THE YENYENNING LAKES SYSTEM:

A REPORT ON EXPERIMENTAL MANAGEMENT OF OUTFLOWS AT QUALANDARY CROSSING FROM 1985 – 1990 AND RECOMMENDATIONS FOR FUTURE MANAGEMENT

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Yenyenning lakes Working Group

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Cover Photograph: Yenyenning (Beverley) Lakes, with Qualandary Crossing in the foreground, in October 1978.

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1. INTRODUCTION

This is the final report of the Yenyenning Lakes Working Group, established in 1983 to provide advice to the then Minister for Works, the Hon Ken McIver M.L.A., concerning management of the lake system outflow at Qualandary Crossing.

This report presents results obtained from six years (1985-1990) of experimental opening of the culvert at Qualandary Crossing and from the associated program of water depth, flow and salinity monitoring.

The usefulness of the culvert in reducing salinities in the lake system is discussed and recommendations for future management of the lake system outflow are made.

The report also gives brief accounts of previous related studies and provides a history of the lake system and its management.

2. THE STUDY AREA

The Yenyenning Lake system, comprising the Beverley and Channel Lakes, is located 130 km ESE of Perth, in the Beverley, Brookton and Quairading Shires (Figure 1).

In normal years, the lakes receive most of their inflow from farming country to the east and discharge into the North Branch of the Avon River approximately 39 km upstream of the town of Beverley. In exceptional years substantial flows may be received from the eastern limits of the lake system catchment, in the Goldfields, or from backflow of the Avon River if it is running at very high levels (Figure 2).

The lakes are reserved for the purposes of Recreation and Conservation of Flora and Fauna and vested in the National Parks and Nature Conservation Authority of Western Australia. The lake system outflow at Qualandary Crossing, however, is under the control of the Beverley Shire Council.

In 1965 the system outflow level was raised by construction of a new causeway, approximately 0.5m higher than its predecessor. One of the objectives of raising the causeway level was to retain water to a greater depth, over a larger area and for longer periods than previously, in order to provide increased recreational opportunities for the local community and more habitat for waterbirds, particularly ducks.

Following good winter rains, the lakes now fill to a depth of approx 2.2 metres, have an area of approximately 1700 hectares and retain water all year round (Photograph 1).

3. THE PROBLEMS

Raising of the lake outflow level has been considered successful with respect to providing more water for longer periods for recreational users and waterbirds.

Concerns have been expressed, however, about the high salinity of the lake water, particularly during periods of low inflow (in recent times, summer salinities have been several times more salty than sea water). Recreational users would like the raised water level to be maintained, but, at the same time, would like the salinity of the water to be reduced.

Adjoining landholders have different concerns about the lake system. Their view is that retention of water in the lakes at a higher level and for longer periods has contributed to secondary salinisation and waterlogging problems in some areas of farmland abutting the

lakes. Some landholders therefore want lake water levels to be lowered by removal of the causeway.

This view (that the causeway should be removed) is in conflict with that of recreational users, who want the causeway retained though preferably with some modifications to facilitate flushing of accumulated salt.

4. HISTORY OF ALTERATIONS TO THE LAKE SYSTEM OUTFLOW LEVEL

There is a long history of man-made alterations to the outflow level of the Yenyenning Lakes system.

These alterations, and the reasons for them, are relevant to the current dispute and are described below. The account has been derived from articles published in the community newspaper, "*The Beverley Times*", and from government files and other sources.

4.1 The 1928 Dam Wall

On 21st September 1928 a "busy bee" of local residents dammed the flow from the lakes by constructing a wall, two bags wide and several high, with old superphosphate bags filled with earth (*Beverley Times* 29/9/28). It was estimated at the time that this would raise the summer water level by 18" to 2ft (0.46 - 0.61m).

The principal aim was apparently to prevent the contamination (with salt) of pools on the Avon River, thereby making these pools more suitable for drinking by stock during the summer months. It was also considered that the lakes would become even more popular for duck shooting and picnics if the water lasted longer during summer (*BT* 28/9/28).

How many years this sandbag barrier survived for is not known. Without constant maintenance - and no documentation has been found to indicate that this occurred - the wall probably would have washed away during the first year of higher than average flows. It would certainly not have lasted until 1956, when the next attempt was made to raise the lake outflow level.

4.2 The 1956 Raised Crossing

In the latter part of 1956 the Beverley Road Board constructed a cement-faced crossing at Qualandary, apparently raising the inflow/outflow level by "about two feet" (0.61m) (*BT* 22/9/61).

The aim of constructing the raised crossing was apparently, as in 1928, to improve the quality of the water in the Avon River in summer by preventing highly saline water from being discharged at the end of winter (*BT* 13/7/56, 24/8/56, 14/12/56, 28/6/57). Improved trafficability of the crossing was presumably also an important factor.

At the request of local residents, and with the cooperation of the Public Works Department, two concrete (*BT* 22/9/61) pipes were installed under the new crossing and were fitted with cover plates so that they could be closed in September-October each year, as flood waters subsided.

The pipes were presumably intended to facilitate winter discharge from the lakes and possibly to allow backfilling to occur from the North Branch of the Avon, as in the past. The cover plates were provided to enable outflow in late winter to be prevented.

The remains of one of the pipes and a cover plate may be seen today, some metres downstream from the current causeway.

The initial construction of the crossing was apparently not strong enough to withstand the following winter's flow, and a major washout of the crossing was reported in July 1957 (*BT* 19/7/57). A relatively minor "break-away" beneath the crossing wall also occurred, in 1960 (*BT* 2/12/60).

4.3 The 1965 Causeway

In September 1961, local residents with an interest in using the lake system for waterskiing approached the Beverley Shire Council with a proposal to raise the causeway at Qualandary Crossing by an additional two feet (0.61m) to ensure plenty of water for boating and skiing over a large part of summer (*BT* 22/9/61, 6/10/61, 27/10/61).

It was thought that raising the wall by an additional two feet would be of added benefit to the Avon River, through a further reduction in salt flows from the lakes at the end of winter.

In 1962 the State Government approved the proposal (costed at 1,200 pounds), subject to a provision concerning non-liability for salt encroachment onto lakeside properties.

Signatures were obtained from adjoining landholders indemnifying the government and Shire Council against any future claims following the raising of the wall (*BT* 17/8/62). It was reported that no objections to the project were raised by local farmers (*BT* 12/10/62).

In 1963 members of the newly-formed Beverley Ski Club built a sand bag embankment to slightly raise the level of the causeway (*BT* 26/6/64). At this time the proposal to permanently raise the causeway by two feet was still under consideration. In August 1964 Beverley Shire Council again gave permission to the ski club to put sand bags on the crossing (*BT* 21/8/64).

Construction of the new causeway - with piling and gravel, and later stone facing and cement - began in the latter part of 1964. This work was commenced by the Main Roads Department (MRD) and completed in June 1965 by the Beverley Shire Council with MRD funding (*BT* 6/11/64, 19/3/65, 18/6/65, 9/7/65).

A culvert measuring 4ft wide by 18" high (1.22m x 0.46m) was provided, but not an intended flood gate to control the water flow (*BT* 21/5/65). As a temporary measure the culvert was blocked with bricks and stones. These remained until their removal by the Council on June 7th, 1983.

On July 6th, 1965 - less than two weeks after completion of the causeway - floodwaters broke through its northern end. The breaches were repaired by Council employees in September of that year (*BT* 1/10/65). Some work on the causeway apparently continued until early 1966.

The final structure (Photograph 2) - 610ft (186m) long with a road surface 16ft (4.9m) wide - has "a stone core covered with a six inch (0.15m) thickness of concrete and has a 500ft (152m) level section approx 20 inches (0.51m) higher than the previous crossing". The total cost was $7,380 (*BT* 25/3/66).

The new causeway had the intended effect of damming water to a higher level in the lakes.

It also had another very significant effect on the hydrology of the lakes. Prior to elevation of the causeway the lake system was normally filled in winter by high flows in the North Branch of the Avon River (*BT* 25/3/66). Raising of the causeway prevented this from happening - except when the Avon flows at an exceptionally high level - and now the lake system is filled almost exclusively by flow from eastern areas (*BT* 16/6/67). This alone

may have caused a significant increase in lake salinity[1] as there is much salt country, both man-made and natural, in the eastern catchment.

4.4 Recent Works (to 1990)

The only significant changes made to the causeway from 1966 to 1990 have been:

i) The removal of the obstruction in the box culvert by the Shire Council on June 7, 1983. (This was replaced by another, unauthorised obstruction around October 25, 1983, which was removed by Council on October 31)

ii) Installation by Council of a control gate on the culvert in 1985.

Table 1. Summary of Significant Works at Qualandary Crossing (to 1990).

Year	Action Taken
1928	Level raised 18"-24" by construction of a sand bag wall (presumably washed away before 1956).
1956	Level raised approx 2 ft by construction of cement-faced causeway. Two pipes with movable cover plates fitted.
1965	New causeway constructed raising level a further 20" (total approx 3'8" (1.12m). Single box culvert provided but not used (blocked).
1983	Removal of obstruction in box culvert.
1985	Control gate installed on culvert.

5. PREVIOUS INVESTIGATIONS

As mentioned in 3. above, raising of the outflow level of the Yenyenning Lakes system has been considered successful with respect to providing more water for longer periods for recreational users and waterbirds.

Concerns have been expressed since the early 1970s, however, about the salinity of the lake water, which appears to have increased since construction of the new causeway in 1965. High salinities have hampered recreational activities such as waterskiing and swimming and are believed to have made the system less suitable for use by waterbirds.

In more recent times concerns have also been expressed by some adjoining landholders about the possible impact of the raised water levels on waterlogging and salinity problems experienced on their properties.

1 This is supported by a report (*BT* 12/8/66) that in winter 1966 the lake system was filled by "..exceptionally heavy early season falls eastwards and northwards of this (Yenyenning Lakes) district". The water in the lakes was described as being ".. an intense blue and not mud colour as is usual at this period". Salty water is typically less turbid than fresh water.

As a result of these concerns, three previous investigations have been undertaken into various aspects of one or both of the apparent problems.

5.1 Public Works Department (1973-74)

The first investigation was conducted by the Public Works Department (PWD) at the request of the Department of Fisheries and Fauna and the WA Wildlife Authority in whom the lakes were vested. The aim was to consider ways by which the salinity of the lakes' waters might be reduced.

Two proposals were assessed.

i) Trenching of the lower lakes to enable remnant, saline water to be drained in late summer.

ii) Installation of a gated culvert in the causeway to facilitate removal of saline waters, with or without trenching.

The results of this study indicated that it would be very costly to trench the lower lakes of the system and that, without trenching, installation of a gated culvert at the causeway might not be of significant benefit in reducing salinities. However, PWD also recommended that a longer and more detailed study of the lakes' dynamics be conducted before final conclusions were drawn.

