Okanagan Lake Water Level Management
Review of Past Trends
with Recommendations

INTERIM REPORT #2

for:

Fisheries Section
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by:

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1.0 Introduction

Water supplies in the Okanagan basin are controlled mainly by inflows and outflows from Okanagan lake. This is a large lake with relatively small average throughflow. Hydrologically the area is arid, with low annual runoff amounts, and large interannual fluctuations in runoff. In addition, the evaporation from Okanagan lake is large, so the outflow in wet years vastly exceeds the outflow in dry years. A map of the area is shown (Figure 1), with the downstream river (Okanagan river), leading via Skaha, Vaseau and Osoyoos Lakes to the US border, and from there to the confluence with the Similkameen river. The Okanogan river (as it is called in Washington state) joins the Columbia River about 100 km south of the international border.

The capacity of the channelized Okanagan river downstream of Okanagan lake is not large. The peak flow that it can pass depends on factors such as the backwater exerted by Skaha Lake, and by tributary creeks. The design flow of the channelized river is 60 m^3/s. Under *optimal* conditions higher flows can be released (for example during the early part of August 1997, a flow estimated at about 77 m^3/s was passed). Prolonged release of high flows sometimes causes damage to drop structures m the river downstream of Skaha Lake. The maximum daily volume (about 7.5 million m^3) that may be released from Okanagan Lake at this flow rate is a small fraction (1.8%) of the live storage volume of the lake. Thus many days and weeks of outflows are needed to significantly change the water surface level of the lake.

Water supply management, water quality and related issues for Okanagan Lake were comprehensively investigated in 1972-3, and in 1974 a series of reports which included the *Comprehensive Framework Plan* were published. A summary of selected recommendations from this report is included as Section 3.0 of the present report. The Plan emphasized aspects such as flood reduction, water supply for irrigation and municipal use, phosphate reduction from treated sewage waters, and flow needs for Okanagan river sockeye salmon. A clause was inserted in regard to shore spawning kokanee and regulation of lake levels.

Engineering and other work set out in the Plan was executed, and a report was published at the end of the implementation period (September 1982). The report was titled Report on the *Okanagan Basin Implementation* Agreement, and included details of the management of lake surface levels. Recommendations were made specifically directed at mitigating the effects of man made water surface changes in lake levels on shore spawning kokanee populations.

For the last 15 years the lake has been operated by Water Management Branch staff, following the guidelines set out in the Plan, and in the Implementation Report.

The Plan permits late winter drawdown of the lake, if needed, to create storage for larger than average anticipated runoff events the next spring and summer.

This procedure has the following attributes:

1. *Benefit* in creating space in the reservoir so that high runoff flows appearing weeks or months later can be stored and slowly released. This reduces maximum water surface levels the following summer, and reduces summer flow peaks in the Okanagan river also. Lake-side residents, particularly those with low basements, benefit from reduced flood levels, because inundation of basements is minimized.

• 2. *Detriment* for lake and riverine spawning fish, because a). the lake may be drawn down sufficiently that lake spawning kokanee eggs may be left high and dry prior to completion of incubation and hatching, and because b). high flows in the Okanagan River during the winter months may mobilize gravels and cause wash out of sockeye salmon spawning sites. In this context, both the sockeye salmon run on the Okanagan River and the Okanagan Lake kokanee population are particularly valuable. The sockeye salmon run is one of only two substantial runs left on the Columbia River system, and the Okanagan Lake kokanee are unique, and very different in spawning behaviour and habitat from other salmon stock. They thus have a high value from the point of view of genetic diversity.

Difficulties in managing the system from the point of view of fish spawning and survival stem from the large lead time involved. The fish (both lake and riverine salmonids) spawn during the month of October, and select sites based on water levels (in the river and the lake) that they see at this time. These water levels need to be kept within a fairly close band of the level at spawning time (sometime in mid or late October) to ensure optimum survival. Water levels must be maintained until early or mid April for the kokanee alevins to mature successfully. If these levels are held, and an unusually high snow pack year occurs (as in the 19%-97 winter), there is insufficient time during the April to early May period to create storage space in the reservoir prior to the onset of flooding. The result is very high lake levels and flooding of homes and other facilities around the lake. Although the flood construction level has been set at a relatively high elevation (343.66 m) for many years, there are a lot of non-conforming residences and other properties. If the levels in Okanagan Lake are lowered starting in late January (as was done in 1997), then it is possible to create sufficient storage to reduce flooding in the summer months. However this is done to the detriment of lake spawning kokanee stocks.

In the natural system, with uncontrolled flow over a gravel or cobble bar at the outlet of Okanagan Lake (see Figure 2), the changes in outflow were slow and determined by slowly changing lake levels as the winter months progressed. No provision was possible to reduce peak water elevations during the summer, by pre-releasing water following large snow fall winters. With the installation of a sill and gates at the outlet (starting in 1915), the possibility has existed for the last eighty years of significant lowering ("pulling the plug") of the lake, below previously occurring natural lows. This is done during high snow pack winters, to create room for storage of anticipated flood events.

2.0 Available Hydrological Data

Large amounts of hydrological data have been collected for Okanagan Lake and the Okanagan river system. A listing of a selection of the most important types of data for water level management is listed in Table 1. Water licence information is obtained fiom the Water Rights Information System computer *files*, at Water Management Branch, MEL&P. Meteorological and hydrological information is obtained fiom Environmental Services and Information Division, Environment Canada.

3.0 Okanagan Basin Framework Plan & Okanagan Basin Implementation Agreement

Two important sets of documents were produced, detailing what engineering, construction and administrative work had to be done, and how to operate Okanagan Lake and its tributaries. These were the report on the Canada-British Columbia Okanagan Basin Agreement, 1974 and the report on the Okanagan Basin Implementation Agreement, 1982. The first of these sets of documents included a comprehensive framework plan, referred to as the Plan. Recommendations from these documents were incorporated into the Water Management Branch's operating schedule, which specifies target lake levels and river flows at different times of the year.

Plan: A comprehensive analysis of the situation with water supply, flood potential and eutrophication possibilities for Okanagan Lake was carried out in the early seventies. Under a joint Federal-Provincial effort, a Canada British Columbia Consultative Board was set up to oversee the work that had been funded in October 1969 under the Okanagan Basin Agreement. This work culminated in a report, published in 1974 in three parts:

- Summary Report, including the Comprehensive Framework Plan: Canada British Columbia Okanagan Basin Agreement, March 1974, 42pp.
- Main Report: Canada British Columbia Okanagan Basin Agreement, March 1974,536 pp.
- Twelve Technical Supplement Reports, including Volume 1: Water Quantity Report: Canada British Columbia Okanagan Basin Agreement, March 1974,610 pp.

The study analyzed three growth projections for the period 1970 to 2020. With the highest growth projection (2.6% per annum) of the three, the report concluded that there was sufficient water in the basin to supply all projected withdrawals and to meet proposed fishery and recreation requirements. This assumed the withdrawal of larger volumes of water fiom Okanagan Lake during prolonged drought periods than had occurred in the past. Also forecast was the need for additional headwater storage of water.

Forecast ranges of Okanagan Lake water surface levels were as follows:

> ***Not normally to exceed four feet in any one year, but a total variation of nine feet may occur between an extreme flood level in one year,*** *and* ***an extreme low lake level following a succession of drought years.***

The projected maximum elevation of Okanagan Lake during a 200 year flood event was 1125.5 feet (343.05 m). This maximum elevation was based on statistical projections, and is hard to interpret and use, because the maximum levels attained in Okanagan Lake depend on inflows and how the outflow gates are regulated during the weeks and months leading up to the major flood event.

In the Section concerning "Detailed Recommendations", "Part A Water Quantity", water levels in Okanagan Lake are recommended to be regulated to target values (see Table 2). Target water surface elevations for Okanagan Lake and sill elevations at the lake outlet are summarized on a scale drawing (see Figure 4). Values shown in Figure 4 are as mentioned in the Plan, and as mentioned in the Report on the Implementation Agreement.

Table 2. Target Water Surface Elevations for Okanagan Lake Recommended in the Plan (1974)

Normal Operating Conditions:	Regulated within its normal four foot range (1119.8 to 1123.8 feet, 341.32 to 342.54 m) in all years except *extreme* flood years (inflows projected to exceed 500,000 acre feet/yr, 617 million m^3/yr) and successive drought years (inflows less than 200,000 acre feet/yr, 247 million m^3/yr).
Flood Conditions Predicted:	Lake to be drawn down below its normal low water elevation of 1119.8* feet (341.32 m) prior to freshet by up to one foot (0.305 m). (Draw down to as low as 341.01 m is thus recommended, if necessary).
Drought Conditions Predicted:	Maintain the lake level as high as possible. Under prolonged drought conditions, the lake level may reach as low as 1116.8 feet (340.4 m). The bottom 0.92 m of water storage is known as "emergency storage".

*Normal low water elevation specified in Plan of 341.32 m. Mote that operational experience has shown that in most years meeting this target would result in excessive and unnecessary drawdown. In practice, a minimum level in an average year of 341.5 to 341.6 m is usually sufficient.

Recommendations are also made in the Plan, as follows:

- a Flood plain zoning be implemented and enforced by a regional water management authority up to 1127.5 feet (343.66 m) elevation around Okanagan Lake. Further development on this floodplain should be limited to recreation, parks and agriculture

- a Irrigation and domestic intakes around Okanagan Lake be adjusted as required to be operable at a minimum lake elevation of 1114.8 feet (340.4 m)

- As of March 1974, future intakes, wharves, boat ramps and other structures around Okanagan Lake be built to operate with a lake elevation range of 1116.8 to 1125.5 feet (340.4 to 343.05 m). .

- Water requirements for *sockeye* salmon in Okanagan River should be met in all years, except consecutive drought years, using the following guidelines:

DATES	FLOWS, OLIVER GAUGING STATION	
August 1 to September 15	300 - 450 ft^3/s	(8.5 - 11.3 m^3/s)
September 16 to October 31	350 - 550 ft^3/s	(9.9 to 15.6 m^3/s)
November 01 - April 30	175 - 1000 ft^3/s	(5.0 - 28.3 m^3/s)

"In two or more consecutive drought years, these flows may have to be reduced".

NOTE THAT THESE NUMBERS ARE FROM TECHNICAL SUPPLEMENT IX. THE NUMBERS SHOWN IN MAIN AND SUMMARY REPORTS ARE WRONGLY REPRODUCED.

- Clause 40: That due consideration be given to shore spawning kokanee when regulating Okanagan Lake water levels *over* the winter months. To minimize damage to shore spawning kokanee during the fall and winter months, the drawdown of Okanagan Lake between October 01 a d February 28 should not normally *exceed* six inches. In anticipated runoff years however, greater drawdowns may be necessary to accommodate the spring runoff.

Without long term forecasting, the Plan's recommendations for drought conditions are not possible to meet in practice, because during times of very low inflows into the lake, it is not possible to maintain the water levels high, because of demands on the system. For example during the winter months the Okanagan river flows must be maintained relatively high to avoid exposing sockeye salmon eggs.

The Plan's recommendations for flood conditions to draw the lake down prior to freshet is impossible to do in practice without causing damage to the lake kokanee population (see next section).

Clearly when the Plan's requirements for fish habitat and fish spawning are combined with requirements for flood and drought management there is a conflict. In our opinion, this conflict could be mitigated with long term trend forecasting, i.e. determining by July/August what the following spring's snowmelt runoff conditions were likely to be.

