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Impacts of Regulating Okanagan Lake Water Levels on Shore Spawning Kokanee Stocks

by

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A Brief History of Water Level Regulation Activities

The following information was extracted primarily from Volume I of the 1946 Report of the Joint Board of Engineers on Okanagan flood control, and "Water Quantity in the Okanagan Basin," Technical Supplement I to the Final Report Series for the Canada - British Columbia Okanagan Basin Agreement, dated 1974:

- Prior to 1909, no "improvement" work had been done on the Okanagan River, and a natural bar controlling the minimum level of Okanagan Lake was surveyed at 98.6 ft (equivalent to an elevation of 341,3 m ASL).
- Dredging in April-May of 1912 (for navigational purposes) lowered the natural sill by an unknown amount.
- No official water level records exist for Okanagan Lake prior to 1910, although flood levels in Kelowna were estimated to reach 107.0 ft (343.8 m ASL) in 1904, and higher than that in both 1894 and 1896.
- An "experimental" control dam was constructed at the outlet during December-March of 1914-15. The sill of this dam was established at 97.0 ft (340.8 m ASL) and the top of the dam was at 101.0 ft (342.0 m ASL). Although there were reports of the dam being ineffective at controlling water levels, the conclusion of an engineering report was that it did have an effect on water levels; Sicamous (Shuswap) and Kamloops lakes were noted as being one foot lower than Okanagan in the study year.
- A second control dam, with sill and top elevations of 97.0 ft and 102.0 ft (340.8 and 342.3 m ASL respectively) was constructed January-October of 1920; additional work was done in 1922 to increase the top elevation to 102.6 ft (342.5 m ASL).
- It was estimated in the 1946 report that, in aggregate, existing storage sites on Okanagan Lake tributaries decreased high water levels only by 0.2-0.3 ft (0.1 m).
- The second dam was replaced by the present control structure in 1953. Sill and breastwall elevations were set at 339.75 and 343.93 m ASL respectively, and the

structure was designed for a normal operating range of 341.31-342.53 m ASL. These limits have been exceeded during prolonged droughts (the lowest specified drawdown in the Okanagan River Operations Manual is 340.40 m ASL) and during major floods (the 1-in-200-year flood construction level is specified as 343.66 m ASL; the maximums experienced to date are 343.25 m ASL in 1948, 342.94 m ASL in 1990 and 342.80 m ASL in 1972).

Overview of Water Level Patterns

The following material was summarized from the 1946 report mentioned earlier, plus the Historical Streamflow and Historical Water Levels Summaries of the Water Survey of Canada, and BC Environment’s data records of water levels and flows for the Okanagan Lake Regulation System held in the Penticton Office (see also summary in Appendix 1):

Type of Regulation (Yrs)	Minimum[a]	Maximum[a]	Variation (Average)
Pre-Control (1909-14)[b]	99.35-100.0’	101.50-103.80’	1.8-3.5-4.1’ (3.1’)
Expt’l Control (1915-20)[b]	98.75-99.50’	101.35-102.10’	1.85-3.10’ (2.6’)
Second Dam (1921)	100.7’	103.6’	2.9’
1921 Agreement Range	99.5’	102.5’	3.0’
Current Operating Range	99.1’	103.1’	4.0’

[a] Public Works of Canada datum of 100.0’ set from March 1909 low-water point; conversions used here are 100.0’ PWC = 1120.70’ ASL = 341.7 m ASL

[b] Water level records for 1910-15 are incomplete

- The current Operating Plan for the Okanagan Lake Regulation System (Appendix 2) is more restrictive than shown in the above table; for example, the routine minimum target has actually been held at 341.5 m, or 99.94’ over the last two decades (B. Symonds, Wat. Mgmt. Progr. Eng. Sect., pers comm), versus the 99.1’ that is possible.
- Ranges in the annual water level regime have been altered slightly overall, with the emphasis on reducing flood levels; routine minimums may fall 0.25 ft (0.1 m) lower than historically, and the maximum post-control floods experienced to date have been 1-2 ft (0.3-0.6 m) lower than those seen in the pre-control years.
- With regard to possible changes in the pattern of water level fluctuations, comparison of the regulated Okanagan Lake pattern with those for adjacent natural-flow lakes (Figure 1 and Appendix 3) indicates that Okanagan is shifted 1-2 months later in the season, but that the rate of decline is similar.
- Also with regard to Figure 1, it is of interest to note that Christina Lake, which supports a population of relatively late-timing (ie, November-January) shore-spawning kokanee, has a pattern of <u>increasing</u> water level through the spawning and incubation period, whereas there is a <u>decreasing</u> water level pattern for the October-spawning Okanagan kokanee shore spawners. BCE Water (Penticton) and WSC (Nelson) personnel had no explanation for Christina’s unusual pattern.

- The earliest water level records are from the Penticton station, but Kelowna became the primary station in 1975. This potentially could have create problems in comparing early with more recent records, but review of all available data for both stations (Figure 2) indicates that the records are similar enough to allow direct comparison.
- Initial comparison of the long-term Penticton/Kelowna water level records with the earliest available data, taken during the "experimental control" period (refer to "Penticton 1918-20" on Figure 2, see also Appendix 4) would suggest that post-control levels were higher through most of the year. However, review of the 1915-88 streamflow summary record for Okanagan River at Okanagan Falls (this is the only hydrometric station that covers the entire period in question) indicates that the years of 1918-20 were only 51-77% of the long-term mean (Appendix 5). BCE Water Engineering staff felt that the 4 CMS difference between the 1918-20 annual records and the overall mean would roughly translate into the 0.3 m (1 ft) difference in water levels seen in Figure 2 (B. Symonds, Wat. Mgmt. Progr. Eng. Sect., pers comm).
- Comparing the 1918-20 levels with those for a similar low-flow period in 1943-44 (49-73% of the mean; see Appendix 5) results in somewhat closer agreement between curves (see also Figure 2). While post-control water levels are still slightly higher for August through January, this is probably within the limits of recording accuracy, and also could have been the result of inflow differences between periods.
- It therefore is concluded that the seasonal water-level pattern has not changed dramatically. The most obvious difference is a one-month delay in the hydrograph pattern; there has been a shift from June to July as the maximum-height month, with water levels falling at similar rates thereafter (refer to Figure 2). This potentially could expose kokanee eggs to an additional 0.1 m drop in water level over the incubation period in an average year.

Overview of Kokanee Shore Spawning

- Both shore- and stream-spawning kokanee stocks in Okanagan Lake have suffered major declines since the 1970s (Figure 3). The declines are probably even more severe than indicated in Figure 3, judging from anecdotal reports from pioneer days, when a winter's supply of fish could be easily obtained using just a garden rake!
- While the introduction of opossum shrimp, *Mysis relicta*, is hypothesized to be the driving force behind the simultaneous drop in abundance of both races of kokanee, other factors may be aggravating the situation. For stream spawners, reduction of instream flows and habitats are concerns. While low instream flows would not be an issue for shore spawners, drops in lake water levels during incubation could be.
- Okanagan Lake shore-spawning kokanee have some unique behavioral and biological features, both in comparison to the lake's stream-spawning kokanee stocks (see Table 1) as well as for Pacific salmon populations more generally.
- This stock of shore-spawning kokanee appears to spawn exclusively in water depths of less than 3 m, with water depths of 0.5 m or less preferred (Halsey and Lea 1973).

- These observations agree with those of Dill (pers comm) at Bertram Creek Park. During his 1996 spawning studies, he estimated that 42% of the adults were observed in water depths of 0.5 m or less, and 50% in the 0.5 - 1.0 m depth range; the fish tended to cluster near the 0.5 m mark. Comparing the 1996 spawner distribution to those in previous higher-return years, he felt that the fish tended to stack out deeper when numbers were higher--ie, the preferred areas are in the shallows.
- Surveys of kokanee embryo distribution with water depth (see Figure 4A) reflect the spawners' preference for the shallows. Using water depths corrected back to the approximate date of peak spawning (Nov 01), approximately half of the eggs were found in water depths of 30 cm or less.
- Presumably this behavior confers some survival advantages, possibly related to the reluctance of larger piscine predators to enter shallow waters in pursuit of either adults or eggs.
- The depth at which the eggs lodge in the substrate also has to be considered. In the 1981 surveys, eggs are found up to 20 cm deep in the substrate, and alevins up to 30 cm deep (Harris MS 1984). More recently, Dill (1997) found the majority of embryos at substrate depths of 15-20 cm, and predicted optimal incubation conditions at about 15-30 cm. Addition of these "burial" depths results in a greater total wetted depth than would be indicated from the water depths alone. This may provide some additional flexibility in the ability of the embryos to survive dewatering in the shallows IF they are able to migrate laterally after hatch. Thus drops of 15-20 cm in water level may be tolerated by pre-emergent embryos without major mortality.
- Matthews and Bull (1981) found evidence of lateral migration, but Dill (1996) found that significant numbers of fry were stranded and perished at the Bertram site in the spring of 1996; many of these fry were trapped in sand deposits, and they also were found to be quite inactive at the unusually low ambient water temperatures (3° C).
- The 1995-96 water levels were higher than the means for November through March, and actually increased in December (Figures 2 and 5). This should have resulted in relatively good survival of embryos from the 1995 kokanee brood year. Unfortunately, the March-April period was unusually cold, which probably delayed the development and emergence of kokanee fry. Thus when water levels were lowered in Mar-Apr to prepare for spring freshet inflows, up to 25% of the kokanee were estimated to have perished at the Bertram site (Dill 1996)..
- Spawning normally occurs considerably later along the shore than in the streams, usually starting after mid-October and peaking about Nov 01. Shore spawning can be over within a single week, although there seems to be some geographic variation to its start (B Jantz, pers comm): often, spawning appears to start a week earlier at the south end of the lake (ie, Squally Point to Bertram Creek Park). Dill (1996) found spawner timing at the Bertram site to vary between years, ranging from Oct 11-Nov 09 overall for the 1993-95 period, and peaks of Nov 02, Oct 18 and Oct 26 respectively. Hatching dates found in past studies (Table 1) range from Jan 06 to Mar 15 for shore-spawning stocks. Matthews and Bull (1981) found that hatching was complete by Feb 19 (Figure 4B).