5.2 P.W. Anderton (1975)

In 1975, the Department of Fisheries and Wildlife, acting on the PWD recommendation, funded a study of the lakes' dynamics by Mr P. Anderton, an Engineering Honours student at the University of WA.

On completion of his twelve month study Mr Anderton came to the following conclusions (Anderton 1975).

i) In any ten year period the system may be expected to fill and flow over the causeway approximately five times. On average, this outflow occurs for about two months.

ii) Long term accumulation of salt in the system is unlikely to occur because low salinity inflows mix with remnant, highly saline waters before reaching the causeway. This results in remnant salt being completely flushed from the lakes during periods of significant (2-3 months) outflow.

iii) A deep channel along the centreline of flow through the lake system (as had been proposed to aid winter flushing) would increase the salinity of the lower lakes by enabling more highly concentrated (through evaporation) waters from higher lakes to flow downstream during summer. Such a channel would, therefore, be undesirable.

Mr Anderton recommended the following:

i) Construction of a barrier with a variable gate at Station 290 (Swan Lake exit) or a less costly barrier without gate at Station 270 (Figures 3 & 5) to reduce the salinity of downstream lakes by preventing the postulated flow of waters of higher salinity from upstream lakes during summer.

ii) Increase the height of the causeway at Qualandary Crossing by a further 17"-19" (0.43 - 0.48m), thereby increasing the depth of the lakes and reducing the rate of increase in salinities throughout the system during the summer evaporative period.

iii) Dig a deep water channel at Station 200 (and possibly 270) to reduce localised salinity increases in the shallowest of the lower lakes during summer, and to improve local flushing.

Most importantly, Mr Anderton also recommended further monitoring of the lakes so that his theory of salt flow from upstream to downstream lakes during summer (on which he based his recommendations) could be tested.

PWD evaluated the Anderton report in 1982.

PWD recommended against construction of a gated structure at Station 290 as it would be very expensive and would require an experienced operator close at hand to operate it.

Construction of an earth barrier at Station 270 was considered feasible, at a cost of about $20,000. However, PWD believed there were some aspects (scour, maintenance and effects on water levels and salinities in drier years) which would require further study before deciding whether or not to proceed.

Excavation of a channel at Station 200 would cost in excess of $30,000 and was considered unlikely to significantly improve water quality.

PWD shared Anderton's view that, with the lake system overflowing in 5 years out of 10 (Anderton's estimate), flushing was adequate to prevent long term accumulation of salt.

5.3 Yenyenning Lakes Working Group (1984-85)

The third study, in 1984-85, was initiated by the Minister for Works, the Hon. K. McIver M.L.A., following a public dispute amongst the local community about opening of the culvert in the causeway. This study, by a Working Group of officers from the Departments of Agriculture, Fisheries and Wildlife, Lands and Surveys and Public Works, looked at the concerns of both recreationalists and adjoining landholders.

This study concluded *inter alia* that elevation of the causeway did not contribute significantly to salinisation and waterlogging of adjoining farmlands and, most importantly, that opening of the causeway culvert (or even total removal of the causeway) for all or part of the year would not significantly improve the condition of these lands.

The salinity and waterlogging problems were attributed to very poor natural drainage (some areas of affected land have virtually no slope) and to clearing of higher ground further from the lakes.

The 1984-85 study also indicated, however, that some improvement (reduction) in lake water salinity could be achieved by opening the causeway culvert for a short period each winter (as had apparently been the practice around 1956-1964), though this would be at the expense, in some years at least, of slightly lower water levels. This could (depending upon the magnitude of the reduction) be of benefit to recreationalists and waterbirds.

In May 1985, the Working Group recommended to the Minister for Works and the Beverley Shire Council that the latter conclusions (based upon computer simulations) be tested by experimental opening of the culvert for a short period each winter from 1985 to 1989 and by continued monitoring of lake salinities and outflows during this period.

The Working Group's recommendation was adopted and a five (later extended to six) year program of experimental opening and monitoring commenced.

6. THE 1985-90 YENYENNING LAKES WORKING GROUP STUDY

Each year from 1985 to 1990 the Working Group recommended to the Beverley Shire Council that the culvert at Qualandary Crossing be opened as soon as, but not before, the flow in the North Branch of the Avon River at Beverley reached 15 x $10^3 m^3$/day. In most years this could be expected to occur some time in June or July, soon after the commencement of normal winter rains. A gauge board was installed under the Vincent Road bridge to enable Shire Council officers to conveniently measure the flow (0.2m on this gauge board indicated the required flow rate).

The Working Group further recommended that the culvert be closed on the first Monday in August each year.

This experimental management prescription was intended to allow approximately 1-2 months of water release through the culvert each year, without releasing highly saline water into the Avon River at a time when its water level was low, and without dramatic lowering (by releasing too much water during winter) of the water level in the lake system for the following spring and summer.

6.1 Year One (1985)

Rainfalls and Flows
Rainfall in the Avon River North Branch catchment at the beginning of the 1985 winter wet season was well below average and, as a consequence, there was little flow in this branch until late July. The Qualandary Crossing culvert was therefore not opened until July 22nd, as per the management prescription.

On July 19th, the water level at Qualandary Crossing was 8.86mSL[2], marginally below the culvert "cease-to-flow" or "invert" level of 8.87mSL (Table 2). There was no outflow from the lakes at the time of opening and, due to low rainfall in the remainder of winter, little, if any, during subsequent months.

The culvert was closed, as per the management prescription, on August 5th.

Lake Depths and Salinities
In May 1985, at the end of the summer-autumn dry season, the water depth in the Yenyenning Lakes system was relatively high for this time of the year. Lake 80A (Ski Lake), the most popular recreational lake in the system, was approximately 0.75m deep[3]. The lake salinity was also high, however, at 164 parts per thousand (ppt).

Due to minimal inflows, there was little increase in depth, and probably little decrease in salinity, during the winter months. In July the water depth in Lake 80A was around 0.80m and the salinity was still very high, at 153ppt. Lake depth began to decrease in later months and by May 1986 lake salinity was 293ppt - amost twice that of May '85 and approaching saturation point.

Conclusion
Because there was little or no outflow in 1985, no new information was gained about the usefulness of opening the culvert during years of normal winter flows.

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2 This level was taken from the CALM depth gauge. In 1985 the minimum recording level of the WA Water Authority (WAWA) gauging station was 9.45mSL, which is 0.58m above the culvert invert level. Small flows through the culvert therefore could not be detected. This was not remedied until after the 1985 winter.

3 Extrapolated from CALM gauge readings at causeway.

Table 2. Levels at Qualandary Crossing (See also Figure 4).

LEVEL	mSL*1	mCALM*2	mAHD*3	mDiff*4
Causeway cease-to-flow	10.000	1.84	210.66	0.00
Culvert cease-to-flow (natural outflow level) *5	8.874	0.71	209.53	-1.13
WAWA gauging station minimum recording level (7.3.1986 onwards)	8.585	0.42	209.24	-1.42
Lake bed level at WAWA gauging station (and at CALM gauge site)	8.295	0.13	208.95	-1.71

*1 SL is abbreviation for "Standard Level". All WAWA gauging stations are given an arbitrary SL in metres. In the case of the Qualandary Xing gauging station, the causeway cease-to-flow level is 10.000 mSL.

*2 CALM is abbreviation for "Dept of CALM depth gauge". In 1978, CALM installed a gauge 26m upstream of the causeway. Readings indicate depth of water in Lake 45 (see Fig 3). This gauge was removed 14.4.94.

*3 AHD is abbreviation for "Australian Height Datum". Mean sea level is 0.000 mAHD.

*4 mDiff is difference in elevation compared with causeway cease-to-flow level.

*5 The culvert appears to have been placed on the natural ground surface as surveys have shown the culvert cease-to-flow level is 1.13m below the causeway c-t-f and this is in close agreement with early estimates (Table 1) that the outflow level was raised a total of 1.12m by construction of the 1956 and 1965 causeways.

6.2 Year Two (1986)

Two new Water Authority gauging stations were installed at Qualandary Crossing in 1986. One is upstream of the Crossing and has a minimum recording level of 8.585mSL, which is 0.289m below the culvert invert (Table 2). The other is on the downstream side of the Crossing and also has a minimum recording level below that of the culvert. These stations enable flows through the culvert, including any backflows caused by flooding in the North Branch of the Avon River, to be monitored. This had not been possible in 1985.

Rainfalls and Flows

Rainfall in the Avon River North Branch catchment at the beginning of the 1986 winter wet season was near normal. By June 24th river flow had exceeded the prescribed minimum rate by 20% and the Qualandary Crossing culvert was opened.

Early winter rainfall was also near normal in the lakes' eastern catchments. Significant inflow occurred and on July 8th the lake system water level reached the culvert invert level (Figure 6). The water level continued to rise, and on July 28th, after 20 days of flow through the culvert alone, the lakes overtopped the causeway.

It is estimated that the water discharged from the culvert prior to the commencement of causeway overflow increased salinity levels in the Avon River North Branch at Brouns Farm (53 km downstream from Qualandary Crossing and 14 km downstream from Beverley) by 0.8 - 4.7ppt (Table 3).

Table 3. Effect of controlled releases from Yenyenning Lakes (via culvert) on salinities in the Avon River at Brouns Farm in 1986.

Date of release	Salinity of water released (ppt)	Salinity in Avon following release (ppt)	Estimated change in salinity of Avon due to release (ppt)
13 July	37.1	4.2	+ 3.0
14 July	34.8	3.9	+ 0.8
20 July	21.2	6.8	+ 4.4
24 July	23.3	8.2	+ 4.7

The culvert was closed, as planned, on Monday August 4th, after 27 days of flow through it. Outflow continued over the top of the causeway until October 1st, at which time the water level dropped below the causeway cease-to-flow level and outflow ceased.

The salinity of outflow water varied from around 37ppt at the commencement of outflow through the culvert to 19-23ppt during flow over the causeway (Figure 6).

An estimated 160,000 tonnes of salt and 7.5 million cubic metres of water were released from the lakes into the Avon River during 1986.

Most importantly, only 25% ($1.9 \times 10^6 m^3$) of the discharged water, but around 30% (48,000 tonnes) of the discharged salt, was released through the culvert prior to the lakes overtopping the causeway. This was because the outflow through the culvert prior to the lake level reaching the causeway cease-to-flow level was more saline than the subsequent outflow over the causeway. It was not due to salinity stratification at the causeway (i.e. the water being more saline near the bottom than near the surface), as stratification did not occur.

No "backflow" from the North Branch of the Avon River into Yenyenning Lakes occurred during 1986. Outflow from the culvert was impeded to some (uncalculated) extent on 1st August only, when the level in the Avon peaked at 9.27 mSL (instantaneous level), 0.40 m above the culvert cease-to-flow level but still well below the lake level at the time.