Implementation Agreement Report: Nearly all of the engineering work outlined in the Plan was undertaken during the period 1976 to 1982, and this document describes what was achieved. Of importance to lake levels and outflows are the following:

Okanagan Lake intakes. In order for the intakes to be operable at an extreme low lake elevation of 340.4 m (1116.8 feet), the Plan advised that *all irrigation and domestic intakes be adjusted (lowered) as required* Because of the expectancy that there was a high chance of zero benefit fiom these changes over the life expectancy of the these intakes, and because the work could be done relatively quickly if needed, the Implementation Report quotes the Board as advising that *any* intake *modifications should not be undertaken until such a time as an actual drought event may occur.* All new intakes (1977 onwards) were built to operate at a lake surface elevation of 340.4 m.

Sockeye salmon flows. The allowed flow for the period August 1 to September 15 were changed, to allow more flexibility in releasing flows fiom Okanagan Lake. The revised schedule was:

DATES	FLOWS, OLIVER GAUGING STATION	
August 1 to September 15	300 - 1000 ft^3/s	(8.5 - 28.3 m^3/s)
September 16 to October 31	350 - 550 ft^3/s	(9.9 to 15.6 m^3/s)
November 01 - April 30	175 - 1000 ft^3/s	(5.0 - 28.3 m^3/s)

"After February 1, flood control requirements are given priority over fishery flows and it may *on* occasion be necessary to *exceed* the 28.3 m^3/s upper limit".

Kokanee Spawning. Mention is made of an multi- agency water study concerning both salmon flows and conditions for kokanee (determining how to minimize the drawdown of Okanagan Lake during the winter months). One of the outcomes of this study were key water surface elevations that the operator should aim for in most years. These were

- February 1st flood control target elevation of 1121.3 feet, preceded by
- October 15th secondary target elevation of 1121.8 feet

"If this secondary target level of 1121.8 ft on October 15 is met, then the drop in lake level between October 15 and February 01 should not exceed *six* inches in most years".

The Implementation Agreement Report modifies Recommendation 40 of the Plan, to read:

"To enhance shore spawning kokanee conditions over the fall and winter months, Okanagan Lake will be operated such that, when possible, the lake level is not greater than 1121.8 feet on October 15, subject to flow restrictions for sockeye salmon".

For reasons that are not known to us, the need to preserve water levels within a close range from the spawning period until 28 February (as envisaged in the Plan) were changed, and the February 01 date adopted. This modified date is too *early* to protect kokanee spawn, because emergence happens after this date, even in warmer than average winters, and approximately an additional six weeks are needed after emergence, for successful growth of the alevins in the shoreside gravel.

4.0 Other Selected Reports

Three reports are reviewed, as follows:

Obedkoff, W., 1994. "Okanagan Basin Water Supply". File No. 42500-60/S, Study No. 384, Province of British Columbia, Ministry of Lands, Environment and Parks.

A review, including modeling of monthly inflows and outflows to Okanagan Lake and the downstream river, was carried out. The purpose of the review was to establish what additional future withdrawal of water fiom the system would be possible, under the operating conditions of the Plan, and assuming a worst case hydrological period, equal to three drought years in succession (as occurred in 1929 to 1931).

The conclusion of the report was that an additional 63 million m^3 per year of water could be abstracted from the system, if the maximum lake draw down (i.e. all the emergency storage) was used Following this drought period, it would take three years of at least average inflow conditions for the lake water surface to return to its normal range. Management of flood events was not discussed. Winter fluctuations of Okanagan lake surface levels during drought periods were not discussed m the report.

McNeil, R 1991. "Report on Frequency Analyses of Flood Flows and Levels for Okanagan Valley, Mainstem System", File No. S5111,.S5211. Water Management Division, Hydrology Section, Ministry of Environment, Lands and Parks.

An analysis of peak flow events, and maximum water levels for Okanagan, Skaha and Osoyoos Lakes and for the Okanagan River are computed. 200 year and 20 year return period *events* are listed. The author is *careful* to point *out* that because the *system* is dominated by releases from Okanagan Lake, and because this is not natural but is man controlled, the normal statistical projections do not *apply*. However in the absence of a better way to proceed, the statistical analyses were done, with the data set being tested with all the data (1921 to 1990) and modern data (1951 to 1990). A change in operating procedure for the *system* occurred after 1951, hence the split in the data *set.*

The values computed provide guidance for flood construction levels around the lakes, and for peak channel capacity. The report states that with 0.61 m freeboard above the 200 year peak water surface level for Okanagan Lake, the flood construction level should be 343.66 m, the same level that has been in effect since 1974.

Operational aspects, such as the need to lower Okanagan Lake ahead of a predicted high snow pack season, are not discussed.

Shepherd B.G. 199%"Impacts of Regulating Okanagan Lake Water Levels on Shore Spawning Kokanee Stocks". Okanagan Sub-region Fisheries Section, Ministry of Environment, Lands and Parks. Draft report, 17 February 1997.

The history of water level regulation activities is summarized in the first section of the report. Reference is made to Volume 1 of "Report of Joint Board of Engineers on Okanagan Flood Control" 1946. The outlet of Okanagan Lake prior to 1909 was controlled by a natural bar, whose elevation was surveyed at 341.3 m. Control dams, with sills at elevations 340.8 m were constructed in 1914-15, and 1920. The present control structure was built in 1953, with the sill set at 339.75 m. Clearly with the *gates* of the control structure open, there is the capability of discharging much more water at low lake levels than could be discharged in the original (uncontrolled) situation, because the sill elevation has been lowered.

The report includes a section concerning an overview of water level patterns, and a section concerning an overview of kokanee shore spawning. The Okanagan Lake shore spawning kokanee stock utilize water depths of less than 3 m for spawning, with depths of less than 0.5 m preferred. In a recent report by Dill (1997), the majority of embryos were found at substrate depths of 15-20 cm, with a prediction for optimal incubation conditions at about 15-30 cm. The likelihood of increased mortality of kokanee embryos fiom man induced water level drops during the winter months is discussed. Declines in the kokanee population due to other causes, such as the introduction of *Mysis* in the Lake, is mentioned.

5.0 Licenced Withdrawals of Water from Okanagan Lake

A considerable volume of water is taken from Okanagan Lake for industrial, agricultural and domestic purposes. Licenced and actual withdrawal of water may be significantly different. This is particularly true of large waterworks licences which are intended to provide for future growth in demand.

Currently, there are about 919 water licences allowing diversion of water from the Lake. The water licences grant a total diversion volume of 110 Mm^3 of water annually, and this diversion volume is about 23% of the mean annual outflow of Okanagan River at Penticton. Out of the 996 water licences, 17 licences *grant* about 83% of the total diversion volume, with each licence allowing more than 1 Mm^3 diversion annually. The city of Kelowna has the highest licenced abstraction volume of 47 Mm^3/year, mainly for municipal water supply purposes. Table 3 shows the sum of diversions fiom Lake Okanagan, the total number of licences, and details of the major licences.

Note that

- 1). a considerable return flow *exists* for water pumped from the lake and utilized for various purposes. A factor of 65% return flow is recommended in the Plan, for municipal/domestic water withdrawals, and
- 2). Several water users abstract water in volumes that are significantly below their annual licenced amounts.

Since the inception of the Plan in 1974, all intakes have been designed to function at an extreme low lake level of 340.4 m. We do not know how many old or non-complying intakes exist.

6.0 Annual Water Outflows and Approximate Inflows for Okanagan Lake

The intent of this Section is to provide some approximate values for understanding of the nature of the water management problem. Because the regional climate is very dry, the runoff from year to year fluctuates a great deal. During dry years and wet years net inflows of about 100 Mm3 and 1000 Mm3 respectively are noted. The year 1997 provided a record inflow volume of about 1400 Mm3.

Few of the tributary streams are gauged, so that annual inflow volumes can only be approximately listed based on a hydrological balance for Okanagan Lake. This has a large error attached, because the evaporation from the lake is not known, is hard to determine, and contributes an important part of the water balance.

Ministry of Environment, Lands and Parks Flood Forecasting Branch computed data on net annual inflow volumes into Okanagan Lake, for the periods 01 October to 30 September the following year. Information is updated yearly.

These inflows were computed from outflows, with a correction for changes in storage in Okanagan Lake. Outflows were taken from data from Water Survey of Canada gauging station No. 08NM050, *Okanagan River at Penticton* (see Figure A1, Appendix A). Evaporation is not included in the calculation, so actual inflows are considerably higher than the computed net inflows. The data concerning net annual inflows from 1922 to 1997 are shown in the Appendix A, as Figure A2.

Data fir climate are available in the Plan, see fir example Table 3.2, page 64, Technical Supplement No. 1. The long term annual precipitation averaged for the whole basin is about 560 mm. Forthelake itself the precipitation is much lower, and high summer temperatures lead to a relatively high lake evaporation. Evaporation from the lake basin is estimated as 420 mm per year. The long term average precipitation on the lake is estimated to be 315 mm per year, which is about 56% of the average precipitation over the whole basin.

Evaporation from the lake is hard to assess. Temperature differences from one year to the next have a significant effect on annual total evaporation. The value listed in the Plan is 965 mm per year, and we believe that an error band of ±15% should be attached to this value, because of uncertainties in the true value, and because of year to year fluctuations. This value is confirmed approximately by other published data (Calculated Lake Evaporation data) based on meteorological measurements at Summerland and Kelowna,(see Canadian Climate Normals, 1951-1980, Volume 9).

The mean evaporation from the lake is thus approximately three times that of the precipitation on the lake. Evaporation is a major factor in the water budget for the lake (see Table 4).

A summary of mean annual water budget values is given in Table 4. Errors of measurement are estimated as follows:

- up to 15% is estimated for assessment of precipitation and up to 15% for evaporation directly fiom the lake,
- up to 5% error on the net runoff fiom the basin and flow measurements at Penticton, and
- an error of up to 15% on abstraction, to account for abstracted flows less than licenced amounts.

Table 4. Approximate Annual Water Budget for Okanagan Lake

Description	Annual Volume (Mm^3)	Estimated Error* (Mm^3)	Record period	Reference
Net runoff on the Lake basin (without Lake)	780	±39	1921-1970	Canada-BC Okanagan Basin Agreement, 1974
Contribution from Precipitation on the Lake	100	±15	1931-1960	Assuming annual precipitation on the lake of 315 mm ± 48 mm
Evaporation from the Lake	330	±50	1921-1970	Canada-BC Okanagan Basin Agreement, 1974
Abstraction	96	±14	1997 Record	BC Government Water Rights Information System
Return flow from abstraction	62	±9		Return flow assumed as 65% of the total diversion
Outflow at Penticton	470	±24	1921 to present	HYDAT W ROM

**Our estimate of measuring/calculation error.*

In 880
Out 834
Difference 46

7.0 Historic Water Level Fluctuations

7.1 Review of Water Surface Levels during the Past 40 Years

An analysis of water surface elevations on 01 February was carried out, see Figure 4. In addition, a check was made to determine the amount of surface lowering of the lake during the period 15 October to 01 February the following year (over winter drawdown).

Since the inception of the Plan in 1974,

- the water surface on 01 February has been within the range +0.15 m to -0.28 m of the target level of 341.77 m. The lowest level (01 Feb 1993) in recent years was associated with drought runoff conditions the previous summer.