- Incubation continues in the substrate until emergence in the spring. Estimated emergence dates have ranged Mar 15-Apr 15 (Table 1). Matthews and Bull (1981) estimated that fry would not be fully "buttoned" and thus ready to emerge until early April. More recently, Dill (1996) trapped emerging fry at the Bertram site over the Mar 02-Apr 09 (mean date of March 18) but considered these fry to be emerging prematurely, based on the stage of development observed.
- Development during incubation is driven primarily by water temperatures. Past studies (Table 1) indicated shore-spawning kokanee hatch at 616 (range 550-691) ATU and emerge at 880 (range 750-903) ATU, and Dill (1996) also determined a mean emergence-date value of 880 ATU.
- Using the hatching start-peak-end "milestone" values of 550 616 and 691 ATU, a peak spawning date of Nov 01 and 1995-97 temperature data collected to date by Dr. Dill, it is estimated that hatching would have started Feb 08, peaked Mar 04 and ended Mar 25 for the 1995 brood; up to Jan 26 of 1997, 200 fewer ATU had been accumulated by the 1996 brood, which makes it unlikely that hatching would even begin until after mid-February. If water levels are dropped more than 15 cm prior to hatch, there is likely to be significant mortality.
- However, it should be noted that ATU "milestone" hatch and emergence values will vary with the temperature regime experienced by the embryo; in general, a colder temperature regime should result in hatch and emergence at lower ATU values.
- Dill's 1996 results were checked using sockeye parameter values in the Belehradec Model:

$$10558897.426 / (\text{mean C} + 23.82619)^{3.25602}$$

(see Shepherd and Inkster 1995 for details on this calculation technique)

- Using a mean 1995-96 incubation temperature of 5.4° C provided by Dill (1996) in the above equation gives an estimate of 178 days to achieve emergence, which converts to 961 ATU and a predicted emergence date of Apr 12. Iteration using this longer averaging period results in the emergence date being delayed past the middle of April. While this would tend reinforce Dill's conclusion that fry had emerged prematurely in the spring of 1996, it also calls into question the validity of using sockeye parameters for the shore-spawning kokanee (but it has worked well for other stream-spawning kokanee stocks).
- As mentioned earlier, the 1996-97 water temperature data (Dill, pers comm) show fewer ATU accumulated to date than in 1995-96. Going strictly by ATU milestones, Dill projects that emergence could be delayed by at least one month in 1997 if these lower temperatures continue. Using a value of 4° C in the Belehradec equation gives an estimate of 209 days, converting to 836 ATU and a projected emergence date that stretches into May! Obviously, there will be major mortality if this scenario becomes reality.

Kokanee Brood Year Returns Compared to Water Levels During Incubation

- Kokanee shore spawner escapement numbers were compared to the water levels recorded during incubation for each brood from 1977 to 1995 (Table 2).
- To examine if drops in water levels during the pre-hatch and pre-emergence stages had an effect on returns, the minimum water levels recorded up to January 31 (covering the pre-hatch period), to February 28 (probable 100% hatch date in a normal year), and up to March 31 (probable 100% swim-up date) were subtracted from the maximum water level recorded in the latter half of October (ie, during the peak spawning period). In most years--1996 being an exception--the annual low occurred during March, and then water levels began to rise.
- These analyses (see Figures 6A-C) indicated little relationship between brood returns and drops in water level. If anything, the analyses indicate the opposite of expected; that is, greater drops in water levels appeared to produce larger returns. A more likely explanation is that the reduced drops in incubation water levels implemented over the last decade coincided with kokanee declines driven by another cause (eg, *Mysis*).
- This does not imply that water level fluctuations are not resulting in increased mortality of kokanee embryos. It is probable that the fluctuations are routinely contributing to the mortality rate, and their reduction could help to offset the high mortality currently endured by the kokanee stocks, even if driven by other causes.
- Additional analyses using a stock-recruitment index (the number of "progeny" spawning in a given year, divided by the number of "parent" spawners seen three years earlier--see Figures 7A-C) did not improve the relationship markedly for any of the three periods. But it was noted that, save for one year (1981), replacement-level recruitment (ie, $\geq$ 1.0 progeny/parent) occurred only in those years where drops in water level were < 28 cm to the end of March.
- Further examination of years showing unusually high ($\geq$ 2.5 progeny/parent) or low ($\leq$ 0.25 progeny/parent) recruitment[1] did show some trends. While there was no obvious relationship with regard to the dates that water level minima were reached (Table 3), a pattern was noted with regard to drops in water level during the latter stages of incubation (Figure 8).
- Initial drops in water level between October and January were not statistically different between high- and low-recruitment years, but high variability probably masks the picture (Figure 8). Post-January drops in water level tended to be greater in low-recruitment years, and the difference is definitely statistically significant for the March period. These results would indicate that drops in water level even during the latter stages of incubation could impact recruitment success.
- Looking at the daily water level patterns for the high- and low-recruitment extremes (n = 3 for each group; see Figure 9), there was an unusually large drop in level during the latter part of the 1991/92 incubation year, which could account for the poor

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[1] While the accuracy of the shore-spawning visual estimation technique is uncertain, visual counts for stream-spawning salmon stocks have been shown in a number of earlier studies (see the reviews of Cousens *et al,* 1982 and Shardlow *et al,* 1987) to have an error rate in the order of 50-100%; thus only returns in excess of this range were selected.for this analysis.

recruitment of that brood. In the other two low-recruitment years examined in Figure 9, water level drops during the early phases of incubation were faster than in any of the high-recruitment years, save for the 1987/88 brood.

- Focusing in on water level patterns during the Nov 01-Apr 15 incubation period for all 10 broods with recruitment rates of <0.25 and >2.5 progeny/parent, no consistent differences were apparent (Figure 10).
- It is uncertain why the 1987/88 brood did so well despite large drops in water level during the incubation period; it cannot be attributed to poor spawner estimates, as observation conditions in both the parent and progeny years were considered good (B. Jantz, Okanagan Fish. Sect., pers comm). As mentioned previously, these results may be confounded by the presence of other factors affecting recruitment success, such as competition with *Mysis*.
- These results also may be confounded by interannual variation in the age composition of kokanee shore spawners (see Table 1). Although the returns are dominated in most years by Age 2+ spawners, up to 60% of the runs have been made up of Age 3+ fish in some years. The progeny/parent calculation procedure should be adjusted to account for this variation, but unfortunately the data are too scanty to draw any firm conclusions from such an exercise:

Year	Age 2+	Age 3+	Progeny/Parent*
1989	40.4%	59.6%	10.35
1990	64.2%	35.8%	0.22
1991	98.0%	2.0%	0.13
1992	97.8%	2.2%	0.14
1993	97.8%	2.2%	0.56
1994	100.0%	0.0%	1.40
OVERALL	78.4%	21.6%	*(Taken from Table 3)

While the large number of Age 3+ shore spawners seen in 1989 would help to explain that year's second-highest recruitment rate on record , 1990 had the fifth lowest recruitment despite the presence of significant numbers of Age 3+ fish.

The Feasibility of Seasonal Manipulation of Okanagan Lake Water Levels

- Various physical constraints with the Okanagan Lake Regulation System dictate that water must be released well in advance of the spring freshet period, in order to prevent general flooding as well as damage to control structures. Thus a rapid post-emergence drawdown is not feasible.

- While dropping Okanagan Lake water levels prior to the start of spawning and then stabilizing levels through the incubation period might benefit shore-spawning kokanee in Okanagan Lake, this could have detrimental effects on both sockeye and kokanee stocks spawning in Okanagan River above Osoyoos Lake.
- The Osoyoos Lake sockeye stock is one of just two viable naturally-spawning sockeye populations left in the entire Columbia River system, spawns under unusually warm conditions and thus may be genetically unique (Osoyoos Lake is reputed to produce the largest sockeye smolts in the world), and recent low escapements has prompted suggestions that the stock be nominated as a candidate under the US Federal Endangered Species Act.
- Since 1980, the Washington Department of Ecology and BCE have followed an informal international Cooperation Plan that, in part, defines Okanagan River flow regimes (see Appendix 2) for sockeye spawning and incubation purposes. These releases can only be met by storing water in Okanagan Lake during the fall, resulting in a Catch-22 situation that forces a choice between Okanagan Lake shore-spawning kokanee and Okanagan River sockeye/kokanee (very little is known about the latter kokanee stock, although spawners seem to be somewhat unique morphologically).
- However, when faced with high-water years such as have been experienced in the 1995-97 period, fisheries impacts would be reduced if more water was released just prior to kokanee and sockeye spawning in October, rather than during the February-March incubation period.

References

Cousens, N.B.F., G.A. Thomas, C.G. Swann, and M.C. Healey. 1982. A review of salmon escapement techniques. Can. Tech. Rept. Fish. Aquat. Sci. No. 1108.

