Dam, Skaha Lake Dam and Vaseux Lake Dam (McIntyre) are presently the responsibility of the BC Ministry of Forests, Lands and Natural Resource Operations (MFLNR) (formerly Ministry of Environment). During the period 1998 to 2008 a flow management model was developed by the Canadian Okanagan Basin Technical Working Group as a guide to water management operations for the Canadian portion of the Okanagan River. Named the Fish/Water Management Tool (FWMT) this model is used to balance the water level and flow requirements between flooding, agriculture, fisheries, urban water supply and other interests (Alexander et al 2008).

Even though the development of the Fish/Water Management Tool on Okanagan Lake has placed significant priority for the well-being of downstream and upstream fish resources, ramping rates have not received much attention and were not addressed in the FWMT. In an attempt to understand how ramping rates are managed in BC facilities on the Okanagan River, water managers were asked how they administer this task. Brian Symonds[3] and Des Anderson[4] of MFLNR reported that they are aware that high rates of ramping over a short period of time can have negative consequence on downstream fish resources. Their strategy for large changes in gate settings, which are often necessary in early spring and late fall, is to adjust the

[3] Brian Symonds. Director, Regional Operations. Water Stewardship Division of Ministry of Forests, Lands and Natural Resource Operations. Penticton, B.C.

[4] Des Anderson. Section Head, Public Safety and Protection. Ministry of Forests, Lands and Natural Resource Operations. Penticton, B.C.

gates over a period of hours or days in small increments. The MFLNR operators indicated that they have not received any complaints regarding ramping rates from agencies associated with fisheries management in their area of operation.

The operator of the Zosel Dam indicated that when he adjusts the flows they are accomplished with one or two gate changes a day, with multi-day changes if necessary to reach a desired flow[5]. Depending on Osoyoos Lake levels and flows in the Similkameen River, gate changes can have varying effects on river levels below Zosel Dam. He explained that a few seconds of gate change during certain time periods can have a significant effect on downstream water levels as the gates are not calibrated with river gauges downstream of the dam. He tends to make small changes at the beginning or end of a day and continues the next day if necessary. He stated that his primary goal is to meet the requirements of the Orders for Osoyoos Lake and secondly the downstream flows as specified in the MOUs.

Acceptable Ramping Rates

A review of studies on unregulated rivers by Hunter, 1992, determined that they rarely experience changes in stage (i.e. water surface elevation) in excess of two inches per hour except during floods. He reasoned, therefore, that aquatic life forms in regulated rivers are not necessarily adapted to stage changes in excess of one or two inches per hour. Ramping rates less than one inch per hour were specified to protect steelhead fry on the Sultan River in Washington (Olson 1990).

The most frequent biological impact of flow reductions is stranding. The incidence of stranding is affected by the life history stage of fish, substrate type, river channel morphology, range and rate of flow change, species, and time of day. River channel configuration is a major factor in the incidence of stranding. A river with many side channels, pools, and low gradient bars will have a much greater incidence of stranding than a river confined to a single channel with steep banks. The greatest impact on downstream fisheries resources occurs when flows are being reduced and water levels are declining that can result in stranding of aquatic invertebrates which provide food for juvenile rearing. Less food means reduced overall productivity, survival and health of fish populations.

For some species, the incidence of stranding is influenced by the time of day. Chinook fry are less dependent on substrate for cover at night and thus are less vulnerable to night ramping (Woodin 1984). For this reason, some regulators ramp at night rather than during the day because Chinook will hold in boulder substrate during daylight hours and can become stranded more frequently.

[5] Tom Scott. Manager of the Oroville-Tonasket Irrigation District and operator of the Zosel Dam, Personal communication.

A biologist[6], with Canada Department of Fisheries and Oceans, revealed that as a general guideline, ramping rates on a number of BC interior hydroelectric facilities are deemed to be acceptable if they do not exceed 1.5 inches per hour. Each facility and the fisheries resources downstream can vary widely however. He suggests that downstream river morphology and the species composition play a major role in determining the impacts associated with ramping.

In British Columbia, hydroelectric facilities are often required to develop Water Use Plans (WUP) which are used to determine operational orders. These WUP's are usually developed specific to the well-being of downstream resources and are designed to offset negative impacts on fish, wildlife or property. Studies are normally initiated to determine the potential impacts to aquatic life and the goal is to look for mitigation strategies which will typically include the establishment of ramping schedules.

A review of the BC Hydro Shuswap River Water Use Plan, 2005, which governs operations at Sugar Lake Dam and Wilsey Dam in the interior of BC, indicate that target ramping rates should not exceed 1 inch per hour (April 1 – July 31) and 2 inches per hour (August 1– March 31) (refer to Table 7). It is further noted that ramping down has higher impacts than ramping up which explains the differences in rate per hour guidelines. This ramping schedule also addresses day and night rates. The Shuswap River supports populations of Chinook, sockeye, Coho, rainbow trout, bull trout and kokanee and accordingly, this ramping table has been designed to reduce specific impacts on each of these species.

Maximum Ramping Rates[1]		Down Ramp (cm/hr)		Up Ramp (cm/hr)	Daily Change (cm)	
Period	**Life Stage**	**Day**	**Night**	**Day/Night**	**Down**	**Up**
1 April – 31 July	Emergence	2.5	2.5	5.0	15	15
1 August – 30 September	Rearing	2.5	5.0	5.0	15	15
1 October – 31 March	Over Winter	0	5.0	5.0	15	25% $Q_{DDS(t-1)}$[2]

1 Rate determination based on gate discharge curves, reservoir level, and planned gate position changes. Actual downstream changes may be ± 50 per cent the planning criteria.

2 25% $Q_{DDS(t-1)}$ is 25 per cent of the previous day's discharge from Sugar Dam.

Table 7: Target Ramping Rates – Sugar Lake Dam

It is also specified in these operating orders, that these rates and the maximum daily change may be exceeded by ± 50 per cent as necessary to route flood flows, meet dam safety release requirements, equipment, personnel safety and other emergencies.

[6] Dean Watts. Senior Habitat Management Biologist. Canada Department of Fisheries and Oceans. Kamloops, B.C.

Ramping Rate Monitoring Results

Species of concern downstream of Zosel Dam include Chinook salmon and Steelhead, which are currently listed as threatened by the Endangered Species Act (ESA) (Bartlett and Tweit, 2006). In has been reported in other systems that stranding incidence can increase dramatically when flows drop below a certain water level, defined as the critical flow (Thompson 1970). Towards the end of the incubation period when river levels are normally low, the exposure of the lowest gradient gravel bars from which fry are emerging may account for a higher incidence of stranding. It is noted in a review of historic flow records from Zosel Dam, that ramping down can occur as early as mid-February in order to meet Osoyoos Lake level specified in the Orders for April 1. Most species of salmonids downstream from Zosel Dam, such as Chinook salmon, would still be in the substrate at this time of year. Steelhead trout traditionally are nearing spawning at this time and can be vulnerable to decreasing flows as well.

High ramping rates can also have an impact on other wildlife, vegetation, riparian areas, navigation and boat moorage. These issues can only be addressed by future studies and interactions with downstream agencies.

Okanogan River levels are monitored daily at USGS gauging station # 12439500 located just downstream of the Zosel Dam and records are available in 15 minute segments. Gate changes at Zosel Dam have an immediate effect on river levels at this USGS station and can therefore be examined for any time period. The USGS website cautions, however, that gauging at this site can be affected by storms or backwatering flow levels from the Similkameen River in May and June.

River level changes as recorded at the USGS gauging station # 12439500 were examined for the period October 1, 2010 to March 31, 2011 and partitioned into 1 hour segments. The rate of change was then calculated for each hour of operation and the results expressed in inches per hour. These records were selected from a normal operational season and were outside of any period associated with floods or influence from backwatering of the Similkameen River.

The results show that in this time period there were 15 occasions when flow changes exceeded 1 inch per hour, 7 occasions when they exceeded 1.5 inches per hour and 4 occasions when they exceeded 2 inches per hour. A total of 11 of these intervals were for ramping flows down and 4 were for ramping up. The highest rate of change occurred on December 30, 2010 when river levels declined 3.72 inches in one hour. Records for that day also show that the river levels were dropped a total of 8.16 inches over a 3 hour interval. It should be noted that this is a very simplified view of operations for a 6 month period of time with limited background information. There may have been other operational issues such as weather, safety or lake level condition that could influence a higher rate of change.

It is clear, however, that operations at Zosel Dam can exceed flow changes that would be considered excessive at other facilities. The earlier discussion established that flow changes at a number of other facilities are seldom permitted to exceed 2 inches per hour with a preference of a limit of 1.5 inches. Of particular concern is the fact that these downward changes can occur during the incubation period for salmonids in downstream waters.