- the water surface on 15 October has been within the range +0.33 m to -0.36 m of the target level of 341.92 m. The two highest levels were prior to the preparation of the Implementation Report, and the lowest level was associated with the 1992 drought.

- the overwinter drawdown has exceeded 6 inches (15 cm) eight years out of 23 years. Since the Implementation Report of 1982, the overwinter drawdown has exceeded 6 inches (15 cm) three years in 15 years, see Figure 4.

Graphs of water surface elevations for the whole year, for all years from 1960 to 1997, are shown in the *Appendix* A, Figure A3.

7.2 Drawdowns in the Recent Years during the Spawning Period

The weeks after 01 February are important to kokanee spawning success, because emergence does not happen until approximately 01 March, and approximately six weeks are needed after this date for the successful growth of the alevins in the gravel. Therefore, the water surface level fluctuation up to the *end* of March is considered vital for the overall development of the fish. An analysis of water surface drawdown for the period between 15 October and 01 April of the next year was carried out. Results are given on Figure 5. The water surface elevations for the last 38 years are given in Appendix A, Figure A3, with *special* marks on the 15 October and 01 April levels.

Since the inception of the Okanagan Plan in 1974, the lake surface drawdown has exceeded 6 inches (15 cm) in 17 years *out* of 23 years, and has exceeded 12 inches (30 cm) 9 years in the past 23 years, see Figure 5.

8 Linkage between Southern Oscillation Index and Snow Pack/Runoff

The SOI is a measure of sea level barometric pressure differences between Tahiti and Darwin in the southern hemisphere tropics. During El Niño, unusually high atmospheric sea level pressures develop in the western tropical Pacific ocean, and unusually low sea level pressures develop in the eastern tropical Pacific ocean. An accompanying phenomenon is significant heat build up in the surface water of the eastern Pacific Ocean, changing the ocean surface temperature by as much as 1 to 2 degrees centigrade over an extremely large area. This heat build up takes many months to happen, and once it has arisen, several months are needed before the heat anomaly is dissipated. In this period, tracking patterns of the jet *stream* over the northern Pacific Ocean are *affected,* with consequences for the rain and snow bearing winds that bring frontal storms to our area.

The SOI index measurements are updated monthly and published on the Internet, so access to the data is quick and inexpensive. SOI measurements are available for a very long period, *(year* 1882 to present).

Ministry of Environment Flood Forecast Center has recently provided a WEB site information bulletin concerning the effect of El Niño global climate fluctuations on runoff in British Columbia. The most noticeable effect of the El Niño is along the south *coast* and in the southern interior. For the Okanagan basin, the April 1st 1997 snowpack was below normal a large (74%) proportion of the time following El Niño events, having on average 16% less snow than normal.

An excellent unpublished report (G.A. McBean, 1994), summarizes the possibilities for long term climate and runoff predictions for Canada. McBean found that streamflow in most BC regions was positively correlated with SOI for lagged correlations.

There is good preliminary evidence that climate and streamflow in the US northwest is influenced by world scale climate fluctuations. For example Redmond and Koch (1991) have shown that the ENSO (El Niño Southern Oscillation) measured by the SOI has an effect on temperature, precipitation and runoff in mountainous parts of the US northwest. Snow accumulation is likely impacted by combined *changes* in temperature and precipitation. During El Niño years, the winter climate tends to be both slightly drier, and slightly warmer than normal. Additionally there is a suggestion of cause-effect relationships, with the SOI change preceding the climate change by as much as 4 to 6 months.

8.1 Runoff Correlation for High Altitude Basins

We selected number of medium and high altitude basins in the region with Water Survey of Canada gauges, see Figure 6. Some of these basins were close to the Okanagan valley, but in different river systems. The flow during the snow melt period was totaled, and possible correlations with the Southern Oscillation Index values were investigated.

In almost all basins analyzed, over two thirds of the annual flow appears in the two months of the spring freshet. The volume of flow over the two months was checked for any significant correlation with the mean Southern Oscillation Index of the previous summer. In the analysis, the Southern

Oscillation Index was averaged over three to six months for the periods of April to September, May to September, June to September, July to September, and June to August.

In all the cases best correlation was found between the mean Southern Oscillation Index over the six months period of April to September to the total volume of flow in the two months of May and June of the following year.

In summary, results of correlation analysis show that there is a significant correlation between the six month average SOI and stream flows in the following Spring. The coefficients are given in Table 5. Most of the correlation coefficients are significantly different from zero (the null hypothesis) at the 0.1% level. Scatter plots of the average stream flow for the months of May and June versus the average April to September Southern Oscillation Index are given in Figure 7 for selected basins. The examples on Figure 7 cover basin with areas ranging from 5 km^2 to 185 km^2.

Tabk 5: Correlation between April to September Mean SOI and Following Year May to June Stream Flows.

Station Name & Number	Record Length	Elevation at Station (m)	Basin Area (km^2)	Correlation Coefficient
Whipsaw Creek below Lamont Creek, Station No. 08NL036	30	785	185	0.545
Camp Creek at mouth near Thirsk, Station No. 08NM134	29	1005	33.9	0.556
Vaseux Creek above Terrace Creek, Station No. 08NM171	24	1100	117	0.320
Two Forty Creek near Penticton, Station No. 08NM240	11	1630	5	0.607
Two Forty One Creek near Penticton, Station No. 08NM241	11	1610	4.5	0.565
Dennis Creek near 1780 Metre Contour, Station No. 08NM242	10	1780	3.73	0.517
Trapping Creek near Mouth, Station No. 08NN019	28	1040	144	0.605

8.2 Snow Pack Correlation

We selected a number of snow survey measurement stations in the Okanagan Station. Three of the snow courses selected were near the Okanagan basin, but outside the catchment area. At each snow course station, the maximum snow pack was investigated to check the possible correlations with the Southern Oscillation Index values. In the analysis, the Southern Oscillation Index was averaged over the six months period of April to September for each year and correlated to the maximum snow pack of the following year.

Results of the correlation analysis show that there is a reasonable correlation between the six month average SOI and maximum snow pack for some of the high altitude stations. For eight of the twelve stations the correlation is good, and for four of the twelve stations the correlation is very good. For one station (Mount Kobau) there is no significant correlation.

The coefficient values are given in Table 6.

Table 6: Correlation between April to September Mean SOI and Following Year Maximum Snow Pack.

Station Name & Course Number	Elevation at Station (m)	Record Length	Record Period	Correlation Coefficient
Trout Creek, Course No. 2F01	1430	61	1935-97	0.390
Summerland Reservoir, Course 2F02	1280	56	1942-97	0.449
Graysoke Lake, Course No. 2F04	1810	27	1935-97	0.470
Mission Creek, Course No. 2F05	1780	58	1939-97	0.523
Whiterocks Mountain, Course No. 2F09	1830	41	1953-97	0.210
Silver Star Mountain, Course No. 2F10	1840	39	1959-97	0.338
Isintok Lake, Course No. 2F11	1680	33	1965-97	0.453
Mount Kobau, Course No. 2F12	1810	32	1966-97	0.092
Esperon Creek (upper), Course No. 2F13	1650	28	1966-97	0.337
Morrissey Ridge No 1, Course No. 2CW	1860	28	1961-88	0.576
Mission Ridge, Course No. 1C18[b]	1850	29	1967-95	0.548
Blackwall Peak, Station No. 2G03P[c]	1940	30	1968-97	0.518[d]

[a]The station is located in East Kootenay Sub Basin.
[b]The station is located in Middle Fraser Sub Basin.
The station is located in Similkameen Sub Basin.
[d]Water equivalent data used in stead of snow pack.

8.3 Correlation of Streamflows allowing for Delay in Runoff Associated with Groundwater Storage

For high altitude headwater basins, the contribution of groundwater to streamflows is relatively small. However for medium and low altitude basins in the region, and for the Okanagan river in particular, the contribution fiom groundwater is significant.

Groundwater storage fiom previous years affects the volume of stream flows in the spring fieshet of fbllowing years. After a wet year, where the annual total flow volume is clearly higher than the long term average flow, the ground water storage gets higher and adds to the flows of the following year because of inter-year storage and release of water. In years following wet years, the stream flows are the result of the current year precipiition and groundwater contribution from the past year. Likewise, after a dry year, the groundwater level gets lower and the precipitation of the current year replenishes the storage. Therefore, the stream flows following dry years may be low even though the precipitation of the current year is medium.

In order to analyze the relationship between the SOI and the spring freshet flow, the groundwater contribution was taken out for years following wet and dry years. For all the data set analyzed it was assumed that about 25% of the years were wet, 25% of the years were dry, and the other 50% of the years were neither wet nor dry. For the middle 50% of the cases, no adjustment for groundwater contribution was made.

The following crude procedure was wed to account for the groundwater contribution.

- Compute, long-term mean annual flow volume, V_{mean}
- Compute standard deviation of annual flow volume over the record period, V_{std}
- Set upper flow volume bound $= V_{mean} + 0.7 * V_{std}$
- Set lower flow volume bound $= V_{mean} - 0.7 * V_{std}$
- Compare annual flow volume of previous year (V_{i-1}) with upper and lower annual flow volume bounds
- If V_{i-1} is greater than the upper flow volume bound, then it is assumed that the groundwater volume increases and augments the following year's fieshet. Thus, the adjusted freshet flow volume of the following year will be the measured fieshet flow volume minus contribution fiom previous year.
- If V_{i-1} is less than the lower flow volume bound, then the groundwater decreases and will be replenished fiom the following year's fieshet. Thus, the adjusted fieshet flow volume of the following year will be the measured fieshet flow volume plus some more flow which was used to augment the groundwater storage.
- If V_{i-1} lies between the upper and the lower flow volume bounds, then groundwater storage does not affect the following year fieshet, and no adjusment is necessary to the following year measured freshet flow volume.

After the necessary adjustments for groundwater contribution, the SOI averaged over the six months period of April to September for each year was correlated to the spring freshet flow volume of the following year. Correlation coefficient values for selected sites are given in Table 7. The results of this analysis showed that there is about 2% to 4% higher correlation between SOI and following year freshet flow, when groundwater storage is taken into consideration. Higher improvement of correlation coefficients is observed for flows with larger basin areas, which would definitely have higher storage capacity.

Table 7: Correlation between April to September Mean SOI and Following Year May to June Stream Flows with Groundwater Storage Consideration.

Station Name & Number	Record Length	Elevation at Station (m)	Basin Area (km^2)	Correlation Coefficient without storage	Correlation Coefficient with storage effect
Camp Creek at mouth near Thirsk, Station No. 08NM134	30	1005	33.9	0.556	0.559
Vaseux Creek above Terrace Creek, Station No. 08NM171	24	1100	117	0.320	0.348
Two Forty Creek near Penticton, . Station No. 08NM240	11	1630	5	0.607	0.637
Tulameen River Neat Penticton, Station No. 08NL024	44	640	1760	0.437	0.462
Mission Creek near East Kelowna, Station No. 08NM116	28	427	811	0.556	0.573
Okanagan Lake, Net Inflow	65		6090	0.355	0.401

The final column of Table 7 shows that correlations are medium to very good. In particular there is a medium correlation for the Okanagan basin itself In view of the contribution of rain events during June in particular to the Okanagan river flows, the correlation is surprisingly good. Scatter plots of the average stream flow for the months of May and June adjusted for storage contribution versus the average April to September Southern Oscillation Index are given in Figure 8 for the Okanagan and Tulameen basins.