Lake Depths and Salinities

The lake system was virtually dry by autumn 1986, due to inflow in 1985 being minimal. On May 28th, the water depth in Lake 80A was approx 0.2m and the salinity 296ppt, near saturation (Table 4). A salt crust was evident on the bed of the lake.

With high winter inflows, the lakes filled and salinities decreased dramatically. Lake 80A reached minimum values of 15-16ppt (surface to near-bottom) in August. By September 1986, a very high salinity level (151ppt) had developed near the lake bottom due to re-dissolving of the salt crust and salinities in mid-level and surface waters had also begun to

increase.

Table 4. Salinity (ppt) profiles of Lake 80A (Ski Lake) from May 1986 to April 1987.

Depth	May86	Aug86	Sep86	Oct86	Nov86	Dec86	Jan87	Feb87	Apr87	May87
0.0[s]	293	15	20	21	28	39	45	94	123	120
0.1	296[b]	..	..	..	..	..	..	..	..	..
0.2		..	..	..	..	..	..	..	..	..
0.3		..	..	..	..	..	..	..	123	121
0.4		..	..	..	..	..	62	94	..	..
0.5		..	..	..	..	42	..	..	123	..
0.6		..	..	24	29	..	..	..	..	120
0.7		16	..	..	..	..	..	94	127[b]	
0.8		..	..	..	..	..	59	..	..	
0.9		..	27	..	..	..	..	..	..	
1.0		..	..	..	..	44	..	..	..	
1.1		..	..	..	..	..	..	94[b]		
1.2		16	..	22	32	..	..			
1.3			..	..	..	..	81[b]			
1.4			..	..	..	..				
1.5			..	..	..	117[b]				
1.6			..	..	..					
1.7			..	..	131[b]					
1.8			..	133[b]	..					
1.9			151[b]		..					
2.0			..		..					

[s] Surface
[b] Near-bottom salinities

In subsequent months, salinities in middle and surface waters continued to increase due to concentration by evaporation and further dissolving of the crust. During December-January, when interest in recreational use of the lake system is normally greatest, surface salinity increased from 39ppt to 45ppt, almost 1.5 x seawater.

By February 1987 the crust had reportedly dissolved entirely and the salinity profile became relatively uniform at 94ppt over the lake's depth. Salinities continued to increase into autumn.

Conclusions

It was confirmed by this second year of the study that the culvert is potentially useful in reducing the salt load of the lake system *because it enables water to be released at higher salinities than would be the case if water could only be discharged over the top of the causeway.*

Note that in years such as 1986 when lake waters overtop the causeway in late winter, the release of highly saline water through the culvert in early winter has *no effect on subsequent spring-summer water levels.*

Another conclusion which can be drawn from the 1986 results is that salt crusts formed on the bed of the lakes at the end of dry years are at least partially redissolved in subsequent years of good rainfall and can therefore be flushed, over time, from the system.

6.3 Year Three (1987)

Rainfalls and Flows

Rainfall in the Avon River North Branch catchment at the beginning of the 1987 winter wet season was below average. However, by June 20th river flow had exceeded the prescribed minimum rate and the Qualandary Crossing culvert was opened. The lake system water level at this time was 8.835mSL, that is, 0.04m below the culvert cease-to-flow level.

Early winter rainfall in the lake system's eastern catchments was also low and the water level did not rise consistently above the culvert invert level until July 29th.

The culvert was to have been closed on Monday August 3rd. However, due to an oversight, it was not closed until five weeks later. This greatly affected the outcome, as little outflow ($14.4 \times 10^3 m^3$ or 9%) occurred prior to the scheduled closing date; most outflow ($134 \times 10^3 m^3$ or 86%) occurred several weeks later, between August 20th and the actual closing date, September 8th (Figure 7).

Due to well below average rainfall, there was no flow *over* the causeway in 1987. The maximum water level reached in 1987 was 9.08mSL, 0.21m above the culvert invert and 0.92m below the top of the causeway. This was on 12 September, four days after the culvert was closed.

The total flow through the culvert was only 155,000 cubic metres of water and 17,300 tonnes of salt, far less than in 1986.

The release of this water is estimated by the Water Authority to have lowered the water level of the lake system during subsequent months by approx 0.03m.

There was no significant variation in salinity of the outflow water during the period of outflow; most values were within the range 111-116ppt.

There was no backflow from the North Branch of the Avon River into Yenyenning Lakes during 1987.

Lake Depths and Salinities

The water level in the lake system was still relatively high in autumn 1987, due to the high inflows of the preceding year. On 25th May the depth of Lake 80A was approx 0.7m and the salinity 120ppt (Table 5).

Because inflows during winter 1987 were small, there was no dramatic decrease in the salinity of Lake 80A, as had occurred during the previous year. At the beginning of August the salinity was still very high, at 114ppt. The salinity of Lake 80A did not reach a minimum (of 89ppt) until early September. This was six times higher than the 1986 minimum of 15ppt. The maximum depth of Lake 80A in 1987 was approx 1.0m, also in September.

Conclusions

The previous year of study had demonstrated that, in some years at least, some benefit can be gained from opening the culvert for a period early in winter. This is due to the fact that in some years the salinity of the water at the causeway is higher at the onset of winter than later in the season. In these circumstances more salt can be discharged per unit volume of water at the beginning of winter than later.

The results obtained from the monitoring program in 1987 showed that in some years salinity *does not* vary significantly during the period in which water can be released through the culvert. In these years an opportunity to release more salt per unit volume of water by opening the culvert early (or any other time) in winter does not arise.

Table 5. Salinity (ppt) profiles of Lake 80A (Ski Lake) From May 1987 to May 1988.

Depth	May	Jun	Jul	Aug	Sep	Nov	Dec	Mar	May
0.0	120	119	117	114	89	122	143	130	..
0.1	..	..	..	..	..	..	..	130	135
0.2	..	..	..	..	..	..	..		
0.3	121	119	117	115	..	..	145		
0.4	..	..	..	..	106	122	..		
0.5	..	..	..	..	..	..	..		
0.6	120	119	118	115	..	..	143		
0.7				..	..	123	..		
0.8				..	108	..	..		
0.9				..	..	..	..		
1.0				..	..	..	..		

6.4 Year Four (1988)

Early in 1988 it was reported to the Working Group that repairs had recently been made to a low sand barrier on the Rocky Lake outflow (near Station 235). Concern was expressed about the effect this might have on the monitoring program. Following some enquiries, the barrier was removed. It therefore had no impact on the study.

Rainfalls and Flows

Rainfall in the Avon River North Branch catchment at the beginning of the 1988 winter wet season was above average.

By June 8th river flow had reached the prescribed minimum rate and the Qualandary Crossing culvert was opened.

Rainfall in the lake system's eastern catchments in 1988 was average, however little flow resulted.

The culvert was closed on Monday August 1st.

Because inflows in 1988 were minimal, the lake system water level did not reach the culvert invert level until early August, some time *after* the culvert was closed (Figure 8). There was, therefore, no outflow at the causeway during 1988 and no salt was flushed.

The salinity at the causeway was 96ppt on August 8th.

There was no backflow from the North Branch of the Avon River into Yenyenning lakes during 1988.

Lake Depths and Salinities

Lake 80A was almost dry (approx 0.2m) by autumn 1988 and its salinity exceeded 130ppt (Table 6). It was not until August that some inflow occurred and, even then, lake salinity remained very high, at 142ppt. Maximum water level (approx 1.1m) and minimum salinity (70ppt) were reached in September. By the beginning of summer, surface salinity had again risen to a very high level of 137ppt, approximately 4x sea water.

Profiling in September showed that the salinity of water near the lake bed was approx 50% higher than that of surface water. Towards the end of October, salinities were very similar at the surface, middle and bottom and this pattern continued to March 1989.

Table 6. Salinity (ppt) profiles of Lake 80A (Ski Lake) From May 1988 to May 1989.

Depth	May	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May
0.0	..	..	..	70	107	131	137	152	>153	150	137
0.1	135	152	..	..	..	..	..	..	..	..	
0.2			..	..	..	..	..	..	..	150	
0.3			..	..	..	..	..	..	>153		
0.4			..	..	107	..	..	..			
0.5			..	..	..	..	..	153			
0.6			142	..	..	..	..	..			
0.7			..	..	..	..	..	..			
0.8			..	..	..	131	139	..			
0.9			..	..	109	..	..	..			
1.0			..	108	..	..	..	..			
1.1				..							

Conclusions

Because the lake system water level did not reach the culvert cease-to-flow level until late winter - some time *after* it was closed - no new information on the usefulness of the existing structure in reducing salt loads or salinities was gained from this fourth year of the study.

It should be noted, however, that if the culvert invert level had been lower, some highly saline water could have been released prior to 1st August, though this would have been at the expense of even lower water levels and a more rapid rise in salinity during summer.

6.5 Year Five (1989)

Rainfalls and Flows

Rainfall in the Avon River North Branch catchment at the beginning of the 1989 winter wet season was above average. By June 16th, flow in this branch of the Avon had reached the prescribed rate and the culvert was opened.

Due to heavy rains in the lake system's eastern catchments in late May of 1989, the water level in the lake system was already above the culvert cease-to-flow level when it was opened and outflow began immediately (Figure 9).

The lake system water level continued to rise rapidly and on June 28th over-topped the causeway (10.00 mSL). Flow peaked at 10.32 mSL on 2nd July and maintained this level for two days before beginning to fall. The flow rate at this time is estimated to have been in the vicinity of 2.7 million cubic metres per day.

The culvert was closed on August 8th, however flow over the causeway continued until September 17th.

The salinity at Qualandary Crossing was high at the commencement of outflow through the culvert but declined rapidly to 25ppt on June 23rd and 19ppt at the end of September (Figure 9).

An estimated 1.1 million tonnes of salt and 35 million cubic metres of water were released from the lakes into the Avon River during 1989. These were the largest outflows of both salt and water during the course of the five year study (Figures 13 & 14). Importantly, only 2.1% (930,000 cubic metres) of the discharged water, but 3.1% (34,200 tonnes) of the discharged salt, was released through the culvert prior to the lakes over-topping the causeway

No backflow from the North Branch of the Avon River into Yenyenning Lakes occurred during 1989. Outflow from the culvert was impeded to some (uncalculated) extent from 29th June to 18th July as the water level in the Avon continuously exceeded the culvert cease-to-flow level during this period - by an average of 0.45 m. On 2nd July the Avon peaked at 9.80 mSL (instantaneous level), only 20 cm below the causeway cease-to-flow level.

Lake Depths and Salinities

The water depth in Lake 80A at the beginning of May 1989 was approx 0.1m and the salinity 137ppt (Table 7).

The very high flows that occured during winter caused substantial flushing of the lake system and reduced surface and middle level salinities in Lake 80A to 6ppt in July. These were the lowest salinities recorded during the entire six year study.