As a precautionary measure, it is suggested that ramping guidelines be incorporated into future operating plans for the Zosel Dam. They can be determined according to general guidelines, as established by other fisheries agencies, or examined more closely through a study directed at the Okanogan River downstream of Zosel Dam. Critical elements of the study would include local information on river morphology, substrate composition, salmonid spawning and rearing habitat utilization, and timing. It is also suggested that particular emphasis be placed on downward ramping rates during periods of low flow between October 1 and March 1.

4.5 STAKEHOLDER ACCEPTANCE

Table 21 from Study 1 (Barber et al 2010a) lists different stakeholders and the lake levels that cause concern or inconvenience to them. This list was compiled using comments made by attendees at public meetings which were recorded in the Plan of Study (Glenfir Resources 2006). The information from Table 21, Study 1, is shown as columns one, two, and three in Table 8. The outcomes of the proposed lake management model were then compared to current stakeholder needs to determine if the proposed lake level targets would result in improved lake and downstream conditions. Column 4 represents our expectation of how these stakeholders will perceive the proposed operating scenario.

1	2	3	4
Stakeholders	**Unacceptable Lake Levels**	**Impact**	**Predicted response to new lake levels range of 909.5 – 912.5 feet**
Residents/ Property Owners	>912.5 feet in summer	Erosion issues	Reduced erosion overall
	<912.0 feet in summer	Not optimal for boating	Improved conditions for boating in non-drought years but wake concerns on shore continue
	>909.0 feet in winter	Ice pressure causes damage to the shore line	Marginal increased impact to shore line
	>909.0 feet in winter	Does not help control milfoil	No change
	Seasonal changes in lake levels	Causes inconvenience in terms of raising and lowering the docks	Higher summer levels in non-drought years compared to current
Irrigators	<910.0 feet in summer	Water right will be terminated	No change
Campers	>912 feet in summer	Floods campsites and results in mosquito infestation	Lower lake levels in drought years but higher levels in non-drought years
Boaters	<912.0 feet in summer/winter	Can lead to safety issues	Increased safety compared to current non-drought years
Fisheries Ecological needs Stakeholders	Downstream flows more important than lake levels	Generally concerned with flow magnitudes for fish rather than lake levels	No change
	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	A reduction in lake level range may benefit some species but could be a detriment to those that are dependent on lakeshore flooding for wetlands
Regulators	<913.0 feet in summer	If the Orders prescribe 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, especially during drought years is necessary.	Model predictions are that proposed range of levels and flow rule curve will address lake level needs and downstream flow requirements

Table 8: Impact on Stakeholder Expectations

In general, it appears that the proposed range in lake levels would result in improvements for property owners need for pier height adjustments, campsite flooding and mosquito infestations. Conversely, impacts may increase for ice damage conditions due to higher winter lake levels. Boaters may experience an increase in hazards as reduced summer lake levels will increase the amount of shallow water hazards.

4.6 IMPACT ON BIOLOGICAL PROCESSES

In-lake resources

Control of Eurasian Watermilfoil *(Myriophyllum sibericum),* Cattails *(Typha spp.)*, and Purple Loosestrife *(Lythrum salicaria)* is problematic. These are all invasive species which are a threat to native species. Indications are that a decrease of range of lake elevations rather than an increase may encourage their growth. According to information provided in Study 5 (Barber et al 2010c) water level drawdown has been used successfully in multipurpose reservoirs to control aquatic plants. On the downside, however, this method has been shown to cause significant, negative, impacts on some fish species and also native riparian plant and animals. We therefore conclude that the manipulation of lake levels to control these species is not feasible.

In Study 5 (Barber et al 2010c) described a number of red and blue listed species which inhabit wetlands and riparian areas adjacent to Osoyoos Lake shoreline including Tiger Salamander *(Ambystoma tigrinum melanostictum)*, Western Painted Turtle *(Chrysanasy picta)* and Yellow-breasted chat *(Icteria virens).* It proved difficult to predict how these species might react to proposed changes in lake level management because of the lack of definitive population maps with detailed elevation delineation for the areas surrounding the lake. There is some evidence that with reduced upper lake levels, as is proposed, some backwater wetlands may not receive the quantity of water that they are presently accustomed to. At present we feel there insufficient population status data available to forecast the impacts of our flow simulation.

To a similar degree there are a number of sensitive ecosystems and native plants located within aquatic habitats associated with Osoyoos Lake (Iverson et al 2008). These include short-rayed aster *(Symphyotrichum frondosum),* scarlet ammannia *(Ammannia robusta),* toothcup *(Rotala ramosior),* and small-flowered lipocarpha *(Lipocarpha micrantha)*. These species are also listed as endangered by the Canada Species at Risk Act (SARA) (McIntosh 2010). It was suggested that these species may be protected from further decline by maintaining water levels and reducing wave action and rapid fluctuation of water levels (B.C. Ministry of Environment, 2008a, 2008b, 2009). This leads us to believe that the proposed lake level management strategy could improve conditions for these species.

Fisheries Impacts in Osoyoos Lake

Salmonid concern in Osoyoos Lake consists of: (1) maintaining acceptable water quality in the lake for non-migrating population (kokanee) and juvenile sockeye using the lake as rearing

habitat, (2) providing optimal flow to downstream reaches to promote spawning and rearing habitat for anadromous populations (discussed in Section 4.1), and (3) temperature oxygen squeeze.

Due to their ecological and economic importance in the Okanagan basin salmonids rank highly in the priorities for lake level management and downstream flow considerations. These include Chinook *(Oncorhynchus tsawytscha),* steelhead *(Oncorhynchus mykiss),* sockeye *(Oncorhynchus nerka)* and kokanee (the non-anadromous subspecies of sockeye). Together, fisheries and in-stream flow demands are the largest component of total water demand for Osoyoos Lake and stakeholder interest is high. Depending on the month, they can be 4 to 10 times higher than other demands combined (Barber et al 2010c). Provision of storage levels in Osoyoos Lake and protection of downstream flows for fish and ecological communities continues to be our highest priority in this study.

It is well understood that Osoyoos Lake receives high nutrient loading from sources upstream. The lake's trophic status, however, has improved from eutrophic in the 1970s to mesotrophic presently (Barber et al 2010b). These high nutrient levels contribute to a summer condition where bottom lake levels become anoxic and sockeye fry become compressed into a narrow band between high temperatures in the epilimnion (>17^{0}C) and low oxygen in the hypolimnium (<4 ppm O_2) (Hyatt et al 2008). It was concluded in Study 4 (Barber et al, 2010b), that Zosel Dam exerts no control on lake inflow and nutrient cycling and only affects lake elevation and water depth minimally from year to year. They were unable to suggest changes in dam operation that would directly and knowingly affect water quality in Osoyoos Lake. Hyatt et. all (2008), hypothesized, in the development stages of the Fish/Water Management Tool (Alexander et al 2008) that pulse flows to Osoyoos Lake during August or September can be used to mitigate the potential temperature-oxygen squeeze event. To be effective, however, a summer pulse release should be of sufficient magnitude (>10m^3/sec) and continue for as long as is required. These releases are possible in certain class of inflow years, when storage is available in Okanagan Lake, but would be difficult to provide in a drought year.

Osoyoos Lake is composed of three major basins: north, central, and south. Currently, this anoxic condition prevents sockeye fry from utilizing the central and south basin and confines them to the north basin. During spawning migration, populations of adult sockeye, Chinook, steelhead and kokanee all utilize the north basin for holding and staging periods. Once conditions are favorable for spawning in upstream waters they will advance to those areas.

4.7 SUMMER AND WINTER OPERATIONS CONCLUSION

The purpose of Study 3 was to determine the pros and cons of changing the starting or ending dates of summer and winter schedules. We were asked to consider the impacts on flood risk, biological processes and other interests. During the Study 2 component of this report, we looked at drought operations and combining both studies we have proposed an alternate management regime.

In studying the changes in lake levels we proposed that the range in lake levels be adjusted, both during drought and normal years, to a winter target level of 910.0 feet and a summer target level of 912.0 feet with an acceptable range of plus or minus 0.5 feet from the target. This would result in higher than historic levels during winter and lower than historic levels in summer in drought years but higher than historic levels in non-drought years. It was reasoned that this change in lake levels would result in increased overall stakeholder acceptance as well as provide net benefits to the ecological and biological communities of Osoyoos Lake. In concert with the goal of gaining acceptance from the majority of stakeholders we also predicted that a narrowing of storage levels could provide improved releases downstream that would be of benefit to biological and ecological resources downstream.