8.4 Use of Southern Oscillation Index to assist Forecasting

The relationship between the snowmelt component of stream flows and the Southern Oscillation Index was found apparent in our analysis. The significant correlation coefficient between the six month average (April to September) SOI, and the volume of flows in the two Spring months of the following year will enable a rough forecasting method to be developed for the expected volume of the spring freshet. Although this is likely to be most useful in predicting the snow melt component of the flow, and this component is less than 50% of the spring runoff in some years, we believe the procedure will be extremely useful.

We expect that the use of SOI data for approximate prediction will be used with other tools, such as snow pack developing during winter months, to refine present capabilities for forecasting.

For example advance knowledge of a below average snow pack year ahead would enable the Water Management Branch staff (who are responsible for controlling the lake levels) to feel confident about going into a Fall season with relatively high water levels in Lake, and confident that massive lowering of the lake during mid winter would not be needed.

Several months of advance notice about approximate snow pack will allow adjustments to be made to lake levels starting as early as the first week of September. These water level adjustments, made ahead of the Fall spawning season, will help in the improved management of lake levels and water releases for the fish, fish spawning and incubation of eggs. These improvements will be of benefit both to lake and river spawning fish.

ACKNOWLEDGMENTS

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McBean, G.A. 1994. "Circulation Patterns for Streamflow and Temperature Predictions in Canadian Surface Climate". University of British Columbia, Department of Oceanography Report, for Canadian Electrical Association, Report No. 9206G931