Profiling of Lake 80A from September to December showed that re-dissolving of the crystalline salt deposits on the bed of the lake again occurred, as in previous years.

The dramatic drop in salinities in February 1990 was due to heavy, unseasonal rains (see 6.6 below).

Table 7. Salinity (ppt) profiles of Lake 80A (Ski Lake) From May 1989 to May 1990.

Depth	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May
0.0	137	21	6	9	16	24	31	44	8	9	10	9
0.1		..	..	..	..	..	..	..	..	..	..	..
0.2		..	..	..	..	..	..	..	..	..	..	..
0.3		21	..	..	..	..	..	..	..	..	..	..
0.4		..	..	..	..	..	..	..	..	..	..	..
0.5		..	6	..	..	..	..	..	..	..	..	..
0.6		..	..	..	..	..	..	..	..	..	..	..
0.7		..	..	..	..	..	..	..	..	..	..	..
0.8		..	..	..	..	..	..	50	..	..	..	25
0.9		..	..	..	19	24	33	..	25	..	19	..
1.0		..	..	..	..	..	..	..	..	9	..	..
1.1			..	..	..	..	..	..	..	..	..	..
1.2			6	9	..	..	..	..	..	..	..	..
1.3					..	..	..	..	..	..	..	..
1.4					..	..	..	151	..	..	..	..
1.5					..	..	..	..	..	..	..	30
1.6					..	..	..	..	..	..	..	..
1.7					..	..	>153	..	..	..	24	..
1.8					149	148	..	..	..	..	..	..
1.9					..	..	..	..	47	..	..	..
2.0					..	..	..	..	..	10	..	..
2.1												

Conclusions
The fifth year of the study demonstrated that high flows following better-than-average winter rains will cause substantial flushing of the system and a dramatic lowering of salinity. In particular, it should be noted that opening of the culvert prior to over-topping of the causeway may make an insignificant contribution to total salt outflow in such years.

The fifth year also provided further confirmation that salt deposited one year, or over several years, will at least partially re-dissolve and flush from the system in years of high flow such as 1989.

6.6 Year Six (1990)

Unseasonal Rainfall and Flows
In the last few days (28th-30th) of January 1990, very heavy rainfalls in the lake system's eastern catchments caused substantial inflows to occur. The water level at Qualandary Crossing - which was already high at 9.2 mSL immediately prior to this event - began rising rapidly (Figure 10).

Late on January 29th or early on the 30th an unauthorised person opened the culvert and outflow began.

The lake level continued to rise and on February 3rd, four or five days after opening of the culvert, flow commenced over the top of the causeway. The water level peaked at 10.26 mSL (0.26m above the causeway) on February 15th and the flow rate at this time is estimated to have been 2 million cubic metres per day.

Flow over the causeway continued until 15 March. The culvert remained open until about the same date.

Salinity was highest at the commencement of outflow through the culvert (it was 69ppt on January 30th), but had declined to 11ppt by February 12th when the rate of outflow was nearing its peak. By March 17th, two days after outflow ceased, salinity had dropped to 6ppt (Figure 10).

The total volume of outflow was 35 million cubic metres and the quantity of salt discharged was 490,000 tonnes. Importantly, only 1.4% (490,000 cubic metres) of the discharged water, but 6% (29,300 tonnes) of the discharged salt, was released through the culvert prior to the lakes overtopping the causeway.

No backflow from the North Branch of the Avon River into Yenyenning Lakes occurred during summer-autumn 1990. Outflow from the culvert was impeded to some (uncalculated) extent from 29th to 31st January and 6th to 24th February as the water level in the Avon continuously exceeded the culvert cease-to-flow level during these periods - by averages of 0.18 m and 0.30 m respectively. On 15th February the Avon peaked at 9.40 mSL (mean daily level), 60 cm below the causeway cease-to-flow level.

Winter Rainfalls and Flows
Rainfall in the Avon River North Branch catchment at the beginning of the 1990 winter wet season was below average. However, by July 18th river flow had exceeded the prescribed minimum rate and the Qualandary Crossing culvert was opened.

At this time, the water level in the lake system was high at 9.71 mSL - well above the culvert cease-to-flow level - due to the system having filled in February. Outflow through the culvert therefore began immediately and continued until the culvert was closed, on August 6th (Figure 10).

Inflows in winter-spring 1990 were slight and, as a result, there was no flow over the causeway during this period. The maximum water level reached was 9.94 mSL (0.06 m below the causeway cease-to-flow level) on September 2nd.

There was no backflow from the North Branch of the Avon River into Yenyenning lakes during winter 1990 and the water level in the Avon was below the culvert cease-to-flow level during the entire period of culvert outflow.

Lake Depths and Salinities

The heavy rainfall and substantial inflows of Jan-Feb 1990 caused a lowering of surface salinity in Lake 80A in late summer and autumn to 8-10ppt (Table 7). In March 1990, when lake depth was at a maximum (>2.0m), profiling indicated that salinity was uniform (at 9-10ppt) with depth. In April and May, however, salinities increased with depth, indicating that salt was again redissolving from the lake bed.

Lake 80A salinities rose from the end of autumn to winter in 1990 (Table 8) due to low-volume winter inflows and continued redissolving of lake-bed salt. By the beginning of spring, salinity had risen to approximately that of sea-water and by mid-summer it had doubled again.

Table 8. Salinity profiles (ppt) of Lake 80A (Ski Lake) From May 1990 to March 1991.

Depth	May	Jun	Aug	Sep	Oct	Dec	Jan	Feb	Mar
0.0	9	..	..	35	37	51	..	88	99
0.1	..	..	..	..	..	..	..	..	..
0.2	..	..	..	..	..	..	..	..	..
0.3	..	..	..	..	..	..	..	..	..
0.4	..	..	..	..	..	..	..	..	..
0.5	..	31	33	..	..	..	59	..	99
0.6	..	..	..	..	..	51	..	88	..
0.7	..	..	..	..	..	..	..	..	..
0.8	25	..	..	..	37	..	..	..	..
0.9	..	..	..	..	..	..	..	..	..
1.0	..	..	..	35	..	..	59	..	..
1.1	..	..	..	..	..	..			
1.2	..	..	..	..	..	..			
1.3	..	..	..	..	..	51			
1.4	..	..	..	..	..				
1.5	30	..	..	..	..				
1.6	..	..	..	..	..				
1.7	..	..	36	..	37				
1.8	..	..	..	..	..				
1.9	..	..	..	..	..				
2.0	..		..		..				

Conclusions

The sixth year of the study showed that opportunities to flush highly saline waters through the culvert immediately prior to lake filling will occasionally arise during summer. Such releases may be damaging to the Avon River ecosystem however and should not be made unless this river is also flowing at a suitable rate. Fortunately this was the case in 1990. From 29th January to 2nd February - the period of unauthorised release through the culvert - the culvert discharge rate ranged from 35,000 to 128,000 cubic metres per day. The flow rate in the Avon at the Brouns' Farm gauging station in the corresponding period varied

between 1.0 and 8.6 million cubic metres per day. The impact of the culvert discharge on the salinity at Brouns Farm can not be calculated, due to lack of data.

The sixth year of the study also demonstrated once again both the flushing effect of high flows (in this case, during summer) and the short term salt accumulation that occurs when inflows (in this case, during winter) are insufficient to overtop the causeway.

7. SUMMARY OF RESEARCH FINDINGS

7.1 Usefulness of the culvert in reducing salinities while maintaining water levels

The 1985-90 study has shown that although stratification does not occur at Qualandary Crossing, the salinity of water reaching the causeway varies significantly during most filling periods.

The usual pattern is that remnant waters at the end of autumn are highly saline. As water levels rise with early winter inflow, so the salinity at the causeway decreases. In these years, opening of the culvert for a period when the water level is still low enables more salt to be released per unit volume of outflow (see Table 9) than when the water level has reached its maximum.

In years of flow *over* the causeway, opening the culvert for a period early in winter *allows more salt to be released, with no effect on subsequent (summer/autumn) water levels*, than would be the case if the culvert was not opened, or was opened later in winter, when water is flowing over the causeway.

Table 9. Comparison of water volumes and salt loads discharged through Qualandary Crossing culvert prior to outflows over causeway. See text for detail.

	Water		Salt		Ratio
Outflow period	Volume thru culvert ($10^6 m^3$)	% of total discharge in flow period (A)	Quantity thru culvert ($10^3 t$)	% of total discharge in flow period (B)	Ratio of % salt to % water (B/A)
1986 (w)	1.9	25	48	30	1.2
1989 (w)	0.93	2.1	34.2	3.1	1.5
1990 (su)	0.49	1.4	29.3	6.0	4.3

In some years (but not all, see 1987) of no flow over the causeway, the same strategy may allow *more salt* to be released *with no greater lowering of water level* than would occur if the same amount of water were released later in winter.

7.2 Consequences for the Avon

The above strategy is not entirely dissimilar from one of simply opening the culvert at the end of autumn (i.e. before winter rains) to drain remnant waters. A crucial difference, however, is that draining before winter rains occur would usually result in a slug of

extremely saline water being released into the Avon River at a time of no river flow. This could be very damaging to the Avon River system.

The 1985-90 study showed that the strategy of not releasing water from the lake system via the culvert until flow in the Avon has reached a prescribed minimum of 15 x $10^3 m^3$/day is effective in reducing the impact of these releases on river salinity. The increases (Table 3) recorded at Brouns Farm in 1986 were not insignificant, however, and this aspect of the consequences of controlled releases from the Yenyenning Lakes needs further monitoring.

7.3 Cost-effectiveness of outflow management strategies

The 1985-90 monitoring program showed that the experimental management regime applied during this period is cost-effective. Salt loads and salinities in the lake system can be reduced by selective discharge of highly saline water at the onset of winter, while management costs (visual monitoring of flow height in the Avon at the commencement of winter and opening and closure of the culvert gate once per year) need not be great.

Data from the water level, outflow and salinity monitoring program showed that more intensive management of outflows could increase the gains achieved during most lake filling cycles. In some years the potential gains may be substantial and may justify the cost of more frequent checks (daily while water levels are rising) on water levels and salinities, and "finer tuning" of culvert openings and closures.

7.4 Effectiveness of the pre-1992 culvert

The 1990-95 study has indicated that, while the management *strategy* employed during this period was sound, the actual gains that were achieved were very small when viewed in a long term context (see 7.5 below), due to the small size and high cease-to-flow level of the single, pre-1992 culvert.

For the management strategy to produce substantial gains, larger culverts (preferably several), with lower cease-to-flow levels, are needed.

7.5 Salinity reduction efforts in the context of natural flushing

The 1985-90 study has also shown (once again) that although reductions in lake system salinity can be achieved by strategic opening of the existing culvert, these reductions are small in comparison with the reductions which occur naturally in periods of high flow (eg. winter 1989 and summer 1990) through the lake system.