A review of stakeholder needs suggested that our proposed reduced summer levels in drought would result in reduced lakeshore erosion overall, reduced inconvenience in maintaining docks, reduced flooded campsites and reduced mosquito infestations. However, it was expected that a reduction of higher summer lake levels in drought years would have slightly negative conditions for boaters due to an increase in shallow water hazards.

In non-drought years the lake would behave much the same way, being held very close to 912.0 feet throughout the summer with an improvement in boating from the current operations.

Ecological issues and outcomes of lake level impacts on some endangered species were not clear as it is apparent that we do not have sufficient information on micro habitat needs of species such as Tiger Salamanders, western painted turtles and yellow breasted chat around Osoyoos Lake to make that prediction.

We are encouraged that there may be improvements for some endangered species of plants as a reduced range of lake levels may provide some sheltering from lake level fluctuation and wave action. There does not appear to be any practical benefits of using lake level management to control invasive species such as Eurasian watermilfoil.

There does not appear to be negative consequences for in-lake fisheries values from this proposal as it is expected that the species involved will not be impacted by changes in lake levels. This, and most of the previous studies on Osoyoos Lake, did not report any in-lake significant impacts on fish resources caused by operations at Zosel Dam.

There are trade-offs between and among the various resource users of Osoyoos Lake. We feel that the proposed modifications to lake level management may not have as much consequence to in-lake resources as they will for downstream resource values.

Downstream resource interests and stakeholder concerns clearly are of major priority for operations of Zosel Dam. There is a longstanding history of cooperation between resource managers in British Columbia and Washington State that have shaped the present operating Orders, memorandums of understanding, cooperative plans and non-binding agreements. Management of instream flows is complicated and there doesn't appear to be any simple set of

rules that will benefit all species at all times. It is understood that 90% of the current flow releases from Zosel Dam are required to satisfy downstream fish values. Irrigation water is also taken from these releases downstream of the dam.

In our review of the starting dates for summer and winter schedules for Osoyoos Lake there were clear benefits in moving to a more flexible date for increasing lake elevations. Our review of historic flow records indicate that the early storage of winter flows to meet the current target date has negative consequence on the availability of flows to meet late winter incubation requirements downstream of Zosel Dam. It has been well established that this is a critical period for Chinook egg/fry development and early Steelhead spawning. We have also demonstrated that this is most often the period that downstream minimum flow requirements have not been met. In response to a question to the fisheries agencies regarding the adequacy of the current trans-border flows for the various species of fish and aquatic life downstream the following comment was received; "The drought year criteria are of the most concern as flows below 300 cfs from November through June would represent a major reduction in the amount of summer Chinook salmon production down river or (sic) Zosel Dam."[7]

We believe that our proposal of a fixed annual cycle with a target winter level of 910.0 feet, ranging from 909.5 – 910.5 feet and a summer target level of 912.0 feet, ranging from 911.5 to 912.5 feet will also provide improved benefits to flow conditions through other parts of the season and especially during low summer flow periods. Our modeling demonstrates that most of the time this will improve on historic practice especially during drought periods. Six to eight weeks should be provided for increasing from winter to summer levels and decreasing to winter levels as shown in Figure 15.

We understand that Zosel Dam operators do not have a lot of leeway in the management of flow releases as they must track the flows received from upstream sources closely or risk having unacceptable lake levels. We conclude that the model that we have proposed offers good potential for improving operations at Zosel Dam.

We feel that the suggested targets for lake levels would be acceptable by the majority of stakeholders. There will always be trade-offs between the various resource users and the biological and ecological components. Because of limited storage capacity and lake operations based on inflow targets there are not many options available. We feel that lake levels are best set as targets to satisfy the greatest number of stakeholders and provide a range and the flexibility for operators to make modifications based on inflows and experience

[7] John Arterburn-Anadromous Fish Division, RM&E subdivision lead for the Confederated Tribes of the Colville Reservation

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APPENDIX A

WEAP MODEL OVERVIEW

WEAP MODEL STRUCTURE

The analyses for this study were conducted using software developed by the Stockholm Environment Institute[8]. WEAP (Water Evaluation And Planning) is especially designed for modeling the impacts of water management policies. This section outlines the general structure of the model developed, presents the key assumptions and data used, and summarizes the key results considered.

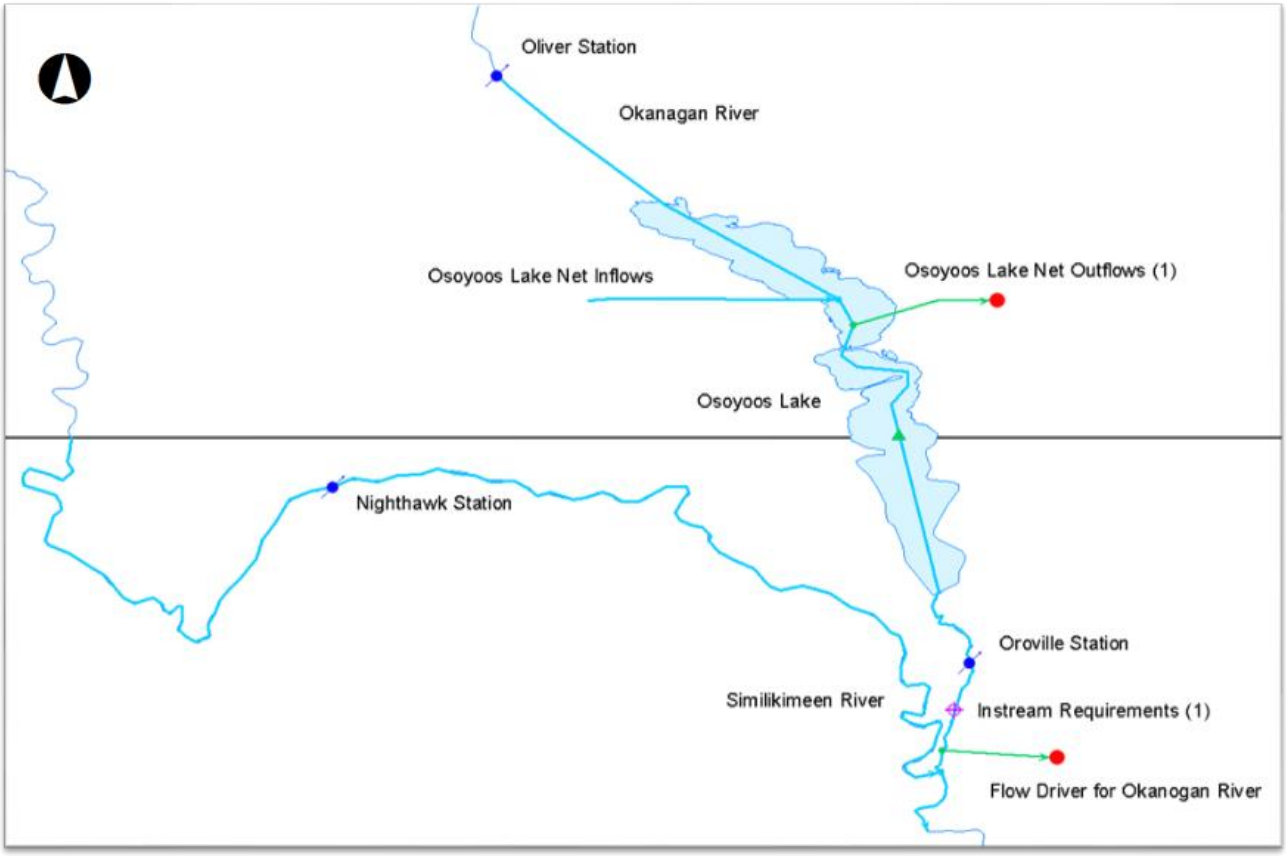


Figure A1: WEAP Model Structure

Model Structure

Referring to Figure A1, the WEAP model includes:

- Two rivers (Okanagan and Similkameen)
- Three hydrometric stations (Oliver, Oroville, and Nighthawk)
- One storage (Osoyoos Lake)
- One in-stream flow requirement location
- Two "demand" nodes (one that represents net outflows from Osoyoos Lake – excluding discharges from Zosel Dam, and one which is used to draw water through the Okanagan River – flows in WEAP are demand, not hydraulically driven)

[8] http://www.weap21.org/

- A third “river” which represents net inflows to Osoyoos Lake (excluding flows from the Okanagan River through Oliver)

Model Operation

For the purposes of this study, historic flow hydrographs were input to the upper-most reach of each river. Demands along the river induce flow to occur (WEAP does not model hydraulic processes directly). As flows travel along each river, they interact with the rest of the modeled elements. In the case of this specific model:

- Flows (Net Inflows) are added to the Okanagan River upstream of the Osoyoos Lake element.
- Flows (Net Outflows) are extracted from the Okanagan River upstream of the Osoyoos Lake element.
- Flows enter and leave Osoyoos Lake (storage element), potentially increasing or decreasing the storage volume and consequently, the water elevation as well.
- Flows in the Similkameen River discharge into the Okanagan River below all other model elements, and therefore have no direct impact on them. The Similkameen River flows are, however, used to calculate the impacts of backwater on the maximum discharge from Zosel Dam.