Dill, P.A. 1996. A study of shore-spawning kokanee salmon (*Oncorhynchus nerka*) at Bertram Creek Park, Okanagan Lake, B.C., 1992 - 1996. Rept. prep. for BC Min. Env., Penticton, BC.

______. 1997. A study of shore-spawning kokanee salmon (*Oncorhynchus nerka*) at Bertram Creek Park, Okanagan Lake - fall, 1996. Rept. prep. for BC Min. Env., Penticton, BC.

Halsey, T.G., and B.N. Lea. 1974. The shore spawning habitat of kokanee in Okanagan Lake and the effect of lake level changes on reproductive success. Task 66E, Canada-British Columbia Okanagan Basin Agreement. BC Fish Wildl. Br., Fish Res. Sect., Univ. BC, Vancouver, BC.

Harper, W.L. MS 1985. Kokanee management plan for the Okanagan Main Valley Lakes (Draft). BC Env. Okanagan Sub-Reg. Fish. Tech. Rept. No. 2214. Penticton, BC.

Harris, B. MS 1984. Enhancement of kokanee shore spawning sites in Okanagan Lake, British Columbia. Memo report on File 40.3502, Min. Env,, Penticton, BC.

Matthews, S., and C.J. Bull. 1981. Effect of water level fluctuations on shore spawning kokanee in Okanagan Lake. BC Env., Okanagan Sub-Reg Fish. Sect. Tech. Rept. No. 2040, Penticton, BC.

Shardlow, T., R. Hilborn, and D. Lightly. 1987. Components analysis of instream escapement methods for Pacific salmon (*Oncorhynchus* spp.). Can J. Fish. Aquat. Sci. 44:1031-1037.

Shepherd, B.G. MS 1990. Okanagan Lake Management Plan 1990 - 1995 (Draft). BC Env., Okanagan Sub-Reg. Fish. Sect. Tech. Rept, Penticton, BC.

______., and G.A. Inkster. 1995. Sockeye and kokanee fry migration study, Okanagan River above Osoyoos Lake, 1994. BC Env. Okanagan Sub-Reg. Fish. Proj. Rept. No. OK-18, Penticton, BC.

Smith, D.R. 1978. A summary of existing data on Kokanee (O. nerka) in Okanagan Lake. BC Env. Okanagan Sub-Reg. Fish. Sect. Tech. Rept. No. 224. Penticton, BC.

Appendices

1. **Okanagan Lake Levels Summary**, undated memo by B.F. Alcock, Wat. Mgmt. Progr., inserted into Penticton, BC (1p).
2. **Okanagan Lake Regulation System Operating Plan**, taken from The Okanagan Lake Regulation System Operations Guide, Wat. Mgmt Progr., Penticton, BC (1p).
3. **Excerpts from BC Historical Water Levels Summary to 1990** (Inland Wat. Dir., Wat. Resour. Br., Wat. Surv. Can., Ottawa, 1992) for selected lakes in Okanagan area (10pp).
4. **Okanagan Lake water levels for 1918-20**, excerpted from Plate 30 of Vol II (Maps) of Report of the Joint Board of Engineers, Okanagan Flood Control, 1946 (2pp).
5. **Excerpts from BC Historical Streamflow Summary to 1988** (Inland Wat. Dir., Wat. Resour. Br., Wat. Surv. Can., Ottawa, 1992) for selected stations on Okanagan system (4pp).

TABLE 1 Comparison of selected characteristics of shore-spawning and stream-spawning kokanee in Okanagan Lake (from Shepherd MS 1990).

Characteristic	Shore Spawners	Stream Spawners	Comments (Source)
Spawning Date	peaks: Oct 25 - Oct 30* ranges: Oct 15 - Nov 04	Oct 01 - Oct 05 Sep 21 - Oct 20	Harper (MS 1985); File 40.3506)
Preferred Substrate	- angular riprap - size >5 cm	- rounded gravels - size <5 cm	Shepherd field observations, 1989
Spawning Behaviour	- no obvious pairing - little defence of redd - school when disturbed - 'bright' spent fish are common	- pairing - redds defended - hide in cover - spent are 'rags' & highly colored	Shepherd field observations, 1989
Nose - Fork Length (n)	250 ± 2 mm (100)	315 ± 8 mm (100) 389 ± 20 mm (100)	Mission - Oct 1987 Mission - Sep 1987
Spawner Age Composition	2+...40-90% 3+...10-60%	2+ 12-36% 3 - 5+...64-86%	Harper (MS 1985) &1989 samples
First-Year Circuli Counts	2+...12-16 3+...11-14	2+...10-13 3+...N/A	Limits ± 2 SE for 1989 samples
Fecundity	430 - 450 eggs**	700 - 1200 eggs** (750 avg.)	
ATU - hatch **(range)** **- emerge**	616 C-days (550-682) 880 C-days	660 C-days (627-693) 902-970 C-days	Under hatchery incubation conditions (Smith 1978)
Hatching Date	Jan 06 - Mar 15	Jan 01 - Apr 30	1989 shore incubator & Deep/Mission trapping results
Emergence Date	Mar 15 - Apr 15	Apr 01 - Jun 15	

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* Shore-spawning at south end peaks 1 week earlier than north end.

** Predicted from following length-fecundity equation developed from stream spawners ($n = 26$; $r_2 = 0.78$): Fecundity = 4.5 (Nosefork Length) - 685