FIGURES

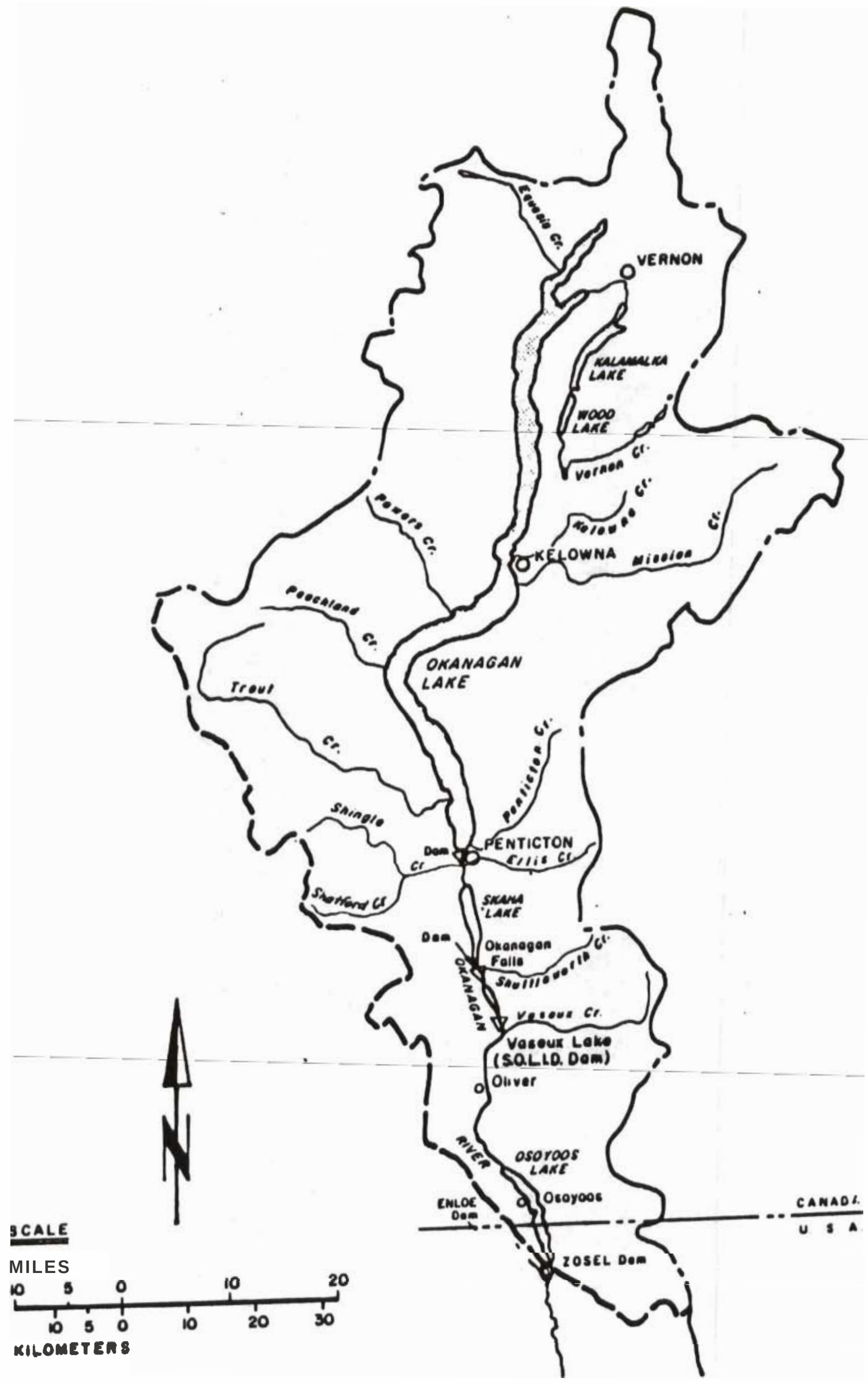


FIGURE 1: THE OKANAGAN BASIN

FIGURE 2: HISTORICAL WATER LEVELS AT PENTICTON

OKANAGAN LAKE TARGET WATER SURFACE LEVELS AND SILL ELEVATIONS

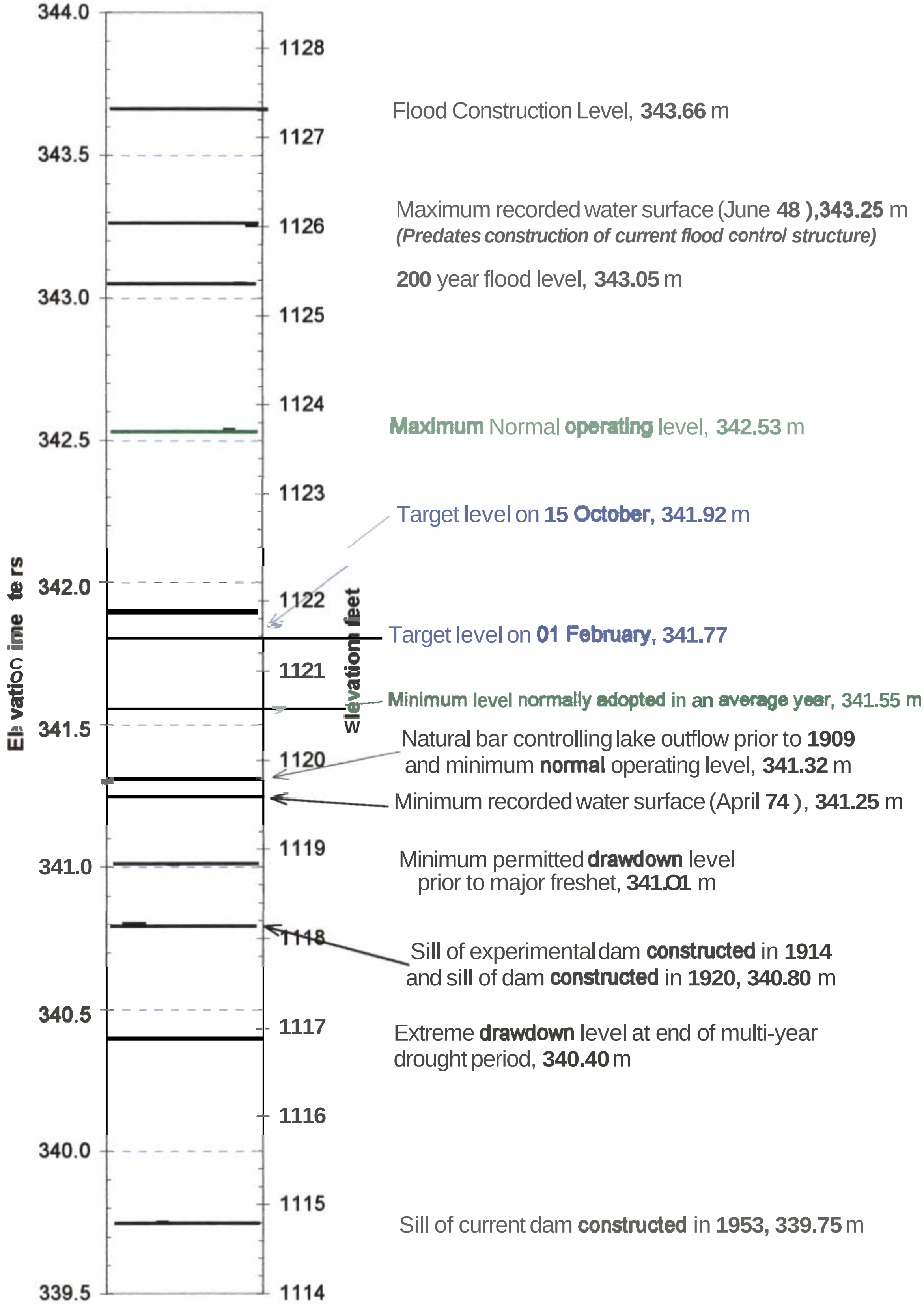
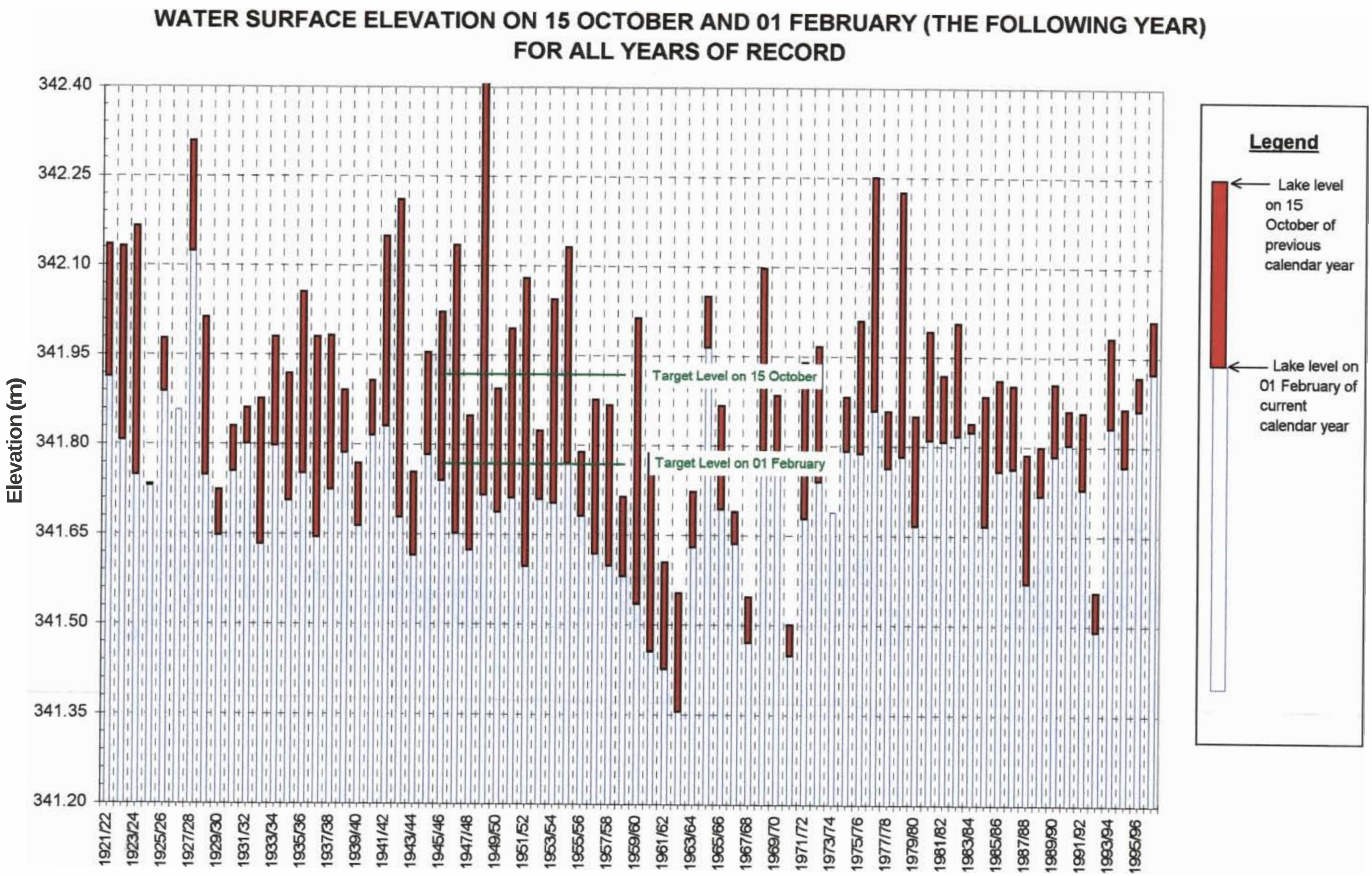
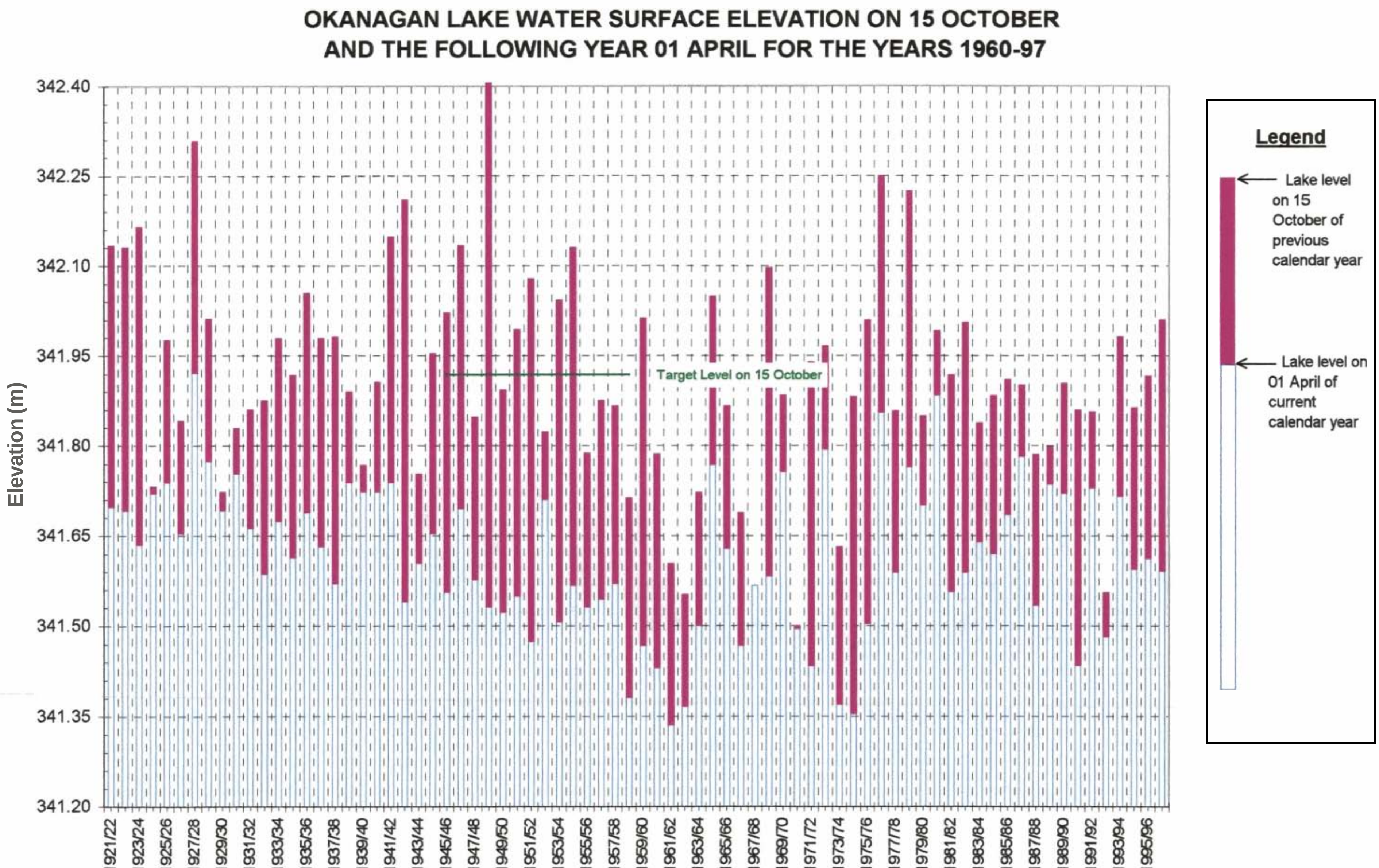


FIGURE 3



Figures99.xls: Figure 4

FIGURE 4



Figures99.xls: Figure 5

FIGURE 5

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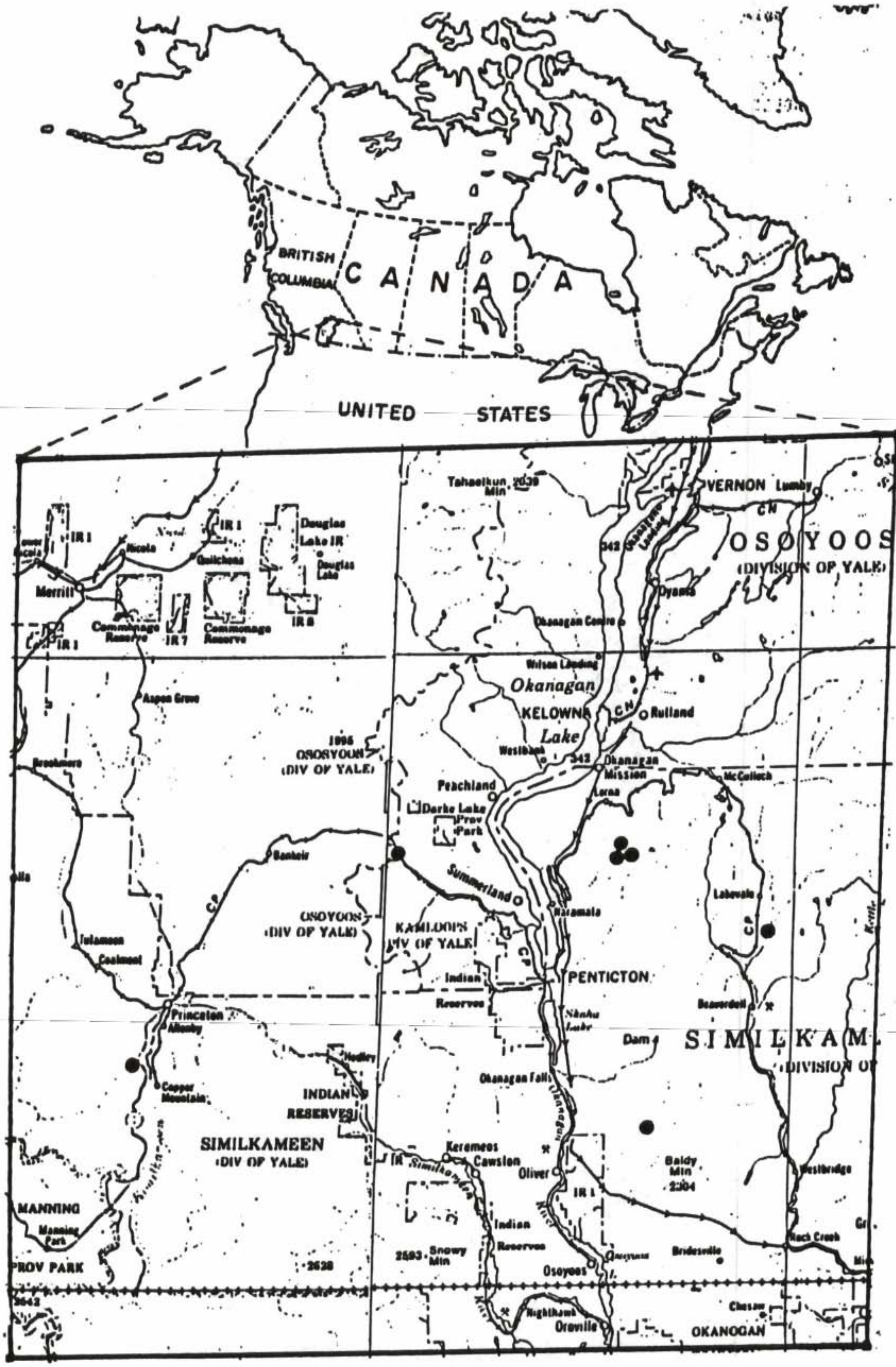


FIGURE 6. LOCATION MAP OF GAUGING STATIONS USED IN CORRELATION ANALYSIS BETWEEN SOI AND STREAM FLOW.