The rest of the elements included in the model are only for reference and comparison purposes. These include:

- The three hydrometric stations. These allow the user to plot hydrographs of the historical flows at the indicated locations.
- The in-stream requirements. The specified in-stream flows are used to plot hydrographs and to calculate statistics regarding requirements coverage. This element does not actually remove or add flows to the Okanagan river.

Each of these items is discussed further in the following section.

Key Assumptions

River Flows

The Okanagan and Similkameen River elements were both populated with historic daily discharge data (1982 – 2010) from the USGS hydrometric data system. Water Survey of Canada data were also available, but the USGS website provided easier access to the data for the desired period. The stations used are:

- USGS 12438700 OKANOGAN RIVER NEAR OLIVER, BC
- USGS 12442500 SIMILKAMEEN RIVER NEAR NIGHTHAWK, WA

Osoyoos Lake Net Inflows and Outflows

The only historic data available for analyzing the impact of inflows and outflow on the water elevation in Osoyoos Lake are:

- Okanagan River flow rates at Oliver (referenced previously),
- Okanagan River flow rates near Oroville (USGS hydrometric station 12439500), and
- Osoyoos Lake water surface elevations (USGS hydrometric station 12439000).

There are many other flows into and out of Osoyoos Lake for which adequate data are not available. These include stream flows, surface runoff, evaporation, irrigation supply, direct precipitation, and groundwater exchange. While quantifying these items is not necessary in order to analyze historical operations, they must be accounted for when analyzing the impacts of proposed operations using historical data.

The water balance of the lake dictates that these un-documented inflows and outflows are inherently reflected in the relationship between the three data sets referenced above. Therefore, daily net inflows and outflows were calculated using these data as follows:

$$Q_{NET} = Q_{OROVILLE} - Q_{OLIVER} + k(dE_{OSOYOOS})$$

Where:

Q_{NET} = net inflow to (if positive) or outflow from (if negative) Osoyoos Lake (cfs)

$Q_{OROVILLE}$ = flow rate recorded at the Okanogan River hydrometric station near Oroville (cfs)

Q_{OLIVER} = flow rate recorded at the Okanagan River hydrometric station near Oliver (cfs)

$dE_{OSOYOOS}$ = change in the Osoyoos Lake surface elevation during the previous 24 hours (ft)

k = units conversion factor (2789.7 cfs/ft of elevation change based on a 24 hour period)

Since WEAP does not accept negative river flow values, the QNET time series was divided into two time series – Net Inflow and Net Outflow. These two additional terms, along with the Oliver station inflows, form the historical input data for the model. This allows the user to adjust the Zosel Dam discharge rates in order to obtain alternative lake elevations as per the scenarios outlined in this report. The historical flows into and out of Osoyoos Lake are plotted in Figure A2 for the period from 1987 to 2010. Note that in general, the river flows significantly exceed the calculated net inflows and outflows.

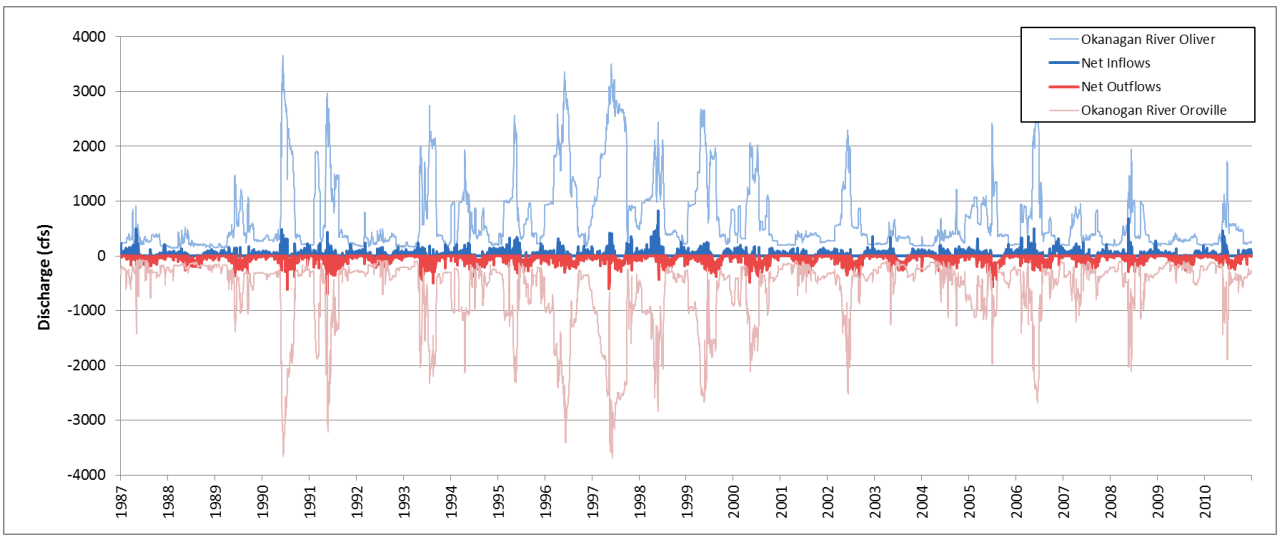


Figure A2: Historical Flows Into and Out of Osoyoos Lake

Osoyoos Lake Storage

International Joint Commission Study 1 defines the stage / volume relationship for Osoyoos Lake. Within the current and proposed operating ranges (909.0 to 913.0 feet), this relationship is essentially linear, and is defined in Study 1 as:

$$\text{Volume (AF)} = 6105.9 \times \text{Elevation (ft)} - 5{,}302{,}563$$

This relationship was used for the WEAP model.

Similkameen River Backwater Effects

As the discharge in the Similkameen River increases, water within the Okanagan River backs up toward the Zosel Dam. At very high Similkameen discharge rates, the capacity to spill water through the Zosel Dam gates can be reduced to zero. International Joint Commission Study 7 presents an equation that calculates the maximum potential discharge through the Zosel Dam with the gates fully open as a function of the Osoyoos Lake water elevation and the Similkameen River discharge. The equation is:

$$Q_{Sx} = 695.5(WL) - 0.14(Q_{SK}) - 630703.8$$

Where:

Q_{Sx} = Okanogan River discharge under backwater conditions caused by the Similkameen River (cfs)
WL = Osoyoos Lake water level (ft)
Q_{SK} = Similkameen River discharge (cfs)

This equation was used to calculate the maximum potential discharge rate at the dam for each day. If the dam discharge (calculated by other means) exceeded the backwater–limited maximum discharge, then the dam discharge for the day was set to the maximum discharge rate as calculated using the Similkameen River discharge and current lake elevation.

Zosel Dam Discharge Control

In order to model the impacts of operating Zosel Dam in order to meet alternative water elevation criteria, it is necessary for the model to adjust the dam discharge rates in response to inflows and lake elevation changes. We therefore developed a logic-based algorithm that considers:

- If the lake elevation is above or below the target elevation,
- If a rapid discharge rate change in the Okanagan River near Oliver is scheduled (the Ministry of Environment typically gives the Oroville-Tonasket Irrigation District advanced warning of any discharge adjustments over 50 cfs),
- If backwater conditions due to the Similkameen River are high enough to restrict dam discharges, and
- If the dam discharge required to raise the lake elevation is below the minimum discharge assumed for the scenario.

Typically, the algorithm increases or decreases the previous time period's discharge rate by a small factor (1.02 or 0.98 respectively), depending on whether the lake elevation is above or below the target elevation. This provides a relatively smooth adjustment provided that the current day's net inflows are not significantly different than those from the previous day.

When the net inflows (positive or negative) change abruptly, the algorithm adjusts the discharge rate to match the Okanagan River discharge at Oliver. This provides for a much more rapid adjustment to the changed conditions. If the lake elevation is below the target elevation, and the discharge rate reaches the minimum allowable discharge rate, no further adjustments are made until the lake elevation reaches or rises above the target elevation. A detailed description of the logic for this algorithm is provided in Figure A3.