The fact that highly effective, natural flushing does periodically occur needs to be borne in mind when considering the cost of the management recommendations presented below.

7.6 Long term accumulation of salt in the lake system

A concern which is frequently raised is that the presence of the causeway may be causing long term accumulation of salt and, as a consequence, a progressive rise in lake salinities.

As explained above (7.5), despite the causeway, natural flushing of the lake system to base salinity levels still occurs (e.g. 1989 and 1990), though less frequently than if the causeway were removed or lowered. It follows that during intervening periods the lake system salt load[4] increases to higher levels than it otherwise would, but may still be expected to return to a similar base level following each flush.

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4 Unfortunately it is not possible to reliably estimate total salt loads for the Yenyenning Lakes system as there is insufficient bathymetric and salinity profile data for this task.

Salinity data for the period 1979-1993 also tend to refute the hypothesis of long term salt accumulation. They show (Figure 12) a cyclical trend with peaks following years of low rainfall (eg. 1979, 1985 et al) and troughs following years of high rainfall (eg. 1983, 1989 and 1992).

It is possible that *base* salinities are somewhat higher with the causeway than without, as with the causeway virtually all inflows are from the eastern catchment whereas without the causeway significant inflow would be received from the (possibly less salty - it used to be) Northern Branch of the Avon River.

8. RECOMMENDATIONS

In the light of the knowledge gained from this study, the Yenyenning Lakes Working Group recommends the following:

i) The causeway at Qualandary Crossing be maintained at its present height (210.66 mAHD).

ii) The (new) gated-culvert at Qualandary Crossing continue to be operated as it has been since 1985. That is, the culvert should be opened as soon as, but not before, the flow in the North Branch of the Avon River at Beverley reaches 15 x $10^3 m^3$/day and be closed on the first Monday in August each year.

iii) The flow monitoring referred to in ii) above continue to be undertaken by officers of the Beverley Shire Council, utilising the gauge board installed under the Vincent Road bridge at Beverley for this purpose (the required flow rate equates to 0.2m on this gauge).

iv) In the event of significant inflow to the Yenyenning Lake system occurring during summer months, the Beverley Shire Council seek Water Authority advice and consult with the Avon River Management Authority concerning the possible opening of the culvert to release saline water.

v) Opening and closure of the Qualandary Crossing culvert only be undertaken by persons so authorised by the Beverley Shire Council.

vi) A log of culvert opening and closure dates and times be maintained by the Beverley Shire Council as this information is essential for the annual reviews proposed at vii) below.

vii) The Avon River Management Authority, in consultation with the Beverley Shire Council, review the effect of the operation of the Qualandary Crossing culvert on salinities in the Yenyenning Lakes and in the Avon River (at Broun's Farm and further downstream), on an annual basis.

viii) The Water Authority provide data and technical support for the annual reviews of vii) above.

ix) The Water Authority modify the existing recording station at Qualandary Crossing to ensure recording of water levels, salinities and flow directions above the new culvert invert level (7.234 mSL), as this information is essential for the annual reviews proposed at vii) above.

x) The Water Authority continue to monitor salinities and depths in Lake 80A (Ski Lake) with salinity profiling to be undertaken on at least three occasions (August, October and December) each year.

xi) A meeting of representatives of the Beverley Shire Council, Avon River Management Authority and WA Water Authority be held in 1994 to clearly identify and confirm the roles and responsibilities of each organisation in i) to x) above.

xii) Beverley Shire Council give consideration to installing additional gated culverts at Qualandary Crossing if and when opportunities arise to do so at an acceptable cost. Prior to installation, Water Authority advice should be sought concerning culvert specifications and placement, particularly the selection of the most cost-effective culvert cease-to-flow levels.

xiii) The Beverley Shire Council seek Water Authority advice prior to undertaking any trenching upstream or downstream of the Qualandary Crossing.

This report completes the work of the Yenyenning Lakes Working Group which is now disbanded.

9. ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions and assistance provided by former members of the Working Group, particularly Rod Banyard and Jeff Waddington (WA Water Authority), Bob Nulsen (Department of Agriculture), Bob Morland (Department of Land Administration) and Ian Crook (former Department of Fisheries and Wildlife).

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The assistance of Robert Powell and the late Don Munro (Department of Conservation and Land Management) in the undertakings of the Working Group is also gratefully acknowledged.

Most of the data presented in this report were collected by the WA Water Authority on behalf of the Yenyenning Lakes Working Group. Figures 1 and 2 of this report have been adapted from maps in ARSMC & WWC 1993; figures 3 and 5 from Anderton 1975. Figure 4 is based on a Water Authority survey diagram. Photographs are by the author.

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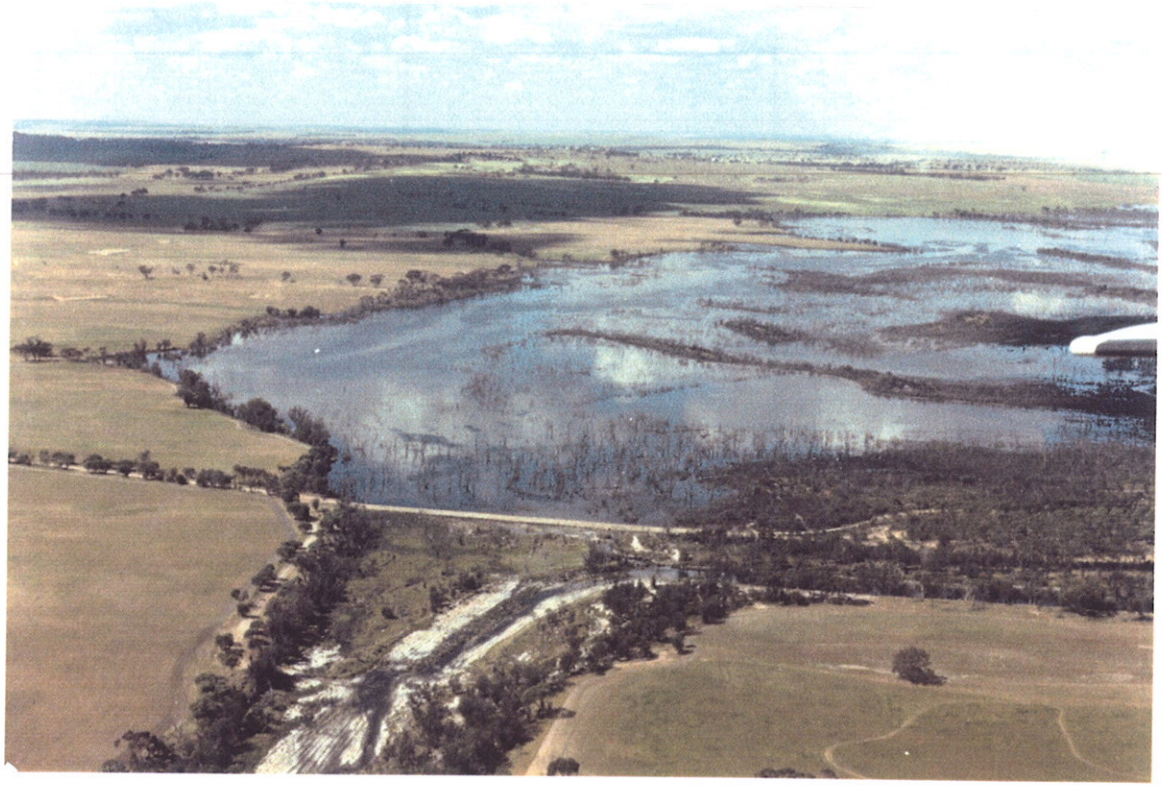
11. APPENDIX

In May 1992, the Beverley Shire Council replaced the gated culvert at Qualandary Crossing with another, larger, culvert. A worm-drive gate was later installed to control flows.

The new culvert has a cross-sectional area of 1.440 m^2 (1200 x 1200 mm), 2.57 x greater than that of the former culvert. Its greater size will allow more water to be discharged in a given time period than was previously possible.

Its cease-to-flow level is 7.234 mSL, 1.640 m lower than that of the former culvert and 2.766 m below the causeway cease-to-flow level. Its lower level will enable water to backflow from the Avon River into the Yenyenning Lakes more frequently than pre-1992.

Early in 1994, the Beverley Shire Council had a trench excavated upstream of the new culvert. It is approximately 550 m long by 3 m wide and at its eastern end is about 1 m below the lake bed. This action, together with the lowering of the culvert outflow level, will permit the release of lake water at lower levels - and higher salinities - than pre-1992.



Photograph 1. The Yenyenning Lakes, October 1978.

Photograph 2. The Causeway at Qualandary Crossing, October 1978.