FIGURE 1. OKANAGAN LAKE WATER LEVEL PATTERN COMPARED TO ADJACENT UNCONTROLLED LAKES

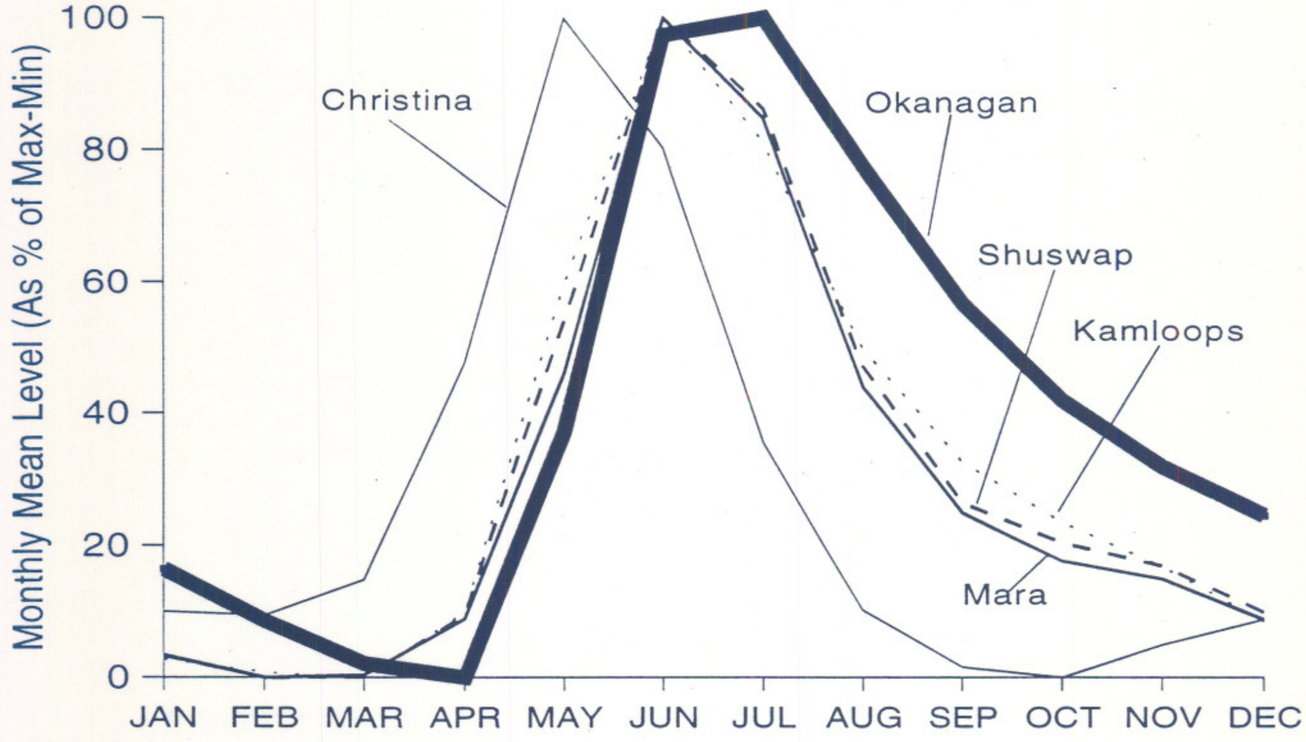


FIGURE 2. OKANAGAN LAKE WATER LEVELS STATIONS AND PERIODS COMPARED

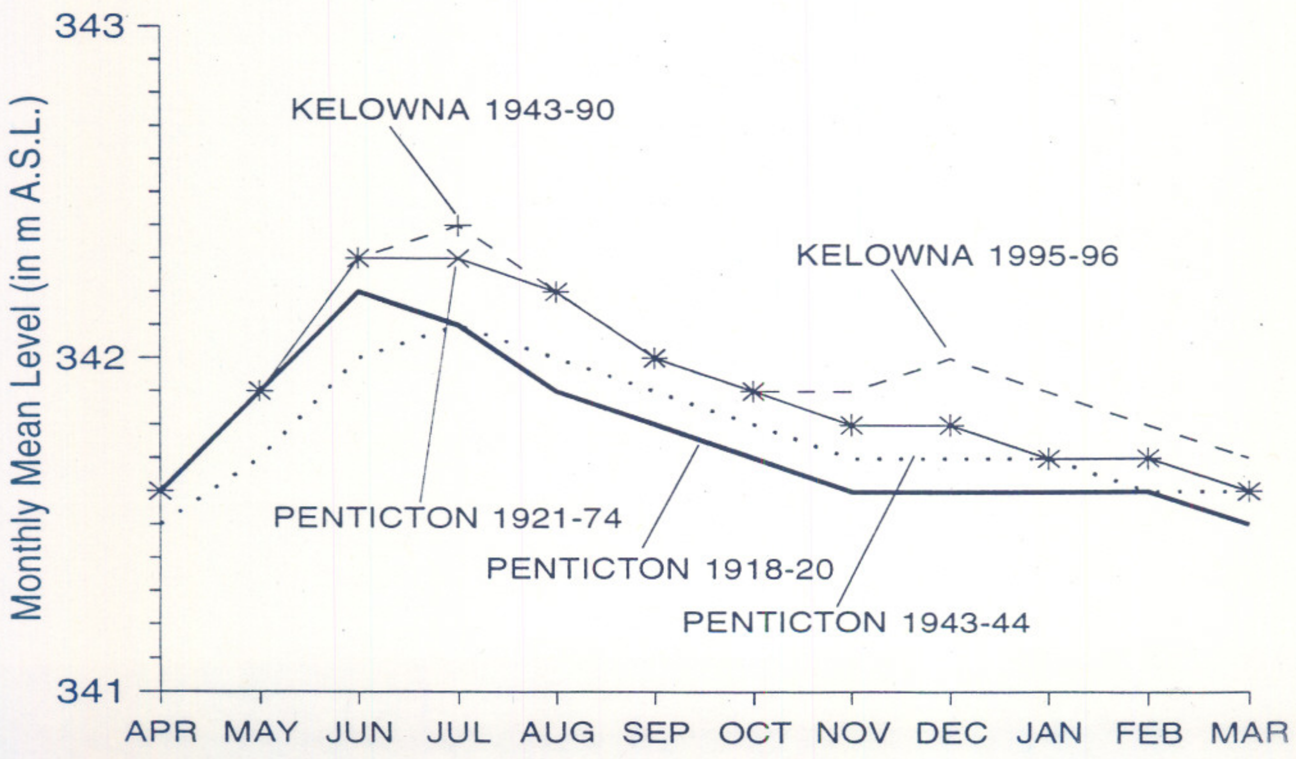
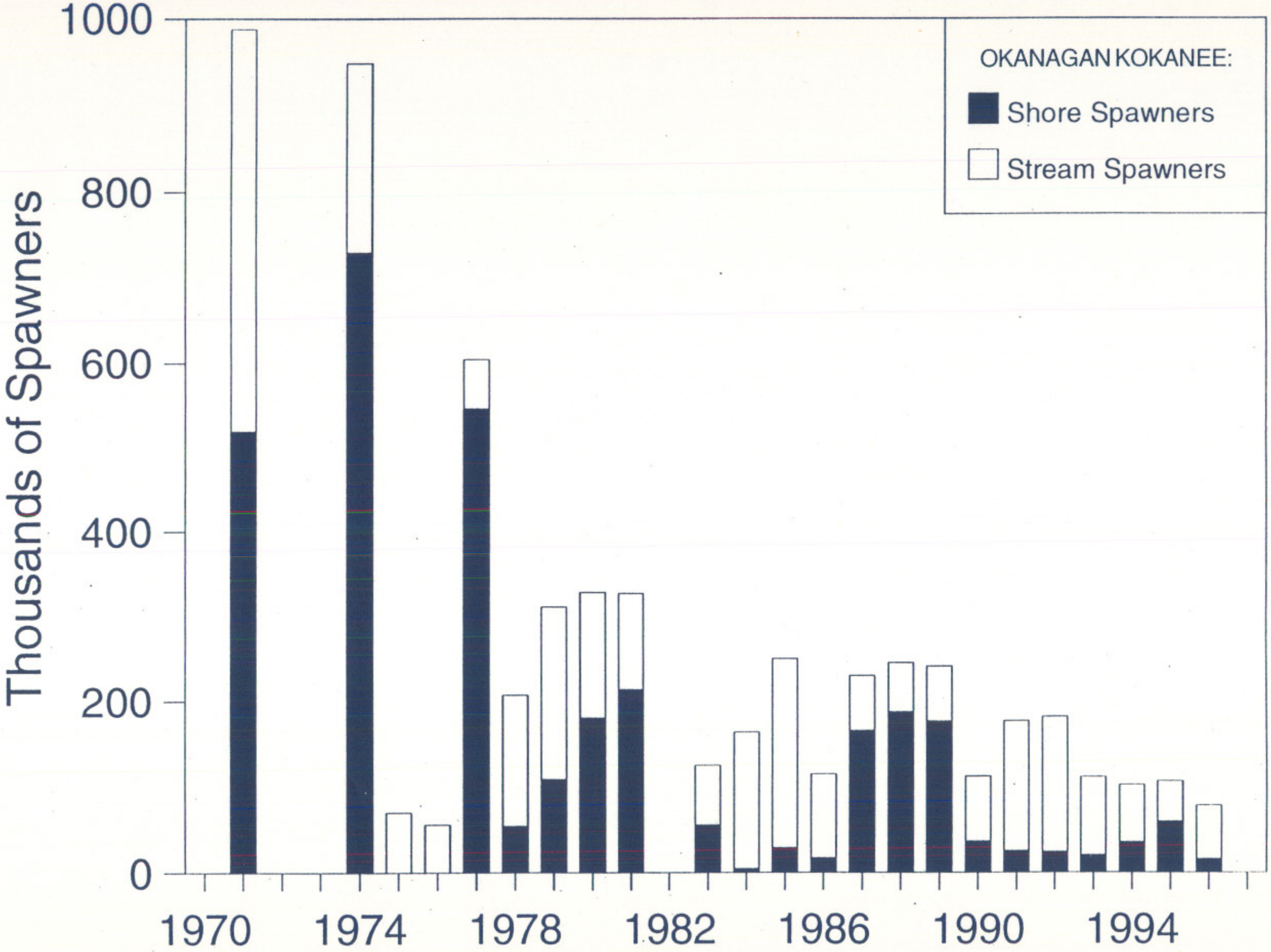


FIGURE 3. OKANAGAN LAKE ANNUAL SPAWNING ESTIMATES

(Note - Routine annual shore-spawner surveys began in 1977)



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- emerge	880 C-days	902-970 C-days	
Hatching Date	Jan 06 - Mar 15	Jan 01 - Apr 30	1989 shore incubator & Deep/Mission trapping results
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** Predicted from following length-fecundity equation developed from stream spawners ($n = 26$; $r_2 = 0.78$): Fecundity = 4.5 (Nosefork Length) - 685

FIGURE 4A. OKANAGAN LAKE KOKANEE SHORE-SPAWNER EMBRYO DISTRIBUTION WITH WATER DEPTH

*Matthews & Bull estimates increased by 12 cm to adjust to Nov 1 levels

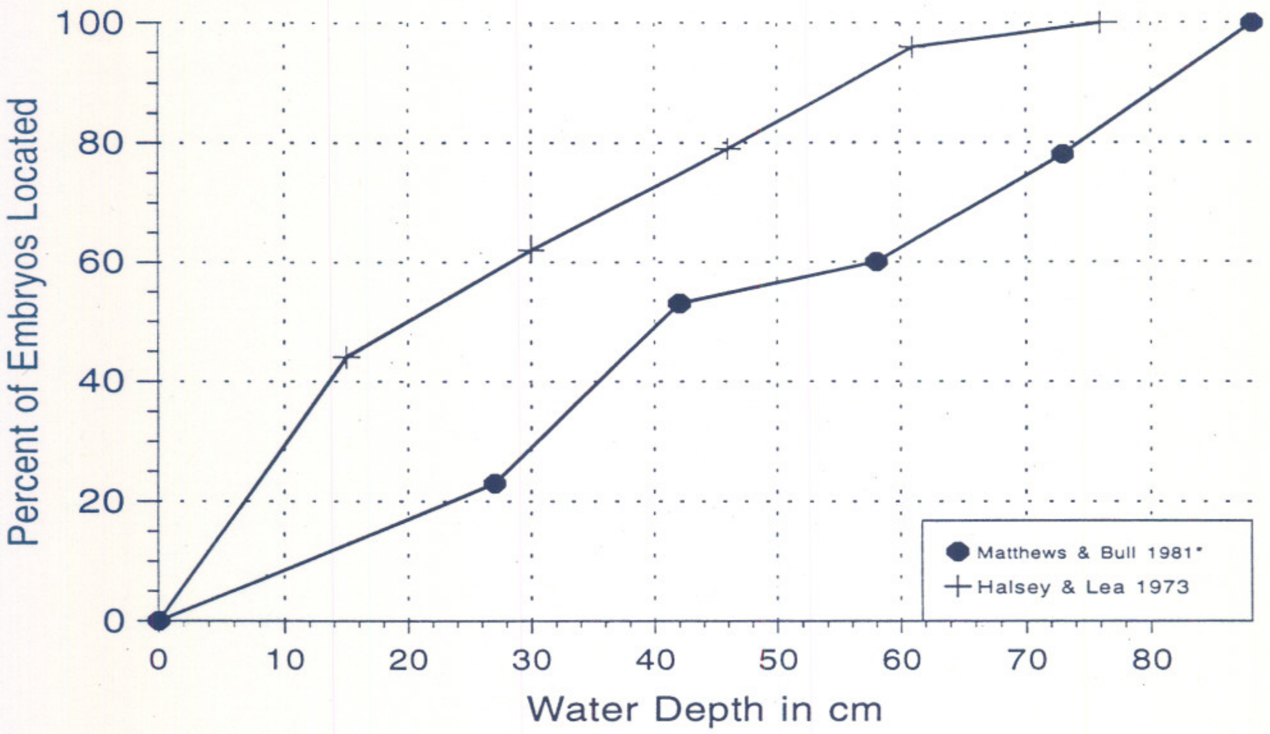


FIGURE 4B. OKANAGAN LAKE KOKANEE SHORE-SPAWNER EMBRYO HATCHING AND EMERGENCE TIMINGS

(From Matthews & Bull 1981; note "emerge" = within 2 wks)