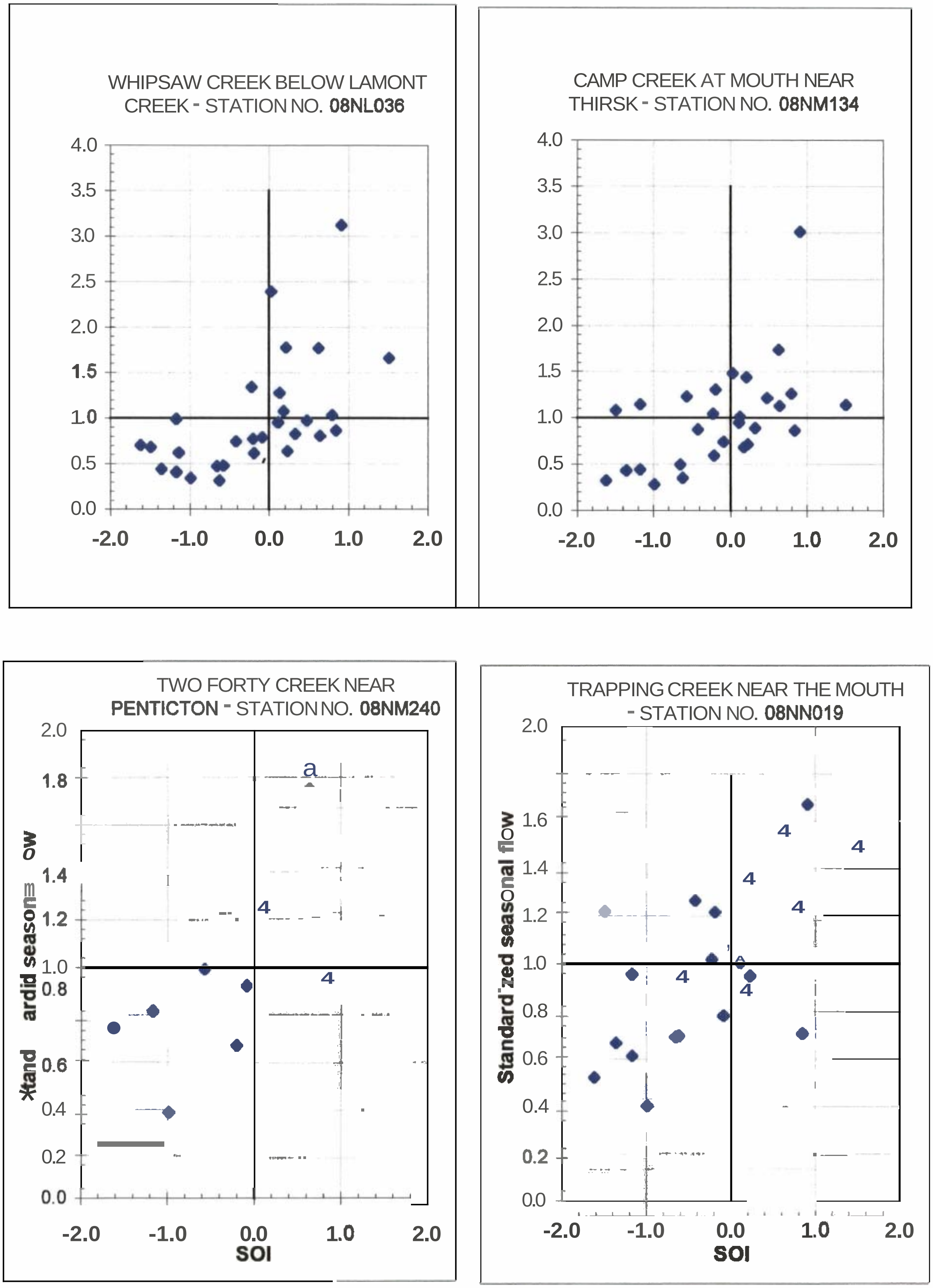
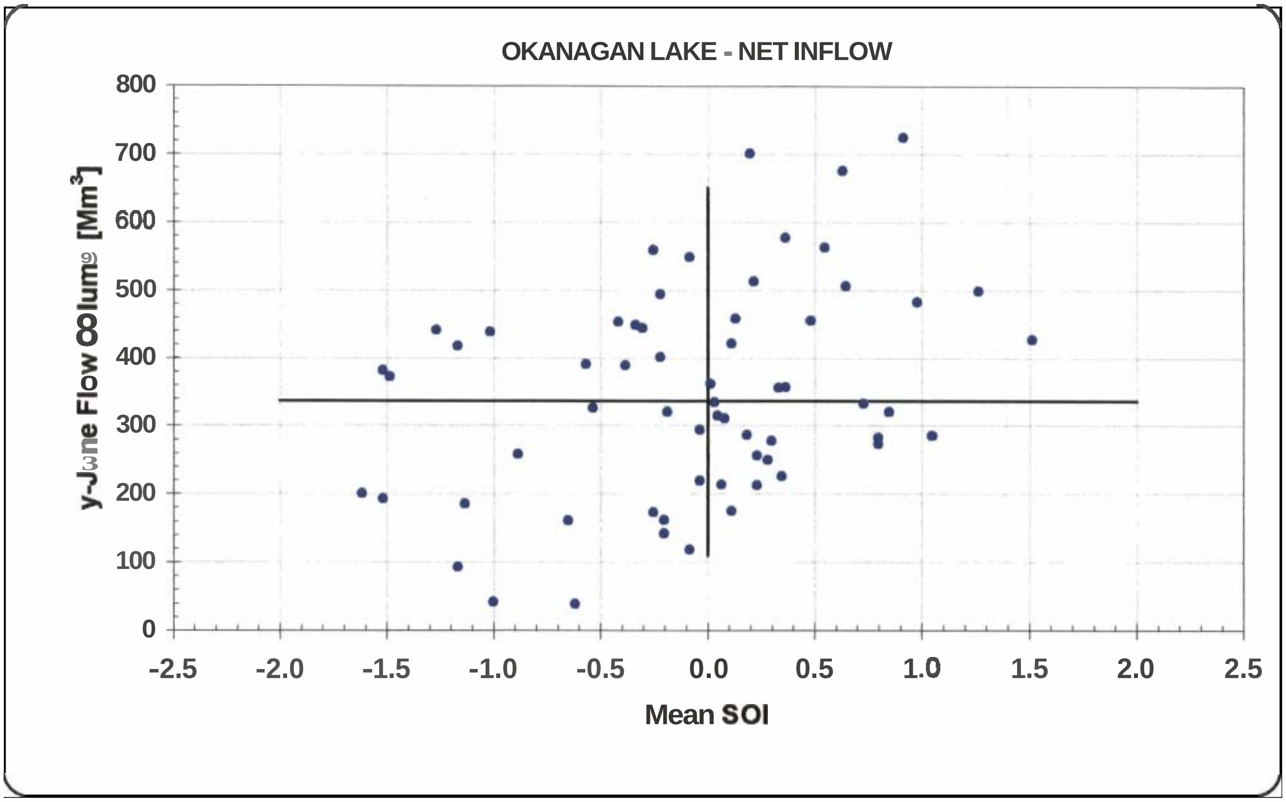