FIGURE 1: Location map

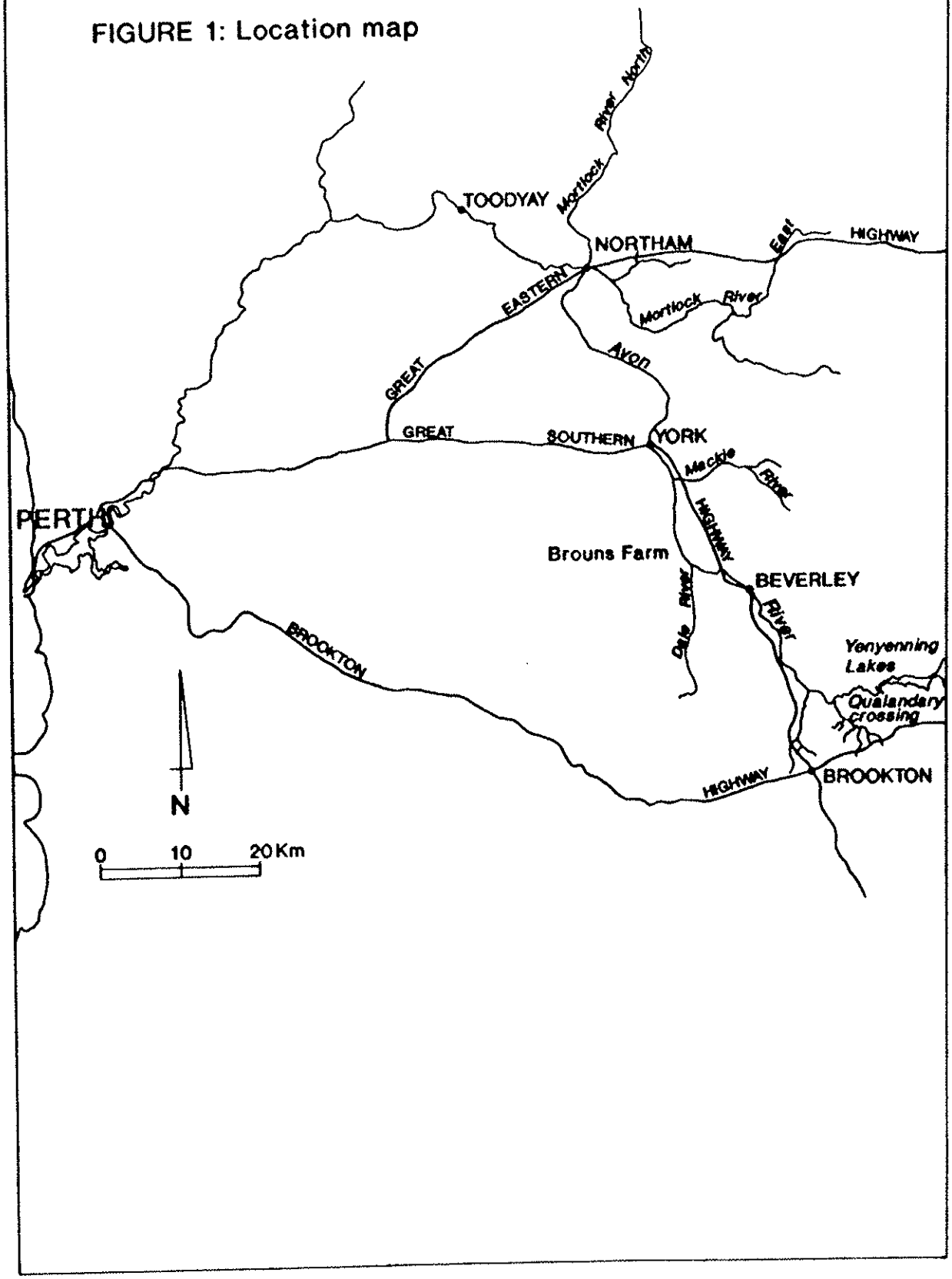
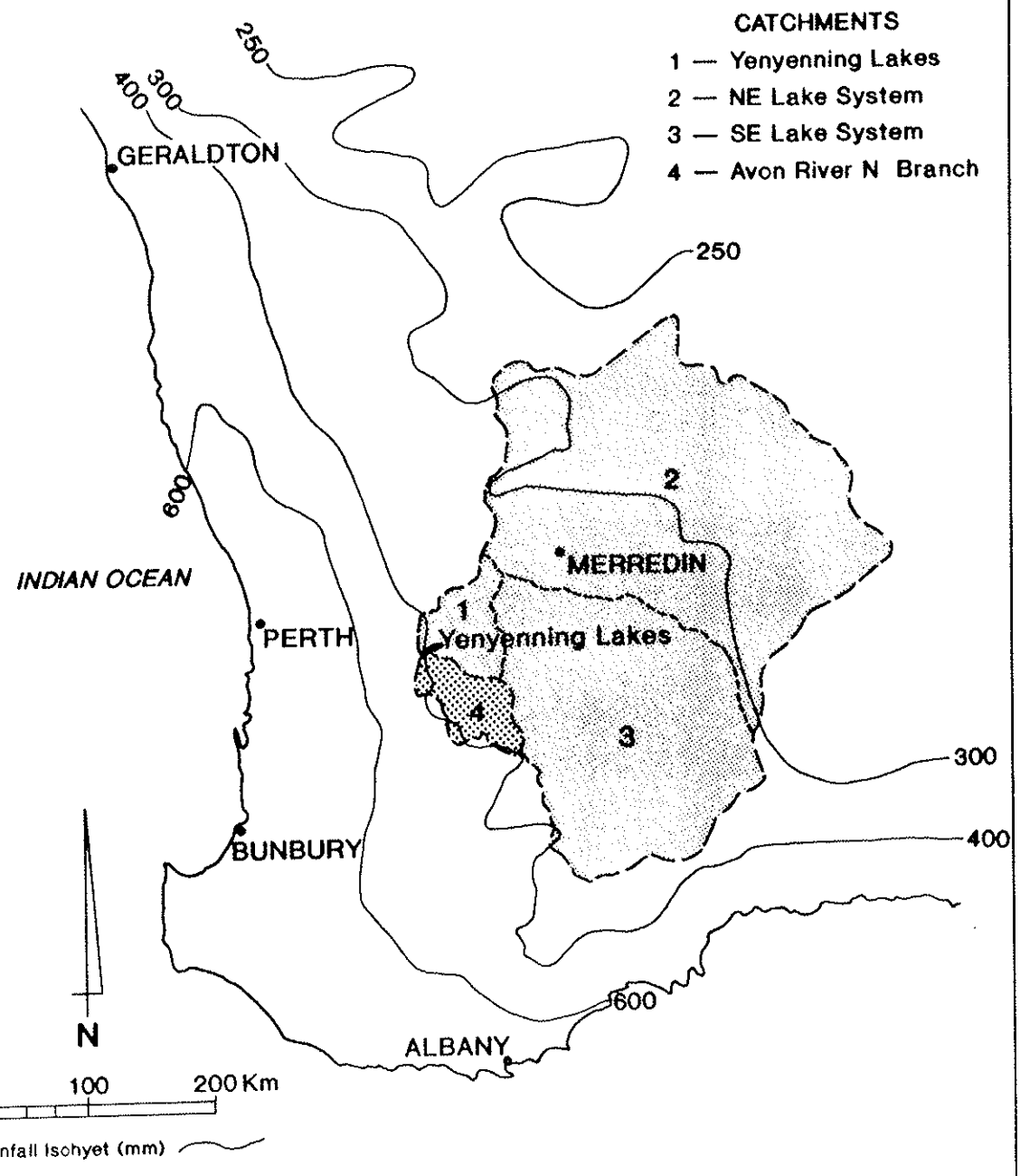


FIGURE 2: Yenyenning Lakes Catchments



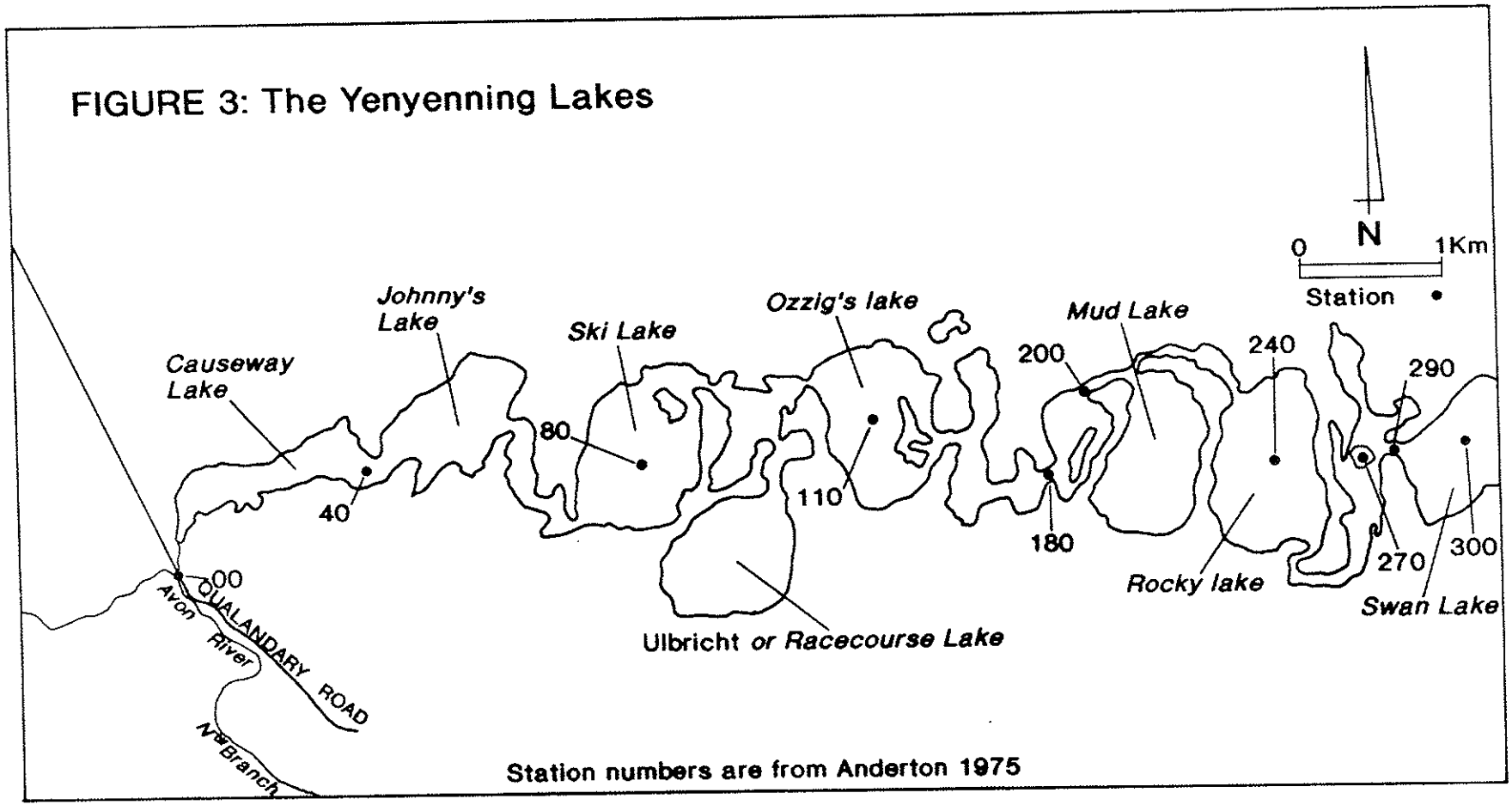


FIGURE 3: The Yenyenning Lakes
N
0
1Km
Station
Causeway Lake
Johnny's Lake
Ski Lake
Ozzig's lake
Mud Lake
00
40
80
110
180
200
240
270
290
300
Rocky lake
Swan Lake
Ulbricht or Racecourse Lake
QUALANDARY ROAD
Avon River
N.E. Branch
Station numbers are from Anderton 1975