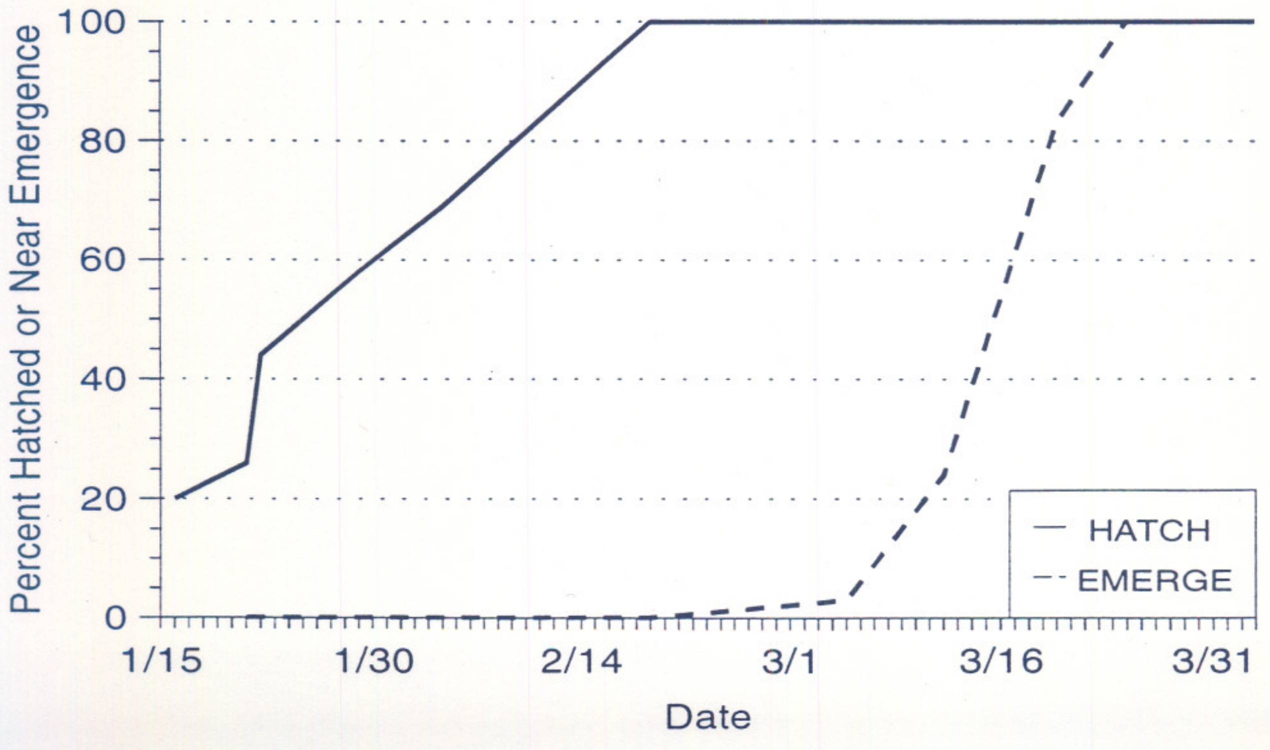
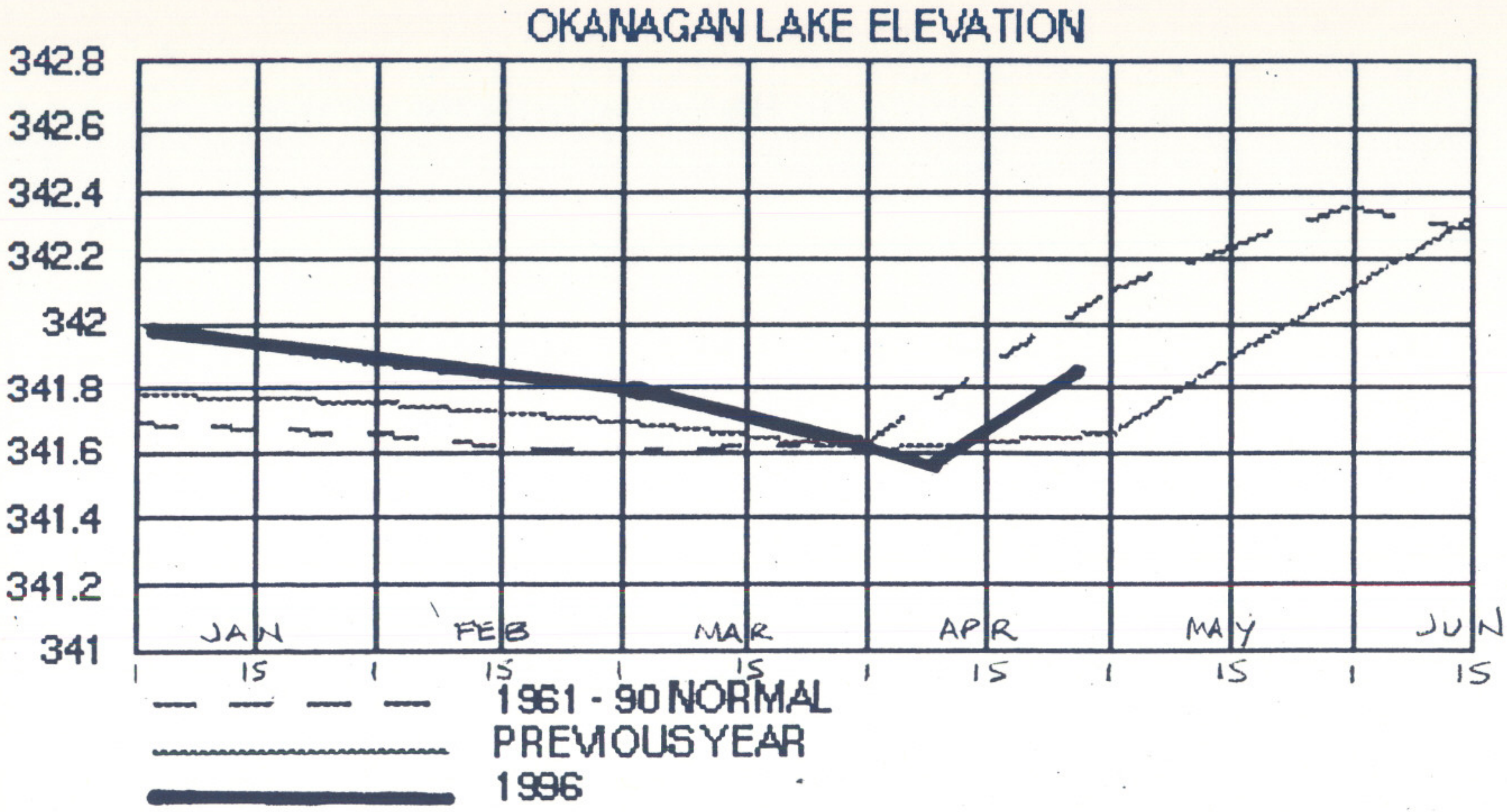


FIGURE 5.



(GRAPH AND DATA TO APR. 1/96 TAKEN FROM SNOW SURVEY BULLETIN; APR/96 DATA UPDATE FROM LAKE LEVEL SUMMARY RECORD)

TABLE 2. KOKANEE SPAWNER RETURNS COMPARED TO OKANAGAN LAKE WATER LEVELS DURING INCUBATION

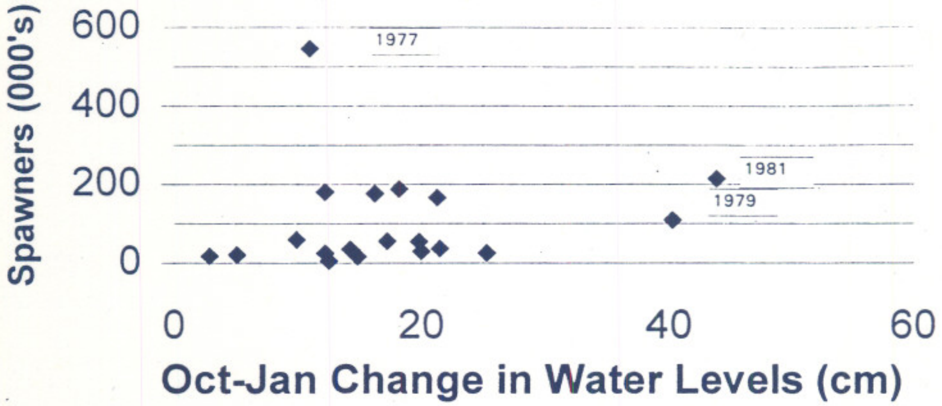
(Lake level readings taken from BCE Water Engineering Section's daily record logs, Penticton)