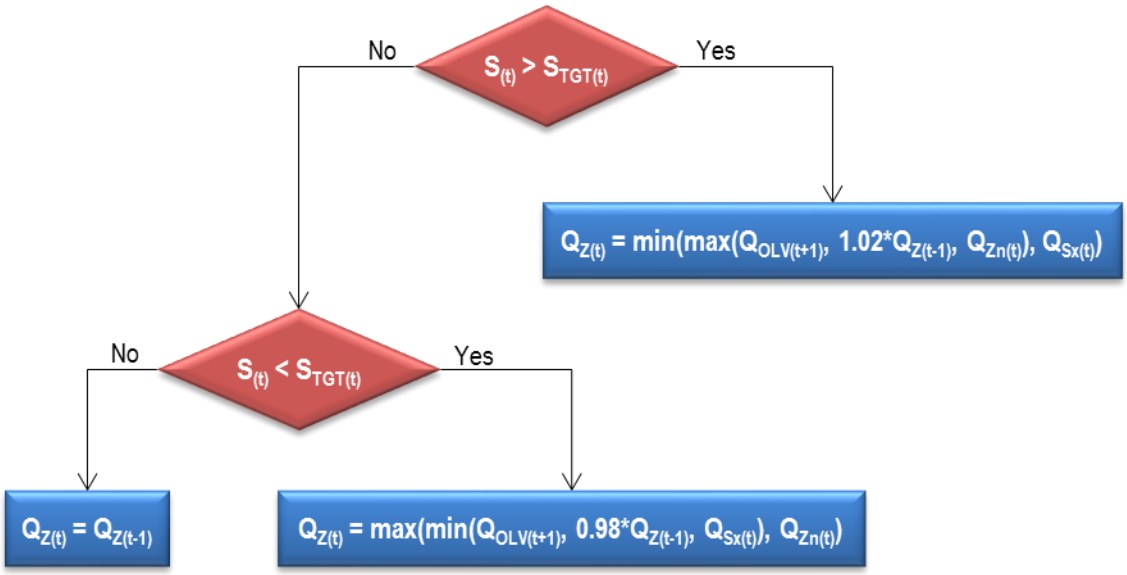


Figure A3: Logic Schematic – Operation of Zosel Dam Discharges

Where:

(t) = current time step (day)

(t-1) = previous time step (day)

(t+1) = next time step – applied only to the discharge measured at Oliver (Q_{OLV}) in order to reflect the fact that the Zosel Dam operator is given advanced notice of significant planned changes to releases from the Penticton Dam on Okanagan Lake (day)

S = Osoyoos Lake storage (ac-ft)

S_{TGT} = target Osoyoos Lake storage (ac-ft)

Q_Z = discharge from Zosel Dam (cfs)

Q_{OLV} = Okanagan River discharge as measured at the Oliver gaging station (cfs)

Q_{Zn} = minimum discharge from Zosel Dam if sufficient water is stored in Osoyoos Lake to provide it (cfs)

Q_{Sx} = maximum discharge from Zosel Dam under backwater conditions caused by the Similkameen River, calculated as $Q_{Sx} = 695.5*WL - 0.14(Q_{SK}) - 630703.8$ (cfs)

WL = geodetic elevation of the Osoyoos Lake water level (ft)

Q_{SK} = Similkameen River discharge as measured at the Nighthawk gaging station (cfs)

The effectiveness of this control algorithm can be seen in several figures within this report. Appendix B contains several good examples of the modeled discharge compared to recorded discharge. Note that in both cases (modeled and recorded), there are periods of relative stability and periods of rapid change. Overall, however, the net effect is to maintain the lake elevations within the specified operational range (with exceptions during high freshet flows).

Ideally, abrupt discharge changes would be avoided to prevent negative downstream impacts. In addition, the algorithm should adjust the rate of change – faster when the lake elevation rises or falls quickly, and slower when the lake elevation changes more slowly. The analyses conducted for this study shows that the model occasionally reacts more slowly than what is noted historically. This is especially noticeable during periods of sustained, high inflow rates (high freshet volumes). The result is that the lake elevations tend to peak approximately 0.5 to 0.7 feet higher than the historical peaks. This is not a function of the target operational range – but is instead a result of the relatively simplistic discharge adjustment algorithm.

Due to the very tight schedule governing this project, there is insufficient time to refine the discharge adjustment algorithm to ensure smoother rate adjustments and to provide variable adjustment rates to improve responsiveness. We are confident, however, that a skilled dam operator or, given sufficient time, a programmed computer, could operate the dam to achieve these objectives. We are also confident that the current modeled results are sufficient for the purposes of this study, and demonstrate the opportunities and constraints associated with the alternative operational controls considered.

<u>In-Stream Flow Requirements</u>

The in-stream flow requirements input to the model were extracted from Table 10, IJC Study 1 as summarized in Section 4. These values are used in two ways:

- as a reference to determine how well each control scenario meets the specified in-flow requirements, and
- as the minimum allowable discharge from Zosel Dam.

Impacts to in-stream flow requirements can be expressed using several methods. These include:

- direct comparison (discharge rate vs. in-stream flow requirement),
- delivered (the amount of the in-stream flow delivered to the subject river reach),
- deficiency (the amount of in-stream flow that was not delivered), and
- coverage (the percent of the in-stream flow that was delivered).

APPENDIX B

BALANCING OSOYOOS LAKE WATER ELEVATIONS AND DOWNSTREAM FLOW CRITERIA

The figures presented in this appendix have been provided to illustrate the challenges of meeting Osoyoos Lake target elevations while still providing sufficient low flows through Zosel Dam. The figures are arranged into five groups, and are based on four primary scenarios and four sub-scenarios. Three of the primary scenarios are described in Section 4, while the fourth scenario is a modified version of one of these. The sub-scenarios are identical to the primary scenarios, except that a different set of downstream flow criteria is used. These scenarios are summarized below.

Primary Scenarios:

All four of these scenarios were run to determine how well each was able to meet downstream flow criteria defined in Table 5, Column 2 of this report as “Fisheries Criteria”.

Scenario 0

This is the historical data for lake levels and releases at Zosel Dam as recorded at the USGS gauges Osoyoos Lake near Oroville (Sta # 12439000) and Okanogan River at Oroville (Sta # 12439500). It reflects actual operations – drought declarations and current Orders. It appears that the discharges from the dam were operated more to meet lake elevation targets than to meet downstream flow criteria. It is apparent, however, that discharges were kept (as much as possible) no less than 100 cfs.

Scenario 1

This is the same as Scenario 0, but was modeled to meet downstream flow criteria as much as possible. Releases through the Zosel Dam were therefore kept at or above the specified downstream flow criteria for the corresponding time period. This resulted in completely draining the live storage in Osoyoos Lake at times during most years. When this occurred, discharges through Zosel were limited to net inflows to the lake.

Scenario 4

This is the proposed management scenario. It assumes no drought declarations, 1987-2010 inflows, and sets the target lake elevations to 912.0 feet for the summer and 910.0 feet for the winter. The Zosel Dam minimum discharge is set at 100 cfs.

Scenario 4 (modified)

This scenario is identical to Scenario 4, except that instead of a minimum discharge of 100 cfs, the minimum discharge is set to the specified downstream flow criteria for the corresponding time period. As with Scenario 1, this resulted in completely draining the live storage of Osoyoos

Lake at times during most years. When this occurred, discharges through Zosel were limited to net inflows to the lake.

Sub-Scenarios:

The four sub-scenarios are identical to the four primary scenarios, except that the downstream flow criteria is defined in Table 5, Column 3 of this report as “Instream Flow Criteria” rather than Column 2 “Fisheries Criteria”.

Figure Set 1: Discharges, Lake Levels, and Fisheries Criteria – All Years

The first two figures of this set of three shows that in order to maintain target lake elevations, discharges at Zosel Dam are often lower than the stated Fisheries Criteria. The third figure of the set illustrates that when discharges are based on trying to meet the Fisheries Criteria, target lake elevations cannot be met. It also shows that at times, it’s not even possible to meet the Fisheries Criteria because the live storage in Osoyoos Lake has been depleted.

Figure Set 2: Discharges, Lake Levels, and Fisheries Criteria – Drought Years

This set of three figures is identical to Figure Set 1, except that only drought years have been included.