FIGURE 4: Cross section of Qualandary Causeway

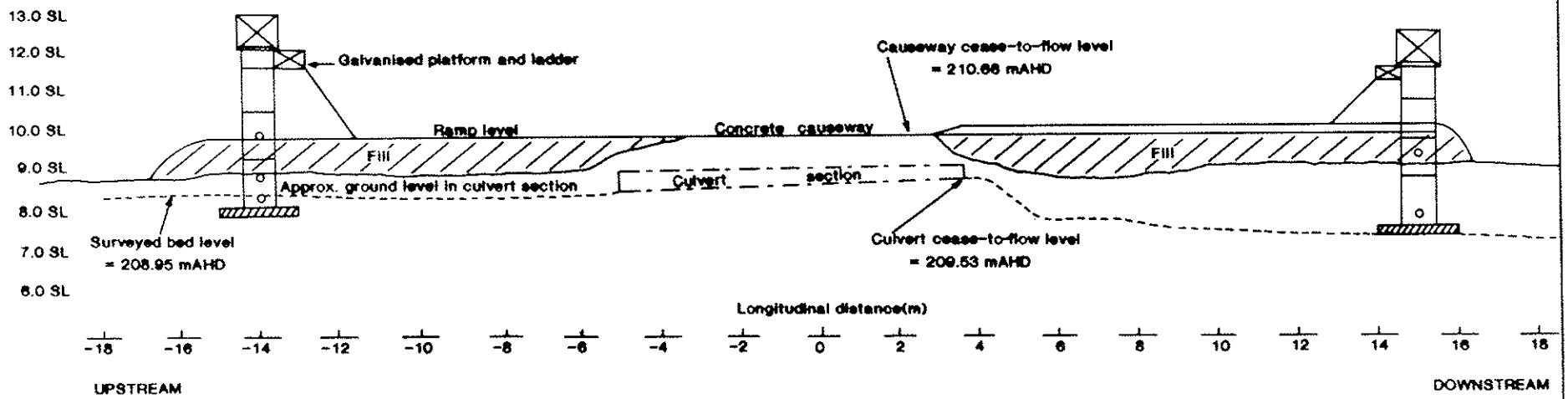
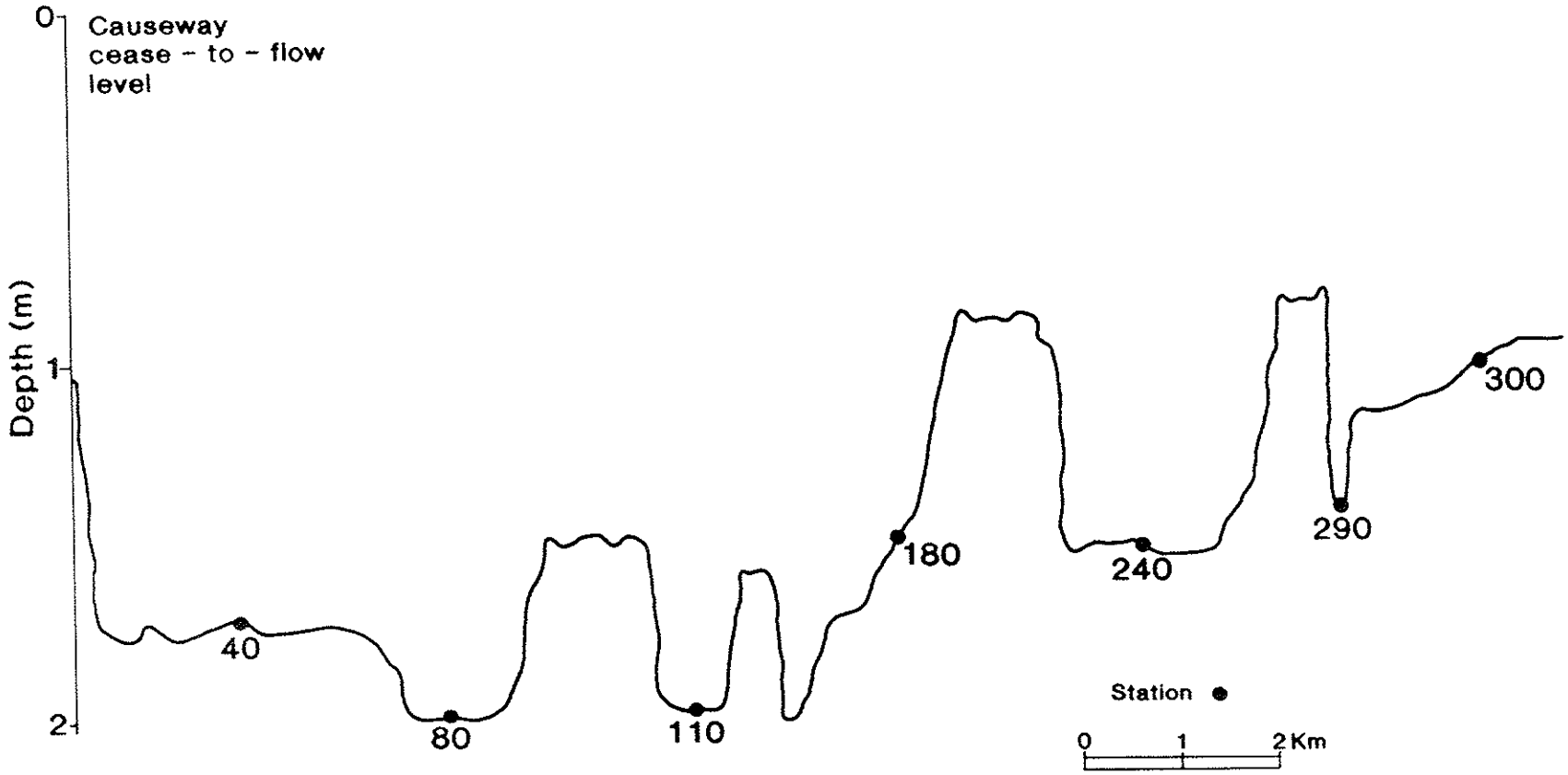


FIGURE 5: Depth profile of Yenyenning lakes



Station numbers are from Anderton 1975

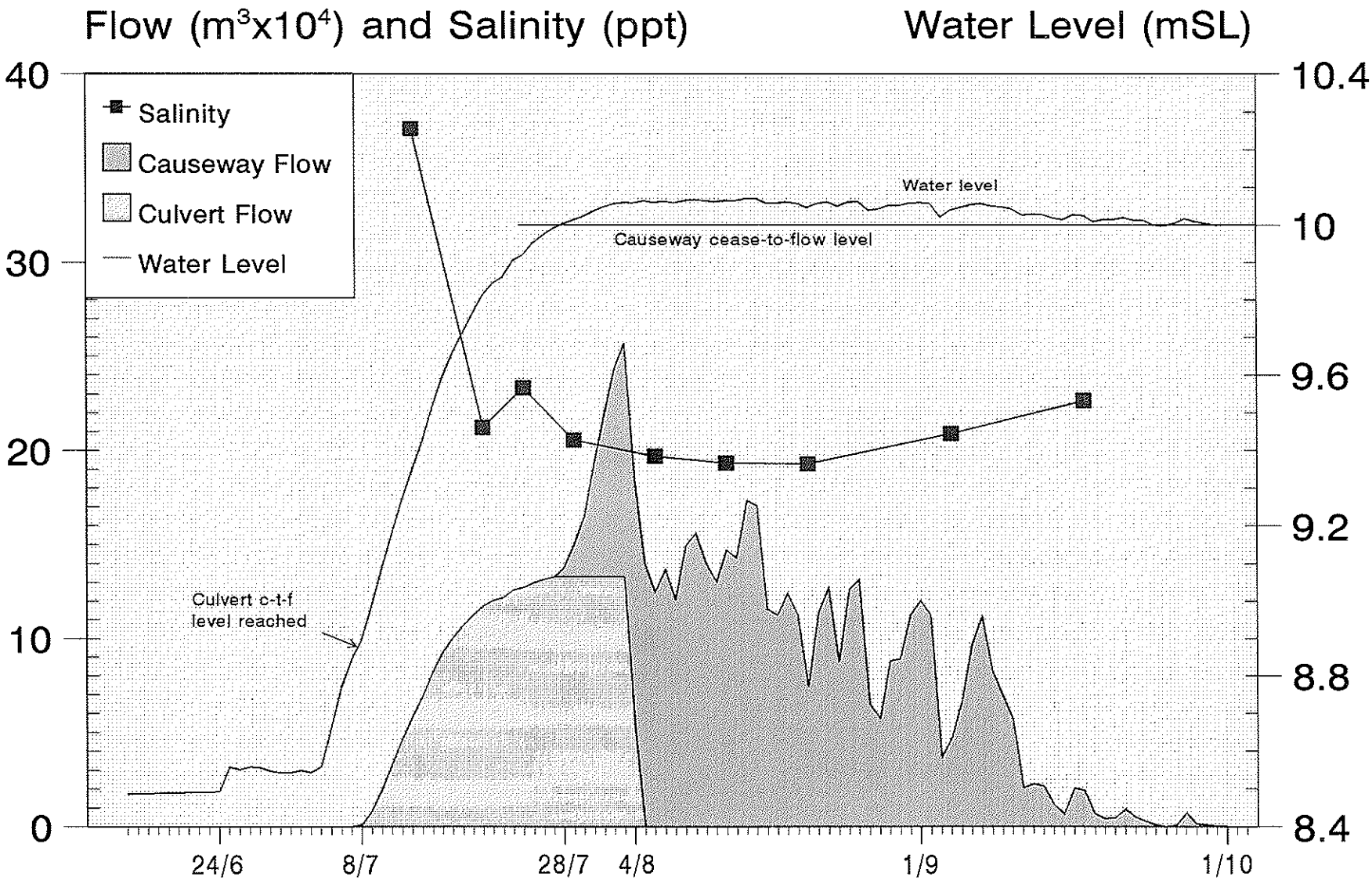


Fig.6 Water levels, outflows and salinities at Qualandary Crossing in 1986.
Culvert was opened 24 June; flow through culvert began 8 July; flow over causeway began 28 July; culvert was closed on 4 August; over-causeway flow ceased 1 Oct.