			LAKE LEVEL (m A.S.L.) AND DATE OF MAXIMUM/MINIMUM WATER LEVELS FOR PERIOD								LEVEL DROP (cm)			
ESC YR	ESC NO	WL YR	MAX OCT	(DATE)	MIN JAN	(DATE)	MIN FEB	(DATE)	MIN MAR	(DATE)	OCT-JAN	OCT-FEB	OCT-MAR	RECRUITS
1977	545	74-75	341.864	15-Oct	341.754	10-Jan	341.656	19-Feb	341.321	31-Mar	11	21	54	
1978	54	75-76	341.986	15-Oct	341.788	31-Jan	341.699	11-Feb	341.492	31-Mar	20	29	49	
1979	108	76-77	342.245	22-Oct	341.842	31-Jan	341.842	8-Feb	341.842	8-Feb	40	40	40	
1980	180	77-78	341.870	15-Oct	341.748	25-Nov	341.647	28-Feb	341.574	20-Mar	12	22	30	0.33
1981	214	78-79	342.220	18-Oct	341.781	22-Jan	341.736	8-Feb	341.736	8-Feb	44	48	48	3.96
1983	55	80-81	341.960	15-Oct	341.788	28-Jan	341.788	28-Jan	341.788	28-Jan	17	17	17	0.51
1984	5	81-82	341.909	19-Oct	341.784	28-Jan	341.690	27-Feb	341.559	31-Mar	13	22	35	0.03
1985	29	82-83	342.020	15-Oct	341.820	28-Jan	341.737	24-Feb	341.594	31-Mar	20	28	43	0.14
1986	17	83-84	341.840	15-Oct	341.811	1-Nov	341.682	29-Feb	341.612	13-Mar	3	16	23	0.31
1987	165	84-85	341.886	16-Oct	341.673	31-Jan	341.642	26-Feb	341.623	12-Mar	21	24	26	33.00
1988	187	85-86	341.920	25-Oct	341.738	10-Jan	341.700	28 Feb?	341.686	14-Mar	18	22	23	6.45
1989	176	86-87	341.912	15-Oct	341.750	20-Jan	341.750	20-Jan	341.750	20-Jan	16	16	16	10.35
1990	36	87-88	341.782	16-Oct	341.567	22-Jan	341.549	23-Feb	341.347	31-Mar	21	23	44	0.22
1991	25	88-89	341.979	24-Oct	341.726	27-Jan	341.692	14-Feb	341.692	14-Feb	25	29	29	0.13
1992	24	89-90	341.906	16-Oct	341.784	29-Jan	341.728	26-Feb	341.728	26-Feb	12	18	18	0.14
1993	20	90-91	341.866	15-Oct	341.815	30-Jan	341.704	25-Feb	341.471	31-Mar	5	16	39	0.56
1994	35	91-92	341.865	15-Oct	341.723	23-Jan	341.712	29-Jan	341.712	29-Jan	14	15	15	1.40
1995	59	92-93	341.566	15-Oct	341.467	21-Jan	341.467	21-Jan	341.466	15-Mar	10	10	10	2.46
1996	16	93-94	341.996	15-Oct	341.848	31-Jan	341.806	17-Feb	341.718	31-Mar	15	19	28	0.80

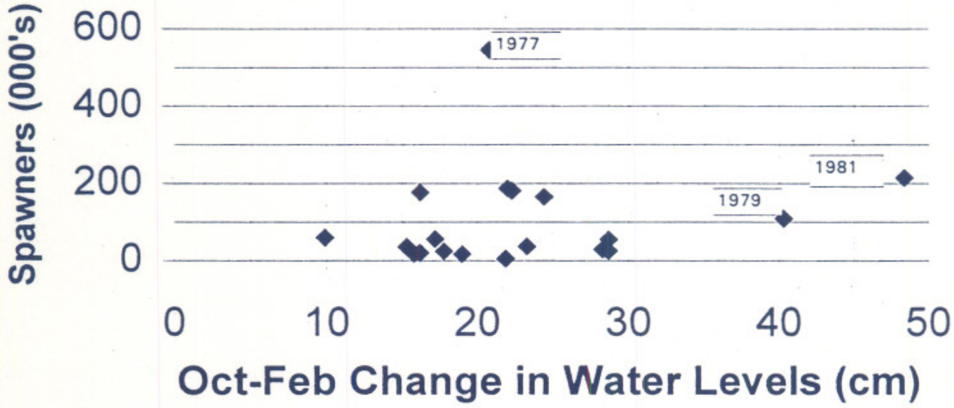
ESC YR = Year of Spawner Count
ESC NO = Spawner Count
WL YR = Winter in Which Brood Incubated
MAX OCT = Highest Lake Level (in m) During October
MIN JAN/FEB/MAR = Lowest Level During Oct 30 - Jan/Feb/Mar 30
RECRUITS = Progeny/Parent

FIGURE 6. KOKANEE SPAWNER RETURNS COMPARED TO WATER LEVELS IN BROOD YEAR

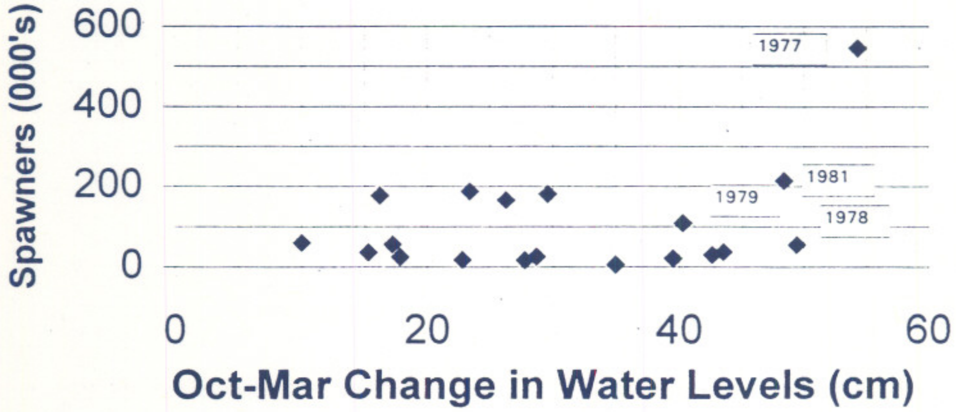
A. PRE-HATCH:



B. TO HATCH:



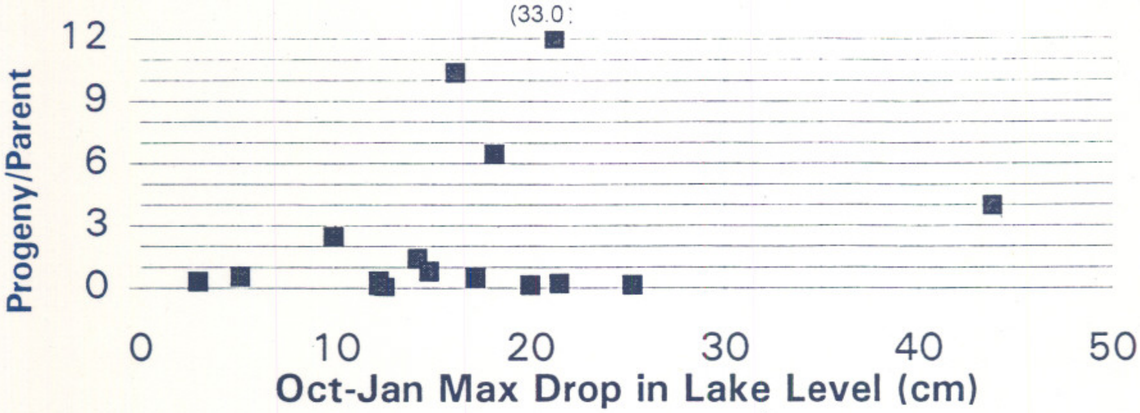
C. PRE-EMERGENCE:



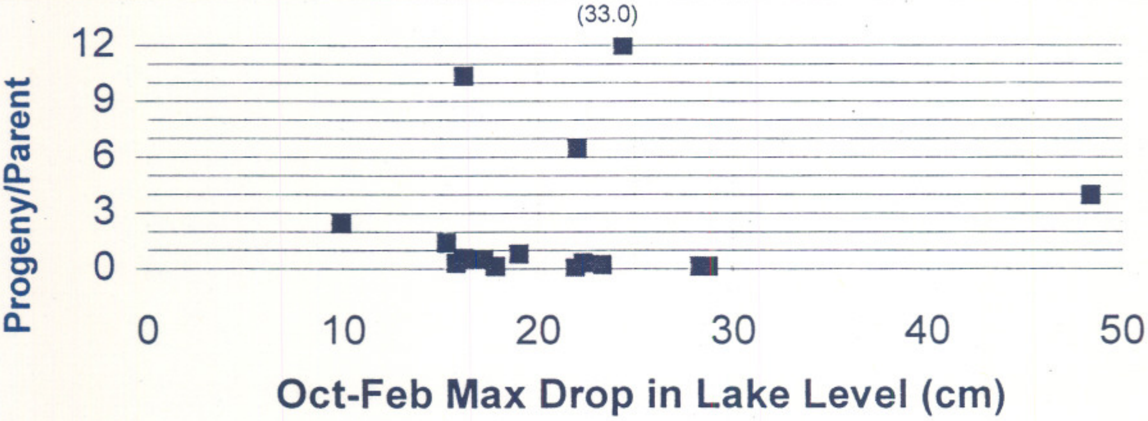
BROOD YEAR =(Year of Spawning - 3 years)