Figure Set 3: Discharges, Lake Levels, and Instream Flow Criteria – All Years

The first two figures of this set of three shows that in order to maintain target lake elevations, discharges at Zosel Dam are often lower than the stated Instream Flow Criteria. The third figure of the set illustrates that when discharges are based on trying to meet the Instream Flow Criteria, target lake elevations cannot be met. It also shows that at times, it’s not even possible to meet the Instream Flow Criteria because the live storage in Osoyoos Lake has been depleted.

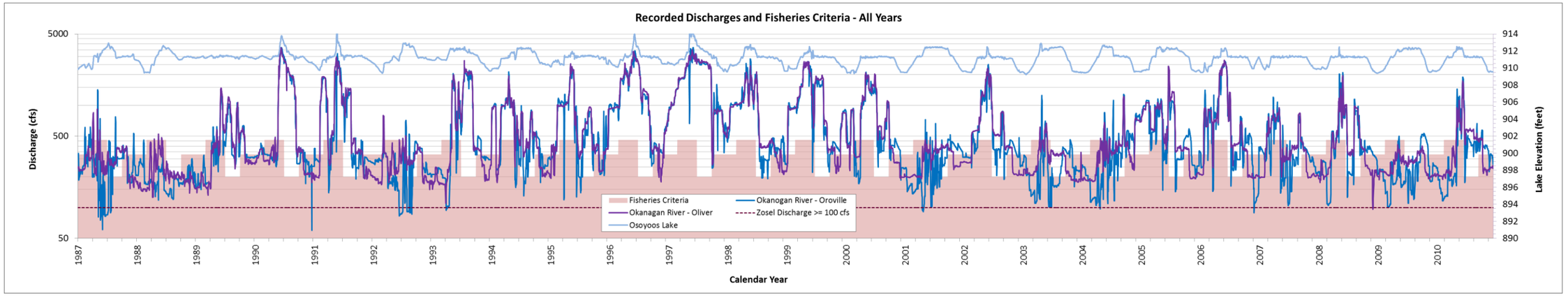
Figure Set 4: Discharges, Lake Levels, and Instream Flow Criteria – Drought Years

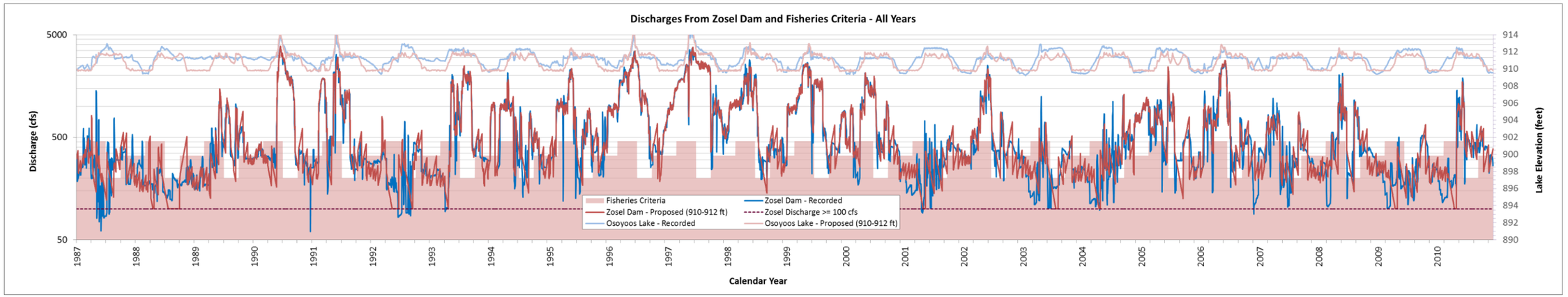
This set of three figures is identical to Figure Set 3, except that only drought years have been included.

Figure Set 5: Criteria Achievement – Drought Years

The two figures in this set show how well the scenarios meet the two downstream flow criteria during drought years assuming a minimum discharge at Zosel Dam of 100 cfs. Scenarios 1 and 4 (modified) were not included since completely depleting the live storage in Osoyoos Lake is not an option. Each figure shows the percent of the downstream flow criteria that is achieved on

the vertical axis, and the percent of the entire period (eight drought years) that the indicated achievement percentage is exceeded. For example, considering the Fisheries Criteria plot, and looking at the Proposed Management Scenario 4 (910-912) line, we see that 80% of the criteria can be achieved or exceeded 50% of the time. By comparing the two figures, we see that both historical and proposed operations can meet the Fisheries Criteria more often than the Instream Flow Criteria.





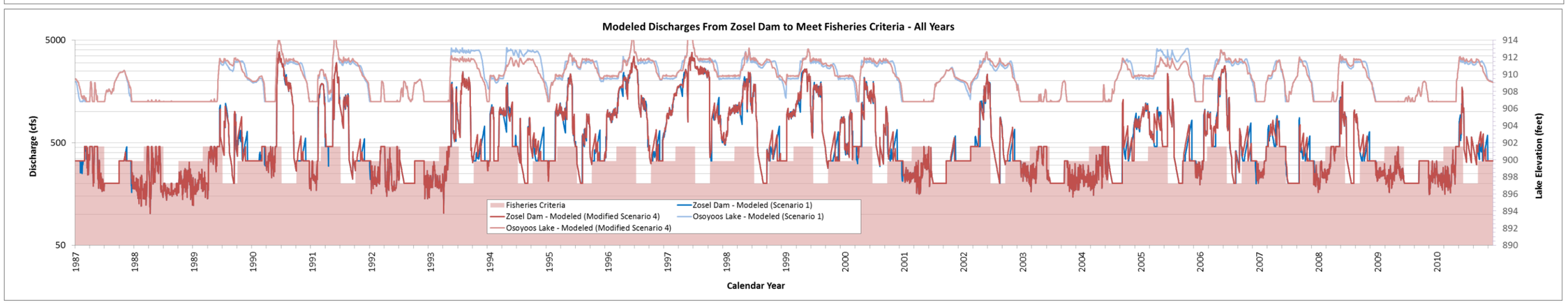
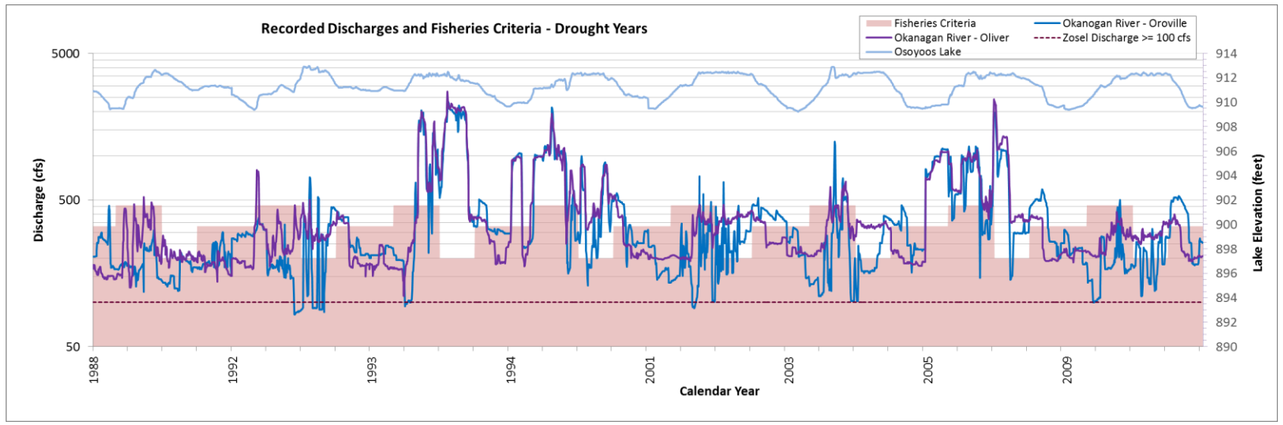
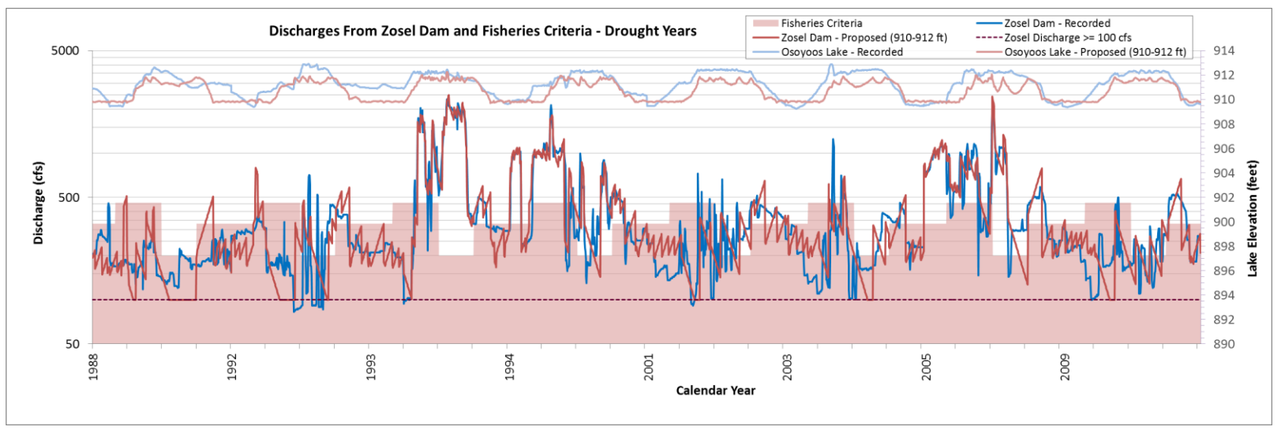