FIGURE 7: SNOW MELT RUNOFF CORRELATION, SELECTED BASINS

APRIL-SEPTEMBER SOUTHERN OSCILLATION INDEX AND FOLLOWING YEAR VALUES FOR MAY/JUNE FLOWS



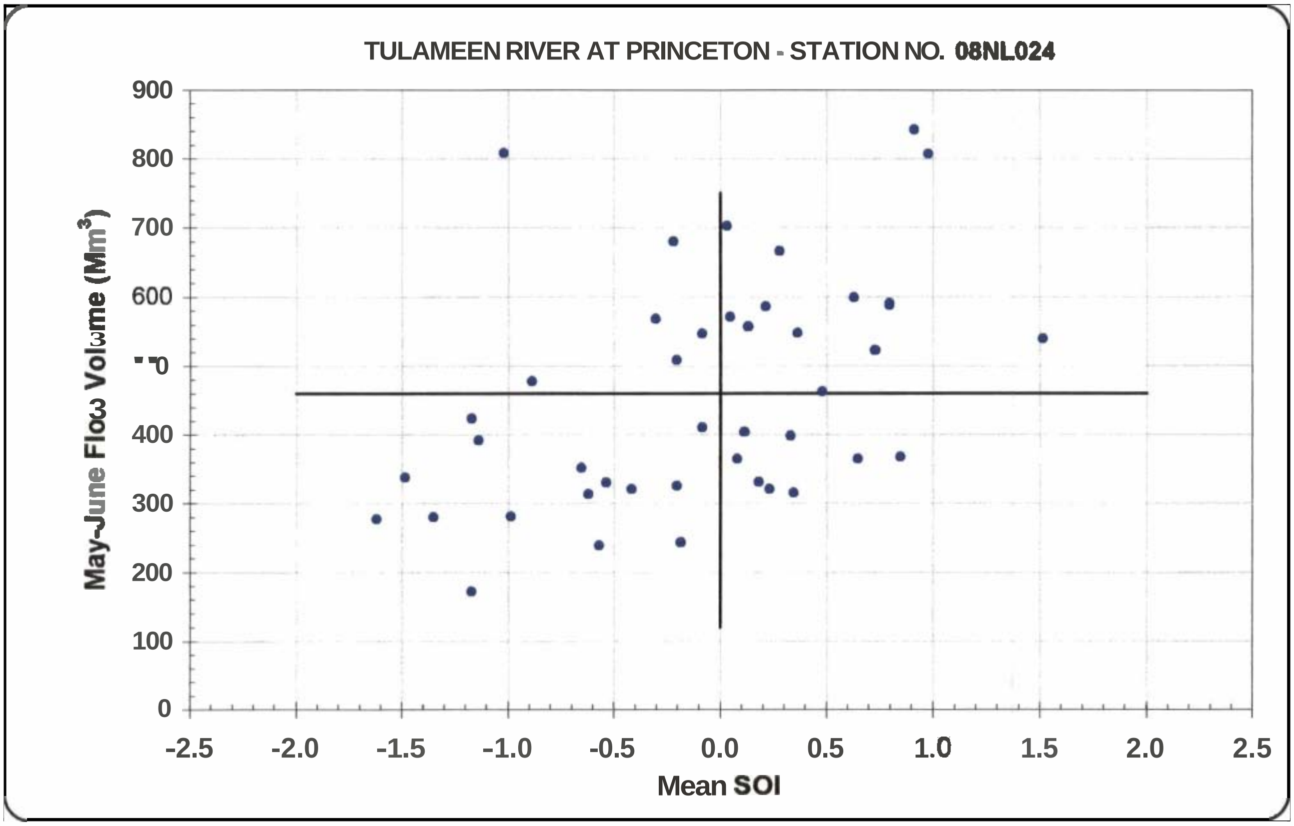


FIGURE 8: SNOW MELT RUNOFF CORRELATION, OKANAGAN AND TULAMEEN BASINS

APRIL-SEPTEMBER SOI AND FOLLOWING YEAR VALUES FOR MAY/JUNE FLOWS ADJUSTED FOR STORAGE

APPENDIX A

Hydrological Data
Okanagan Lake

MEAN ANNUAL FLOWS AT OKANAGAN RIVER AT PENTICTION

STATION NO. 08NM050

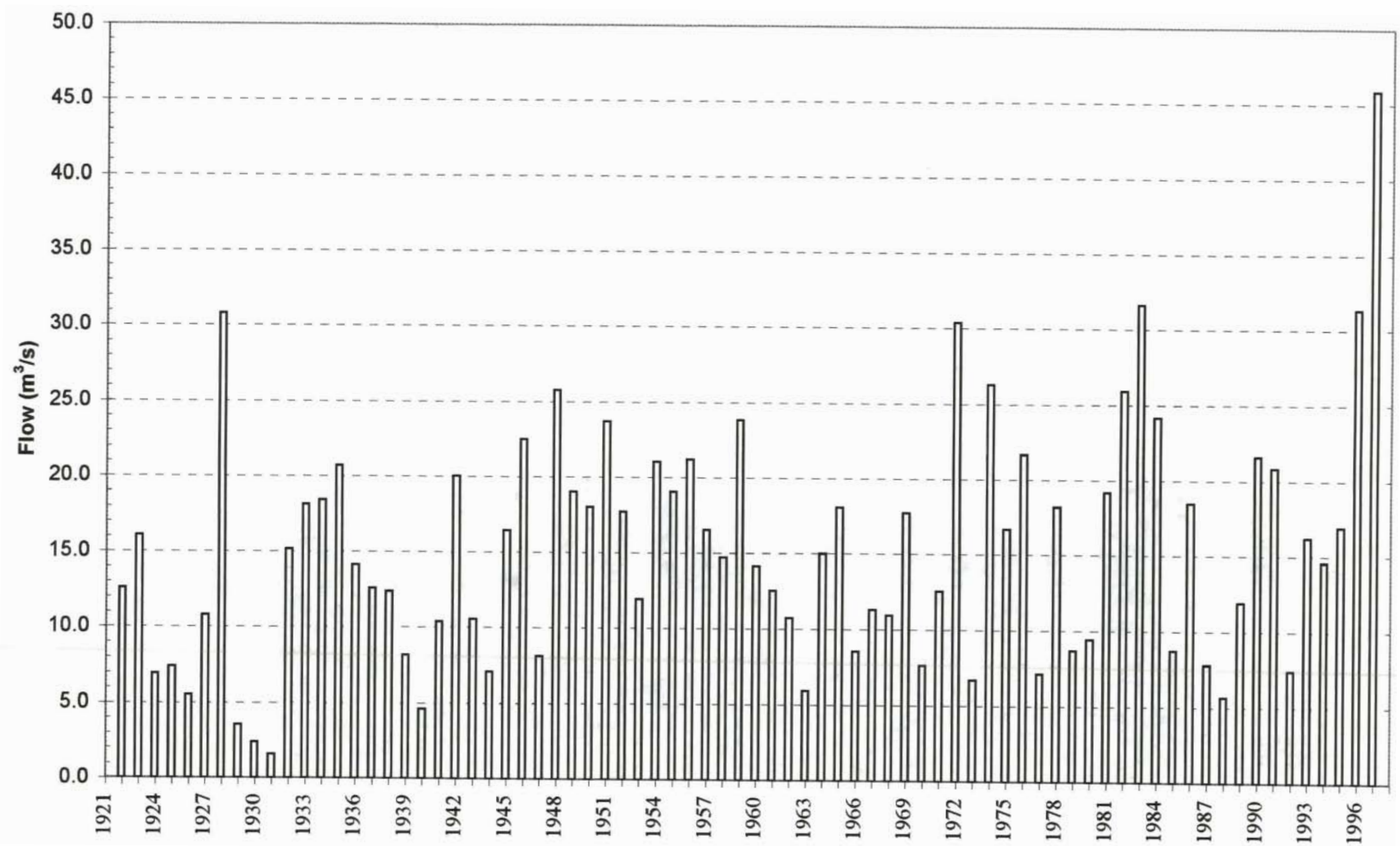


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FIGURE A1

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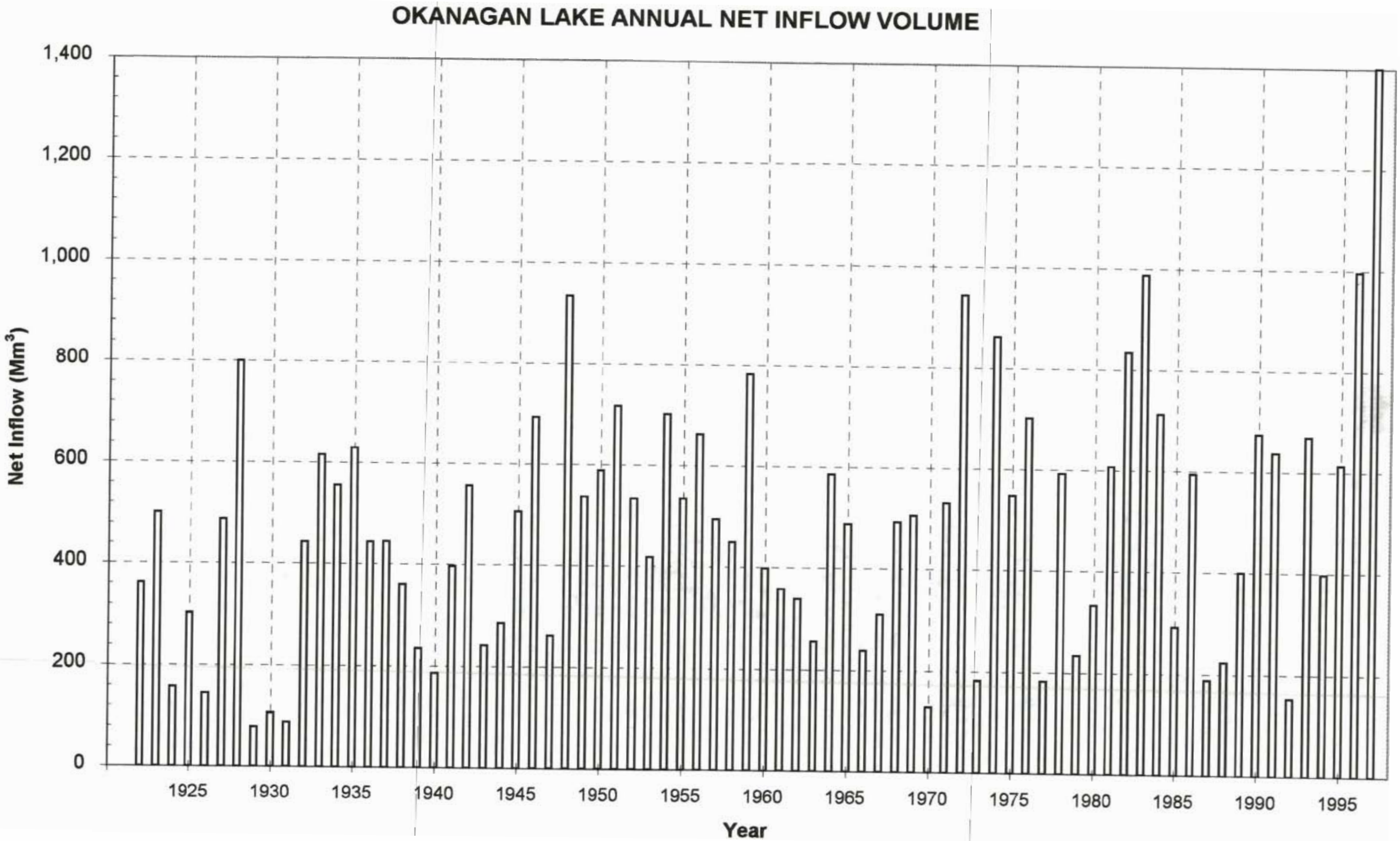

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FIGURE A2

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OKANAGAN LAKE HISTORICAL WATER SURFACE LEVELS

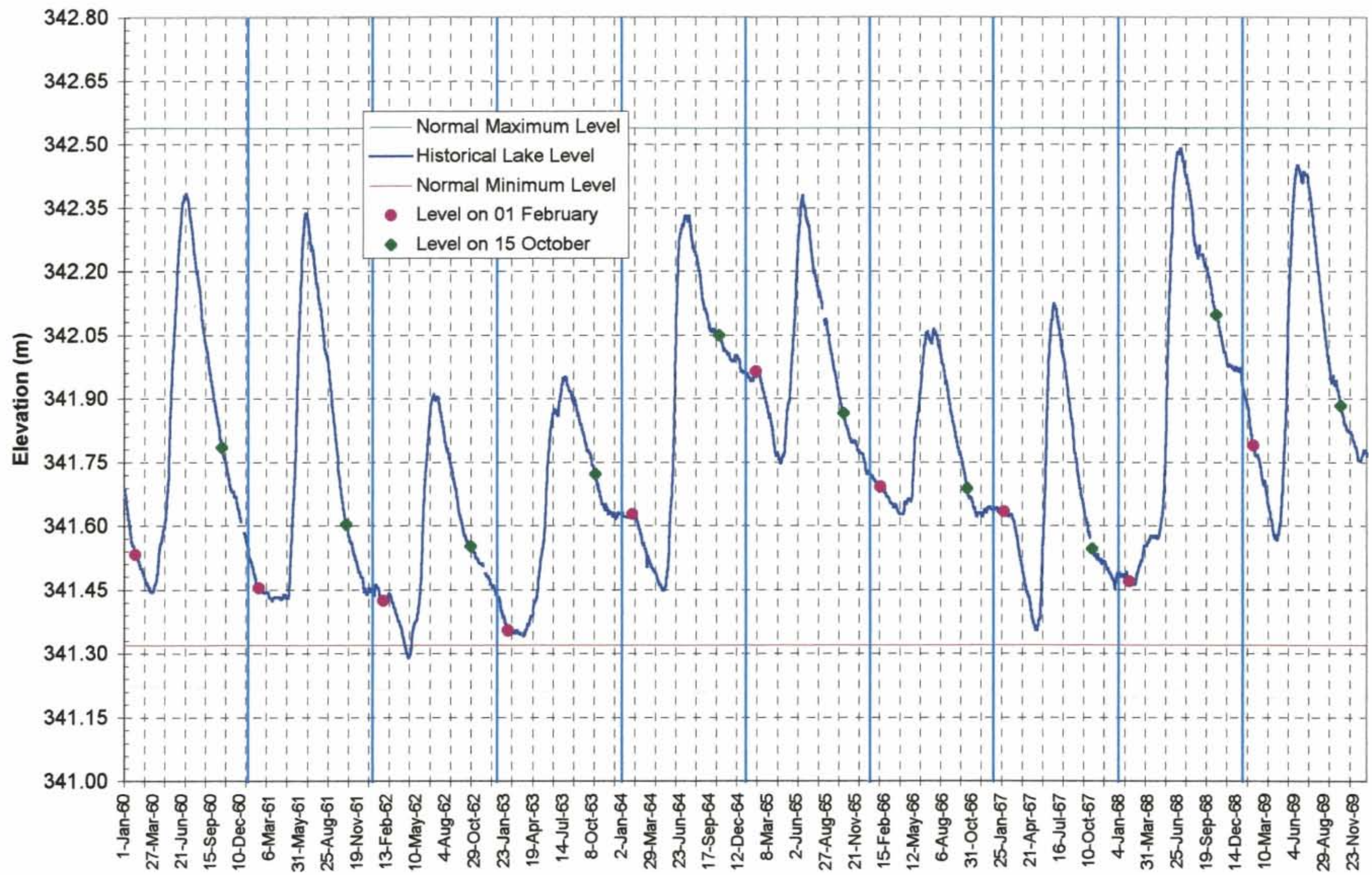

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FIGURE A3 (1 OF 4)