FIGURE 7. KOKANEE RECRUITMENT COMPARED TO WATER LEVELS IN BROOD YEAR

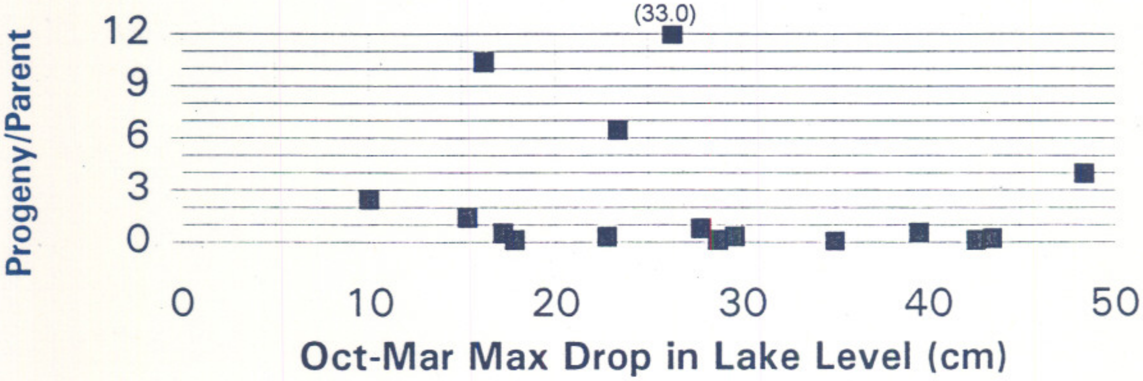
A. PRE-HATCH:



B. TO HATCH:



C. PRE-EMERGENCE:



RECRUITMENT = No. of progeny in escapement year / No. of parents in (escapement year - 3)

TABLE 3. KOKANEE RECRUITMENT RATES VERSUS OKANAGAN LAKE LEVEL PATTERNS

			DATE OF POST-SPAWNING LOW DURING:			OCT-JAN	JAN-FEB	FEB-MAR	
RECRUITS	ESC NO	OCT HI	OCT-JAN	OCT-FEB	OCT-MAR	DROP (cm)	DROP (cm)	DROP (cm)	ESC YR
0.03	5	19-Oct	28-Jan	27-Feb	31-Mar	13	9	13	**1984**
0.13	25	24-Oct	27-Jan	14-Feb	14-Feb	25	4	0	**1991**
0.14	29	15-Oct	28-Jan	24-Feb	31-Mar	20	8	15	**1985**
0.14	24	16-Oct	29-Jan	26-Feb	26-Feb	12	6	0	**1992**
0.22	36	16-Oct	22-Jan	23-Feb	31-Mar	21	2	21	**1990**
0.31	17	15-Oct	1-Nov	29-Feb	13-Mar	3	13	7	**1986**
0.33	180	15-Oct	25-Nov	28-Feb	20-Mar	12	10	8	**1980**
0.51	55	15-Oct	28-Jan	28-Jan	28-Jan	17	0	0	**1983**
0.56	20	15-Oct	30-Jan	25-Feb	31-Mar	5	11	23	**1993**
0.80	16	15-Oct	31-Jan	17-Feb	31-Mar	15	4	9	**1996**
1.40	35	15-Oct	23-Jan	29-Jan	29-Jan	14	11	0	**1994**
2.46	59	15-Oct	21-Jan	21-Jan	15-Mar	10	0	0	**1995**
3.96	214	18-Oct	22-Jan	8-Feb	8-Feb	44	4	0	**1981**
6.45	187	25-Oct	10-Jan	28 Feb?	14-Mar	18	4	1	**1988**
10.35	176	15-Oct	20-Jan	20-Jan	20-Jan	16	0	0	**1989**
33.00	165	16-Oct	31-Jan	26-Feb	12-Mar	21	3	2	**1987**
≤ 0.25 Mean		**LOW-RECRUITMENT YEARS (n = 5)**				**18.2**	**5.8**	**9.8**	
	(± 2 S. E.)					(± 4.96)	(± 2.56)	(± 8.42)	
≥ 2.5 Mean		**HIGH-RECRUITMENT YEARS (n = 5)**				**21.8**	**2.2**	**0.6**	
	(± 2 S. E.)					(± 11.67)	(± 1.83)	(± 0.80)	