Figure Set 1: Discharges, Lake Levels, and Fisheries Criteria – All Years





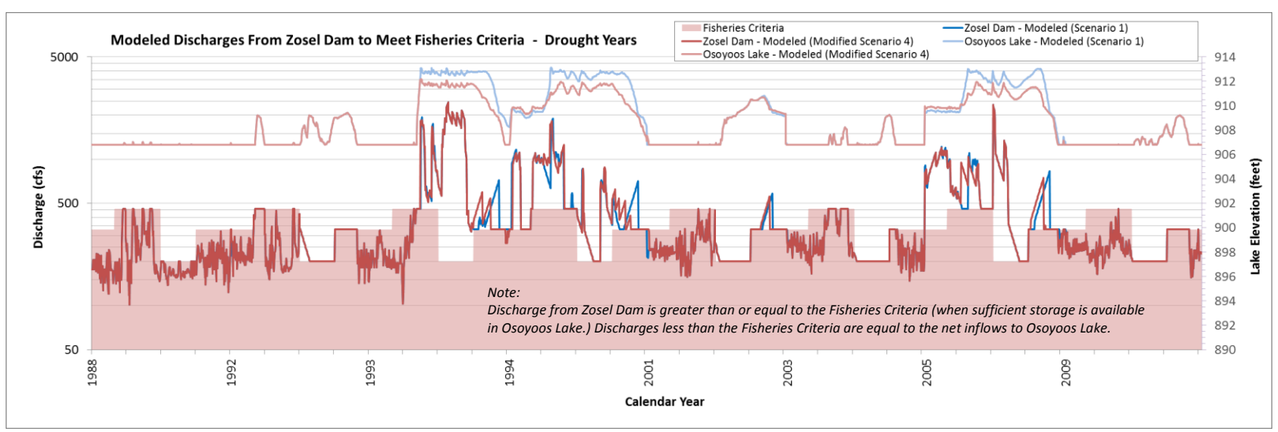


Figure Set 2: Discharges, Lake Levels, and Fisheries Criteria – Drought Years

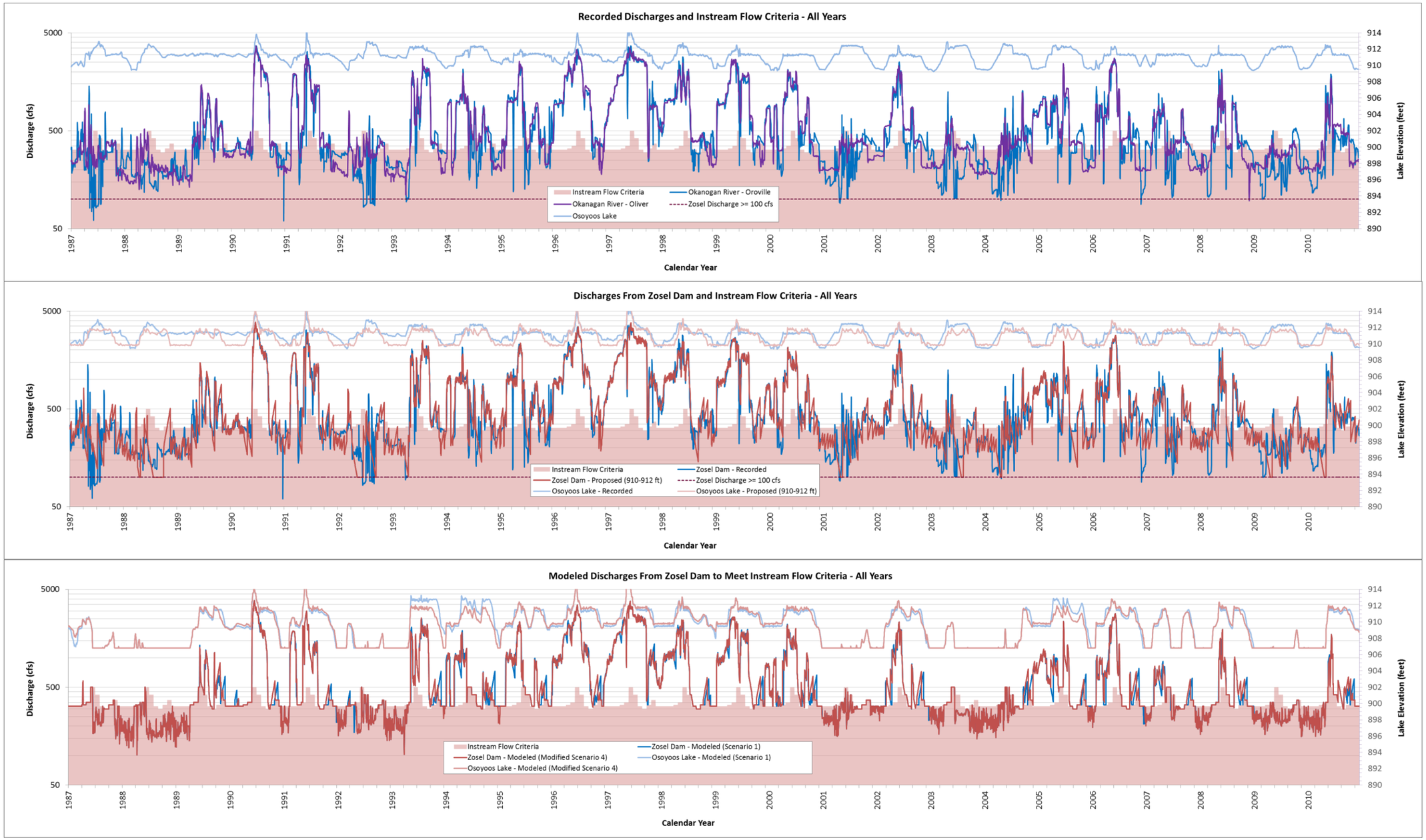
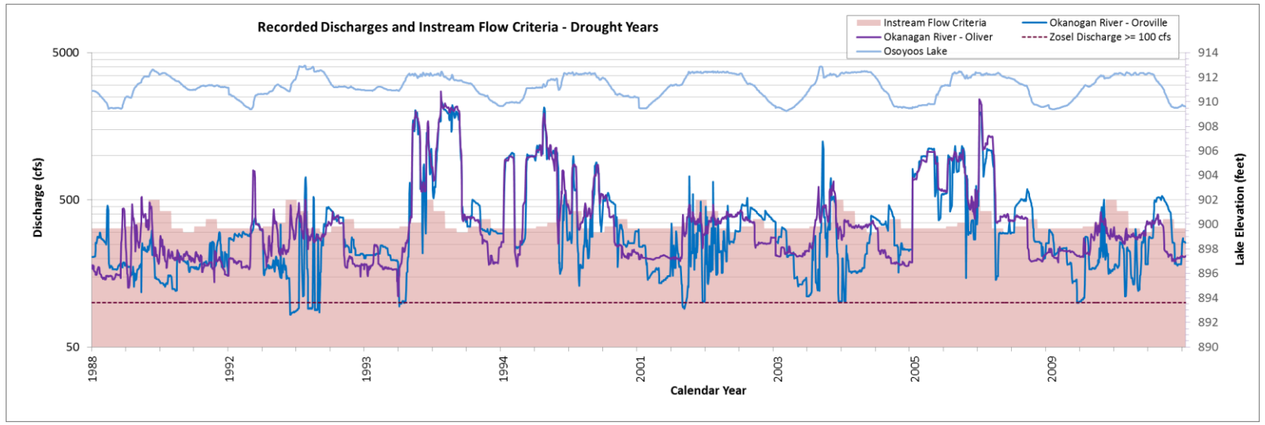
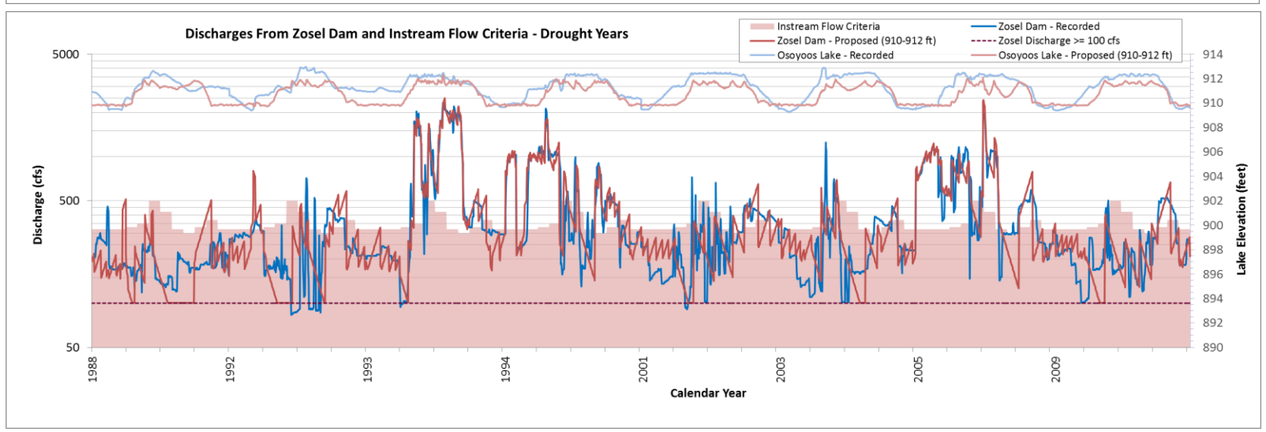