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OKANAGAN LAKE HISTORICAL WATER SURFACE LEVELS

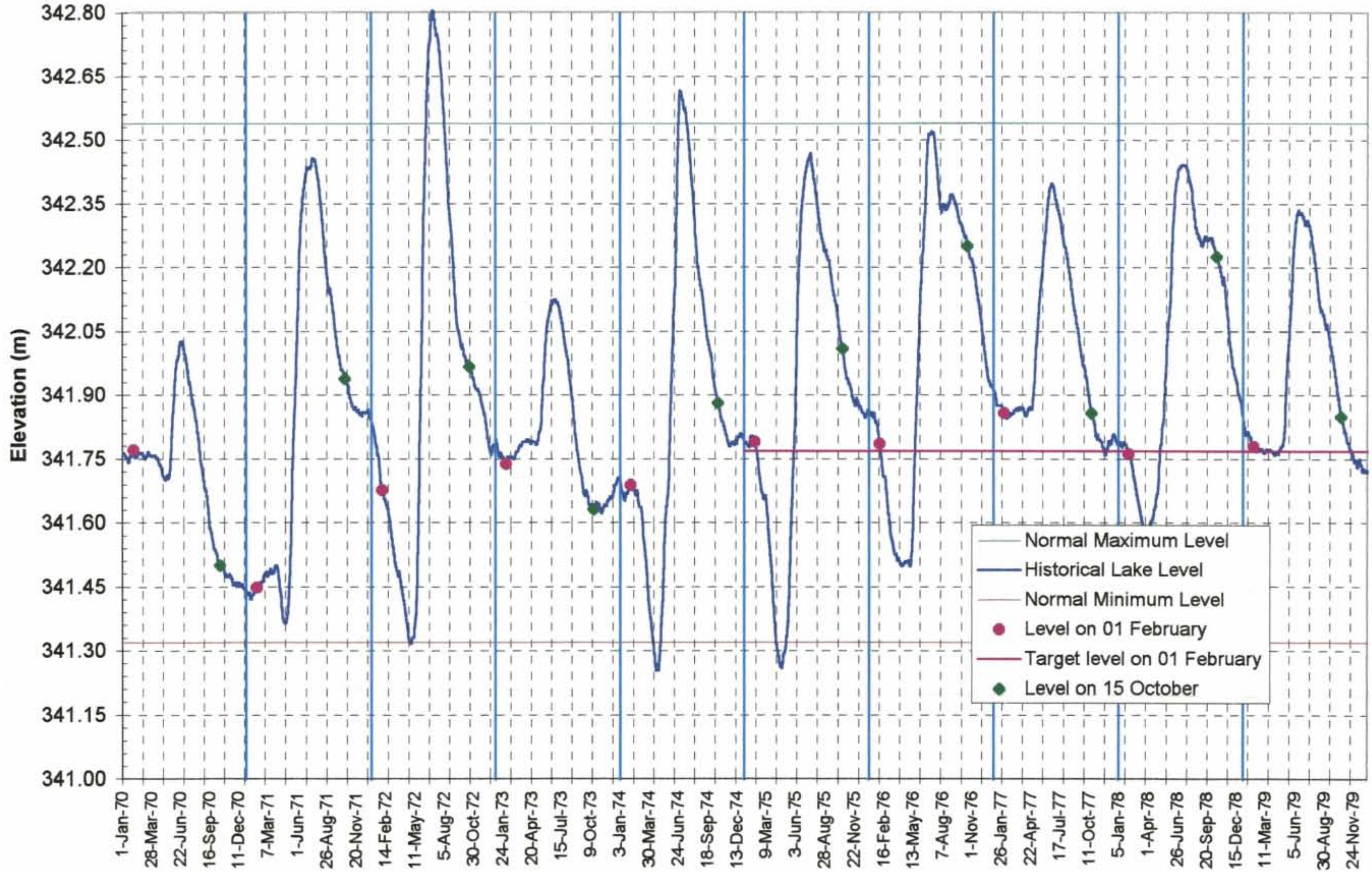

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FIGURE A3 (2 OF 4)

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OKANAGAN LAKE HISTORICAL WATER SURFACE LEVELS

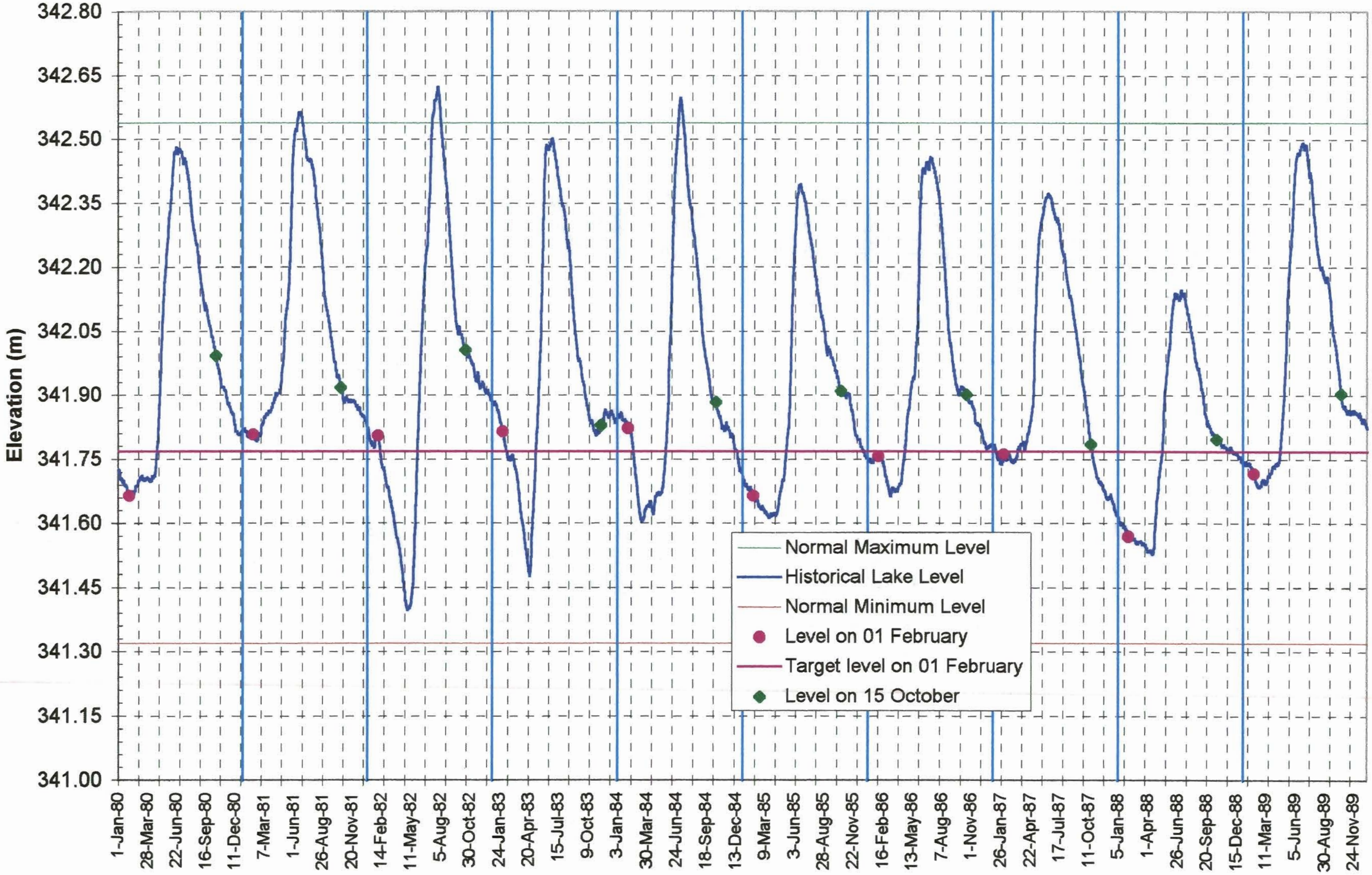

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FIGURE A3 (3 OF 4)

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OKANAGAN LAKE HISTORICAL WATER SURFACE LEVELS

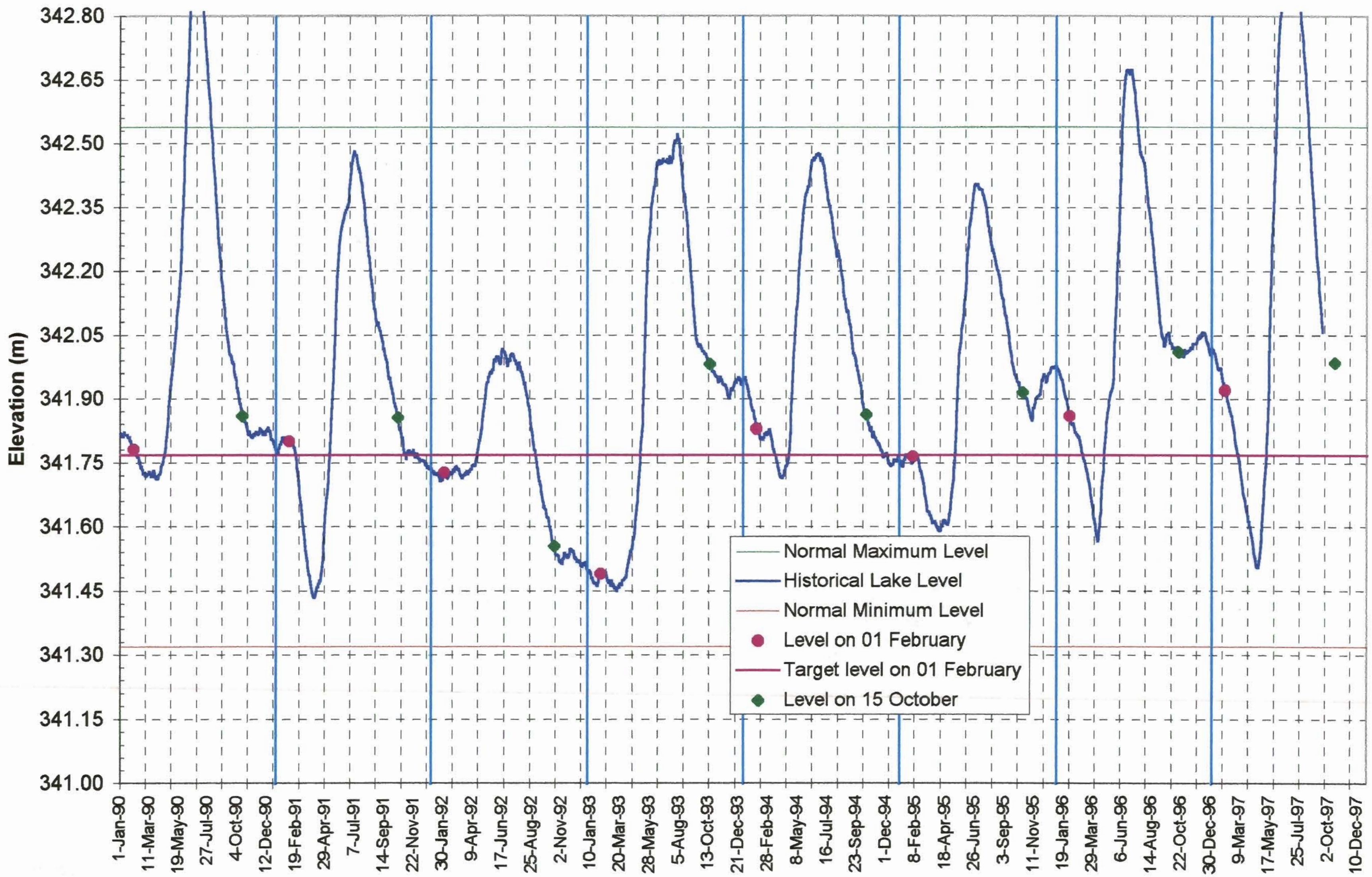

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FIGURE A3 (4 OF 4)

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APPENDIX B

Historical Air Photos
Okanagan Lake at the Outlet

1938 Photo
Approximate scale 1:15,000

1955 Photo

Approximate scale 1:5,000

1977 Photo
Approximate scale 1:12,000

1996 Photo
Approximate scale 1:15,000