FIGURE 8. KOKANEE RECRUITMENT SUCCESS VS OKANAGAN LAKE WATER LEVEL DROPS

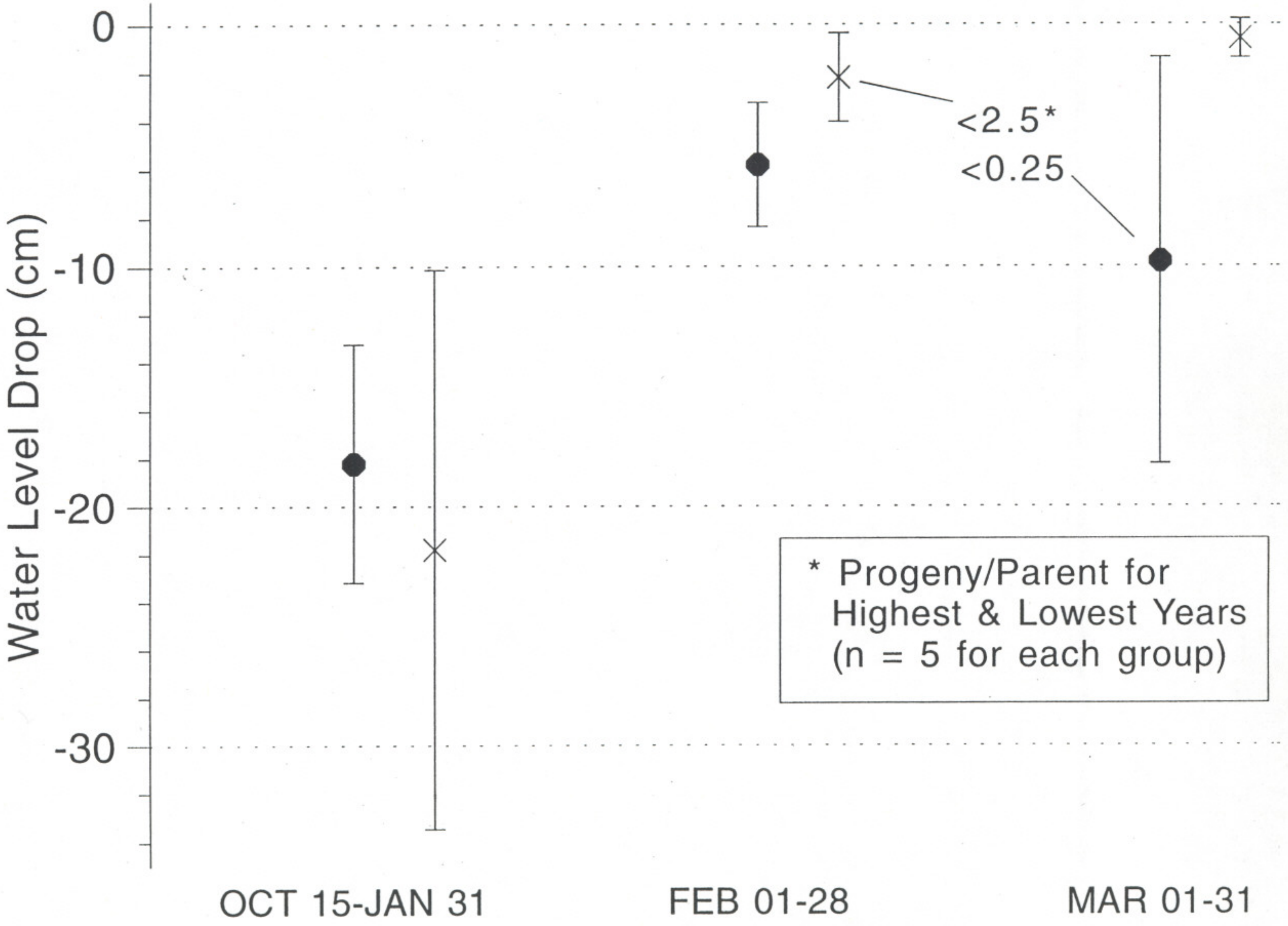
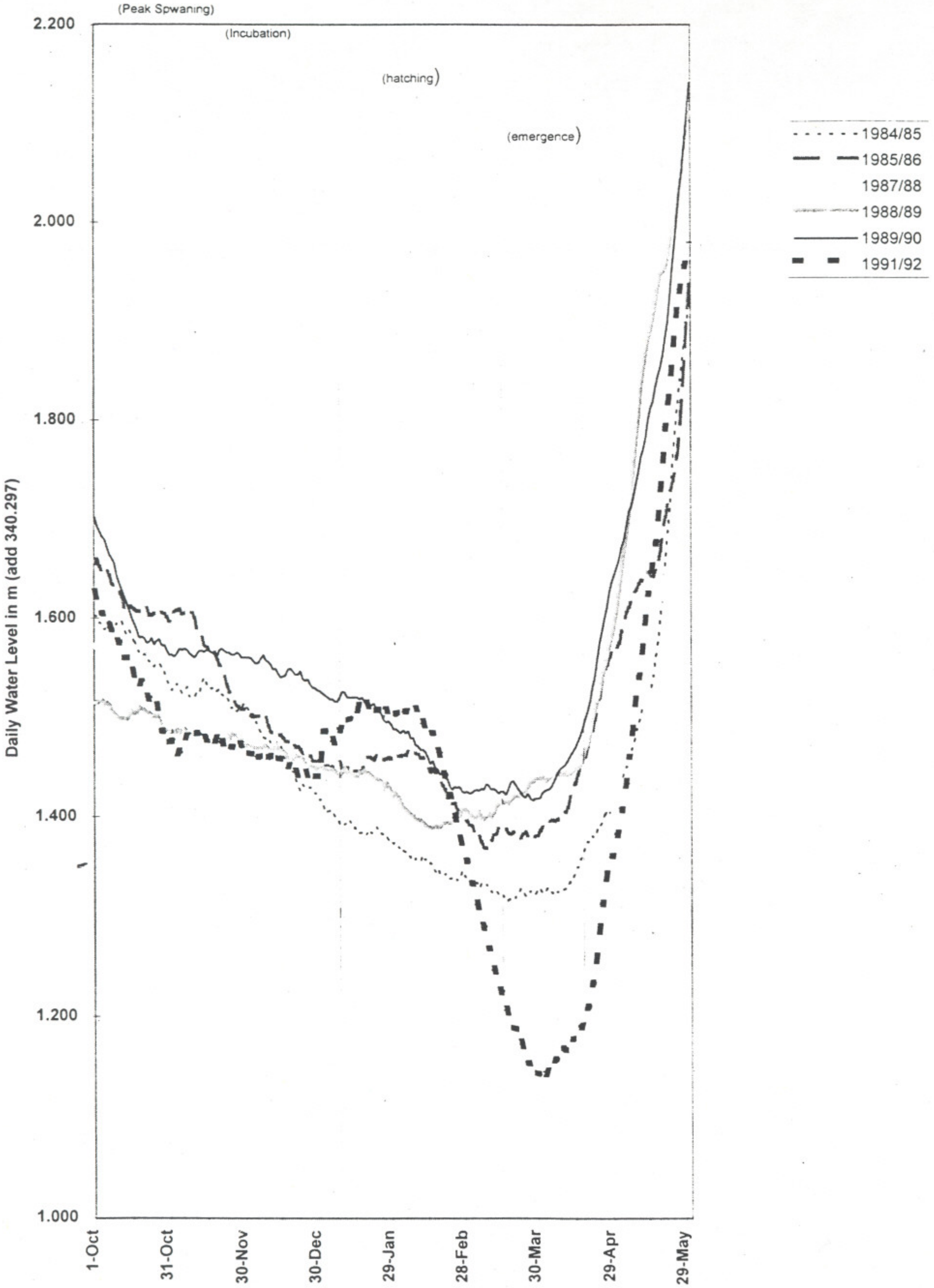
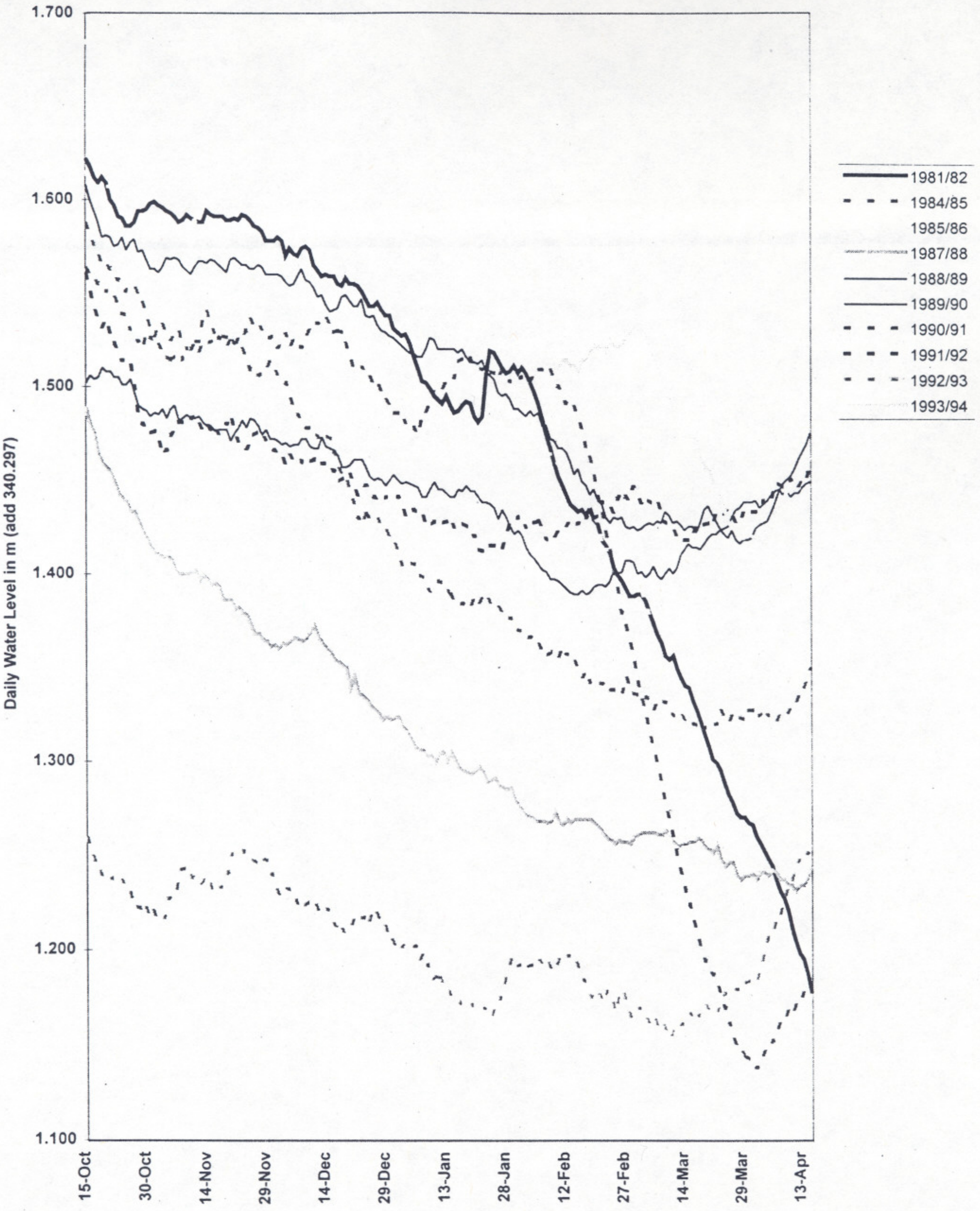


FIGURE 9. WATER LEVEL PATTERNS (WSC DATA*) DURING INCUBATION (Solid lines = high-recruitment years; dotted lines = low-recruitment years)



*Okanagan Lake at Kelowna WSC Station No. 08NM083

FIGURE 10. OCT 15-APR 15 WATER LEVELS* DURING INCUBATION (Solid lines = high-recruitment years; dotted lines = low-recruitment years



*Okanagan Lake at Kelowna WSC Station No. 08NMO83

APPENDIX 1.

OKANAGAN LAKE LEVELS

Normal Operating Range

Maximum - 342.53 metres GSC datum (1123.80 feet)
Minimum - 341.31 metres GSC datum (1119.80 feet)
Emergency Minimum 341.01 metres GSC datum (1118.80 feet)

Minimum elevation for water intakes 340.40 m (1116.80 ft)
Maximum elevation for water intakes 343.08 m (1125.6 ft)
(authorized works shall be constructed to operate with a lake level of 1116.8 to 1125.6 feet)
(340.4 to 343.08 metres) Geodetic Survey of Canada datum

1 in 200 year flood level - 343.08 m (1125.6 ft)

1 in 200 year flood construction level - 343.66 m (1127.49 ft)

Maximum levels recorded Okanagan Lake

1948 - 343.25 (1126.14 ft)
1972 - 342.80 (1124.67 ft)
1990 - 342.94 (1125.13 ft)

Barry F Alcock
B.F. Alcock
Water Management Officer
Water Management Program

BFA/pa

APPENDIX 2.

OKANAGAN LAKE REGULATION SYSTEM OPERATING PLAN

ONTH	VOLUME FORECAST (million cu. m.)	OKANAGAN LAKE ELEVATION (metres)	SKAHA LAKE ELEVATION (metres)	VASEUX LAKE ELEVATION (metres)	FLOW AT OLIVER (cu. m./sec)
n.		341.8	337.8	327.4	5.0 to 28.3
b.	< 430	As High as Possible	337.8	327.4	5.0 to 28.3
	> 430	341.6			
r.	< 620	As High as Possible	337.8	327.4	5.0 to 28.3
	> 620	341.45			
il	<250	As High as Possible	337.8	327.4	5.0 to 28.3
	370 to 500	341.4			5.0 to 28.3
	> 620	341.0			> 45.0
y		Lake Filling	337.9	327.5	> 6.5
ne		342.5	337.9	327.6	> 6.6
y		342.3	337.9	327.6	> 8.2
gust		342.1	337.9	327.6	10.6 to 28.3
pt.		342.0 (Sept 15)	337.8	327.5	9.2 to 28.3 (Sept 1)
		341.95 (Sept 30)			9.9 to 15.6 (Sept 15
t.		341.9 (Oct. 15)	337.8	327.4	9.9 to 15.6
v.		341.9	337.8	327.4	5.0 to 28.3
c.		341.9	337.8	327.4	5.0 to 28.3

TES: Lake elevations are targeted for the end of the month unless otherwise noted.
Flows at Oliver are targeted for the begining of the month unless otherwise noted.
Max. flows at Oliver may be exceeded in August and September due to extreme flood conditions.
Lake levels may be exceeded due to extreme flood conditions.
Okanagan Lake levels may not be attained due to extreme drought conditions.
Okanagan River flows at Penticton and Okanagan Falls are "as required to obtain lake levels".
Flows at Oliver from Nov. 1 to April 30 not less than 50% of the Sept. 15 to Oct. 31 flow.
Minimum flows at Oliver will be met in all years except consecutive drought years.