Figure Set 3: Discharges, Lake Levels, and Instream Flow Criteria – All Years





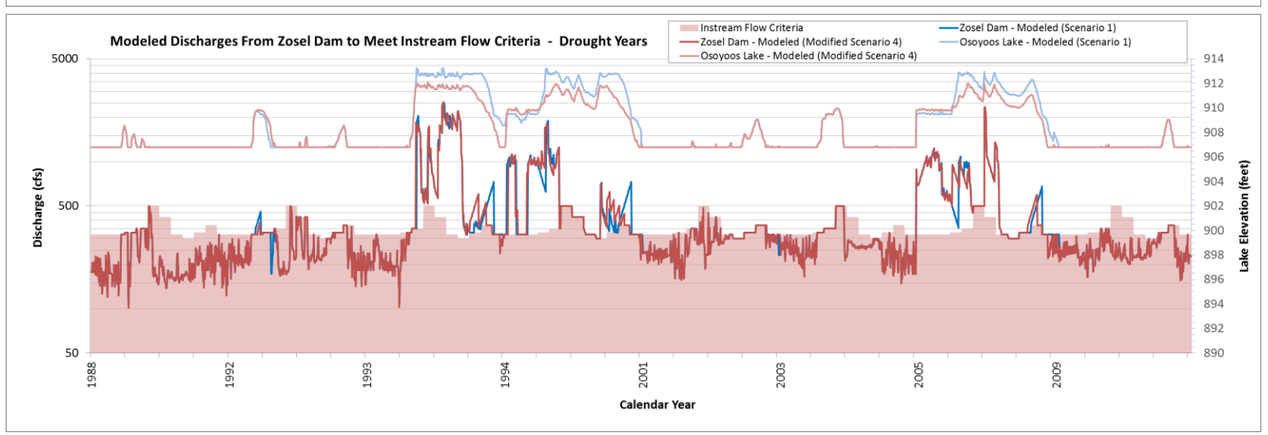
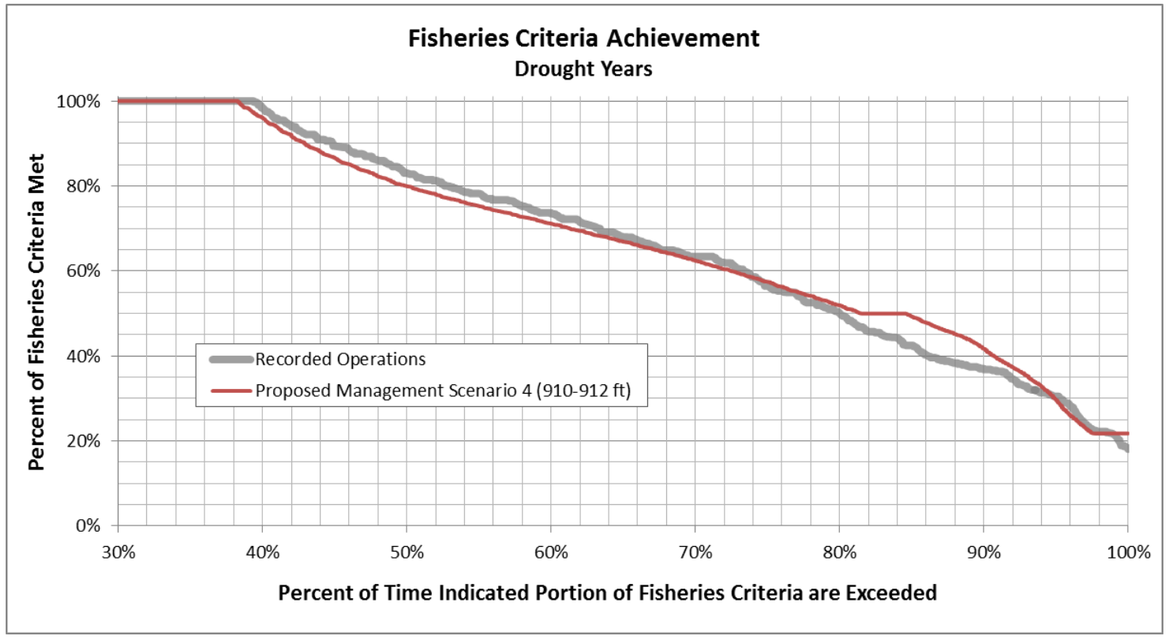


Figure Set 4: Discharges, Lake Levels, and Instream Flow Criteria – Drought Years



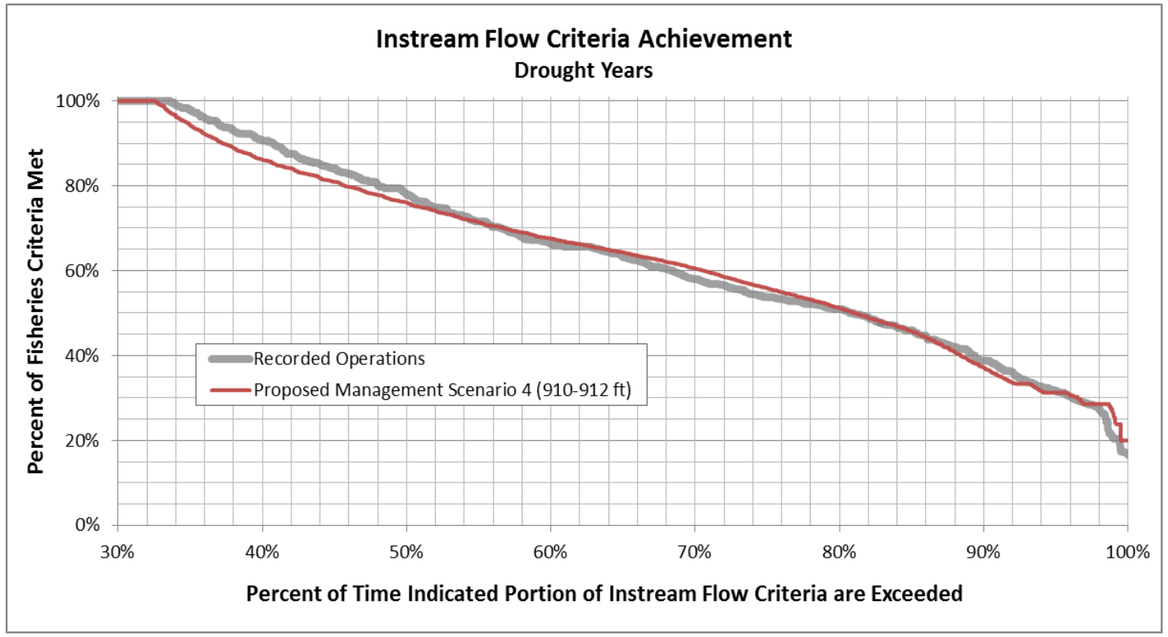


Figure Set 5: Criteria Achievement – Drought Years