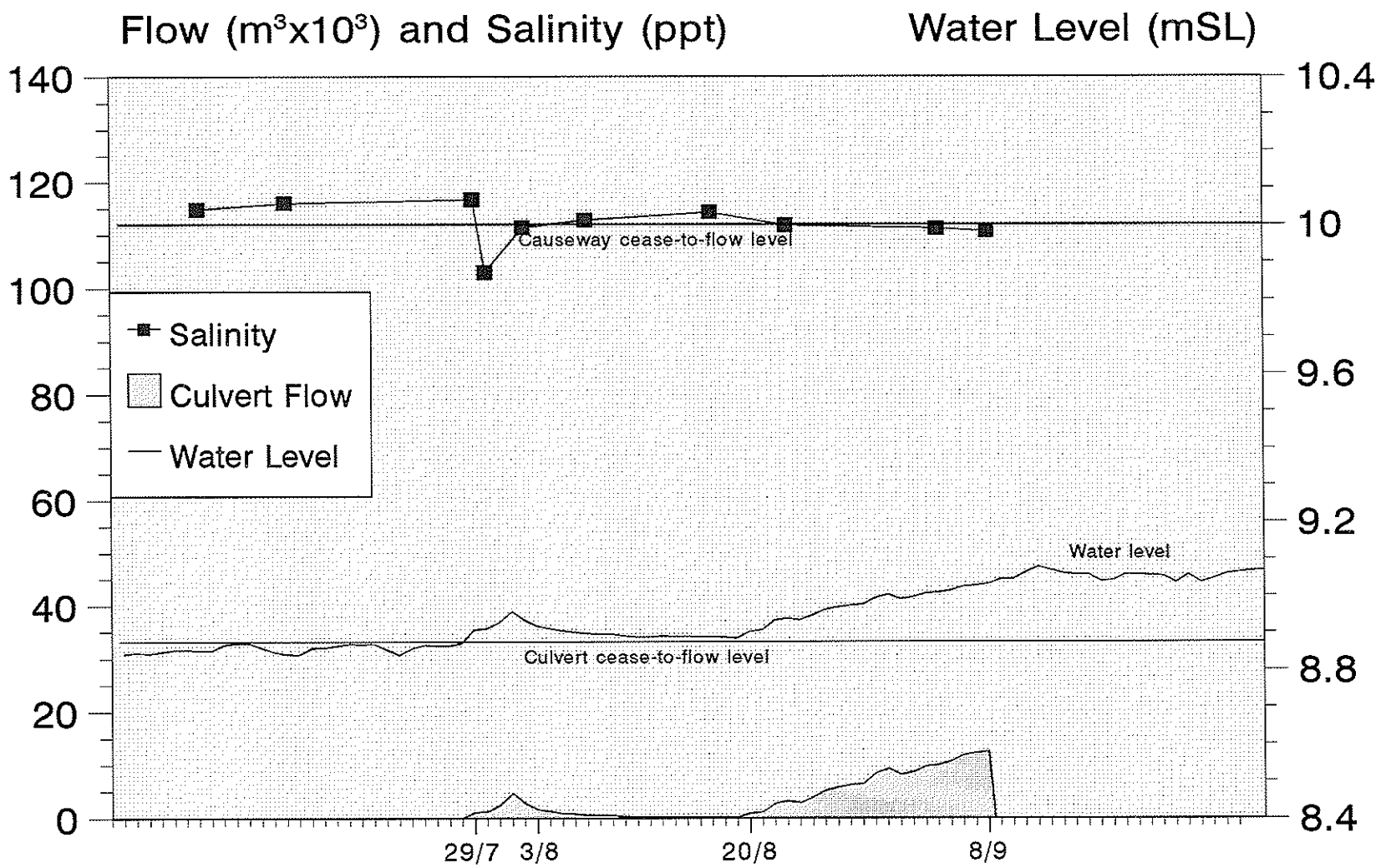


Fig.7 Water levels, outflows and salinities at Qualandary Crossing in 1987.
Culvert was opened 20/6. It was due to be closed 3/8 but was not closed until 8/9. The entire outflow was through the culvert.

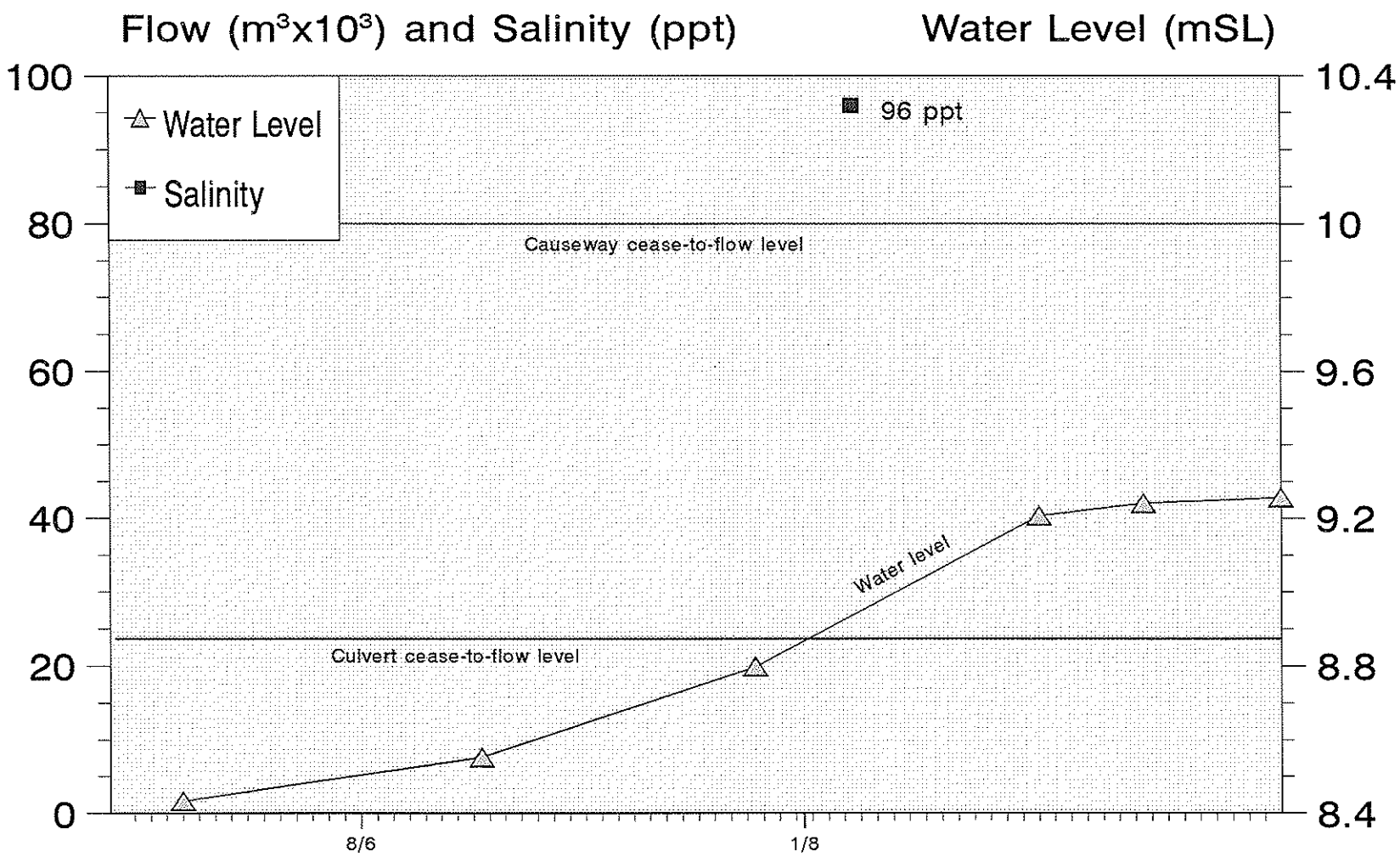


Fig.8 Water levels, outflows and salinities at Qualandary Crossing in 1988.
Culvert was opened 8 June and closed 1 August; there was no outflow in 1988.
Water level was not measured continuously in 1988.

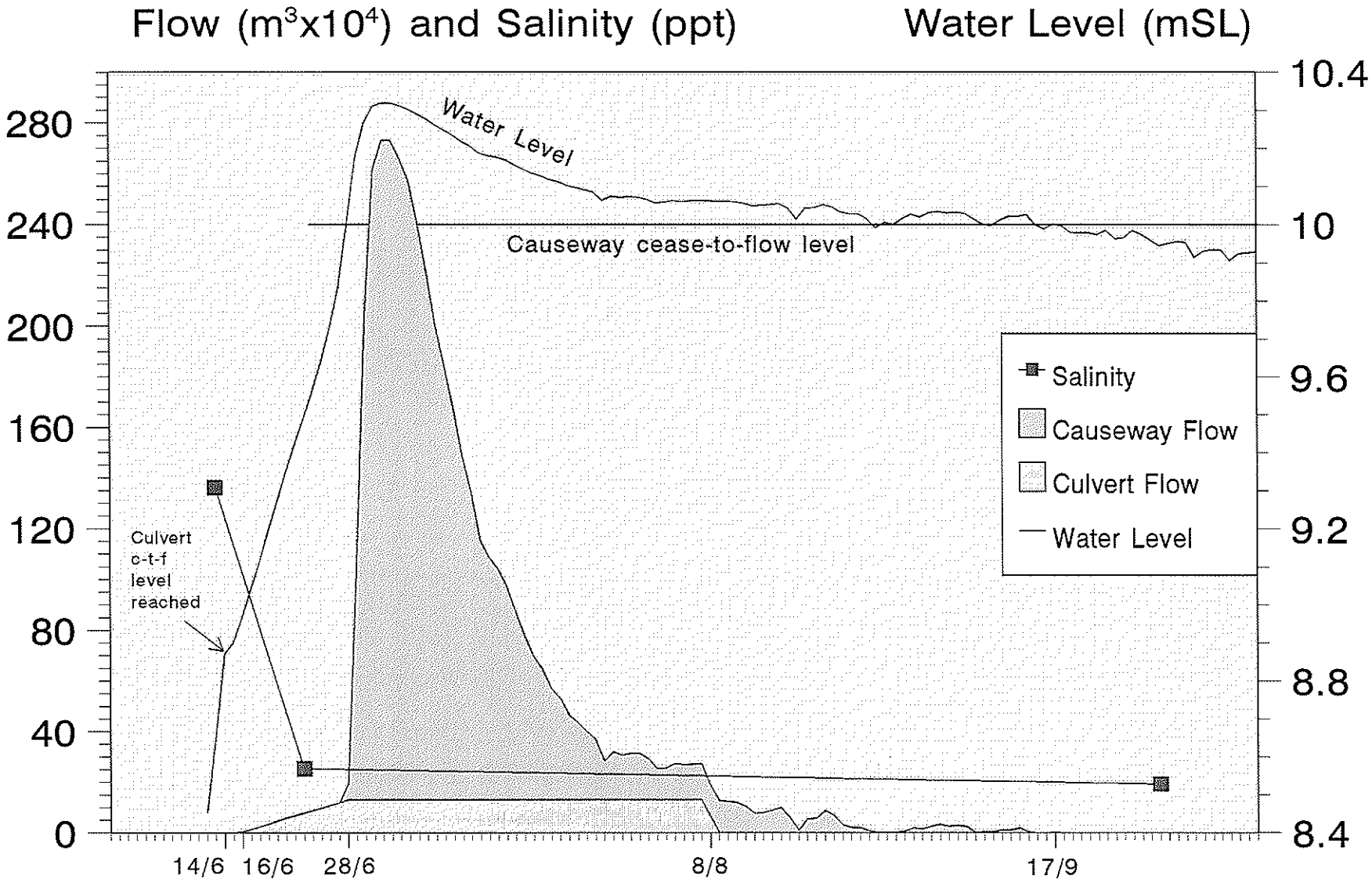


Fig.9 Water levels, outflows and salinities at Qualandary Crossing in 1989.
Culvert c-t-f level reached 14/6; culvert opened 16/6 and flow began;
flow over causeway began 28/6; culvert closed 8/8; all flow ceased 17/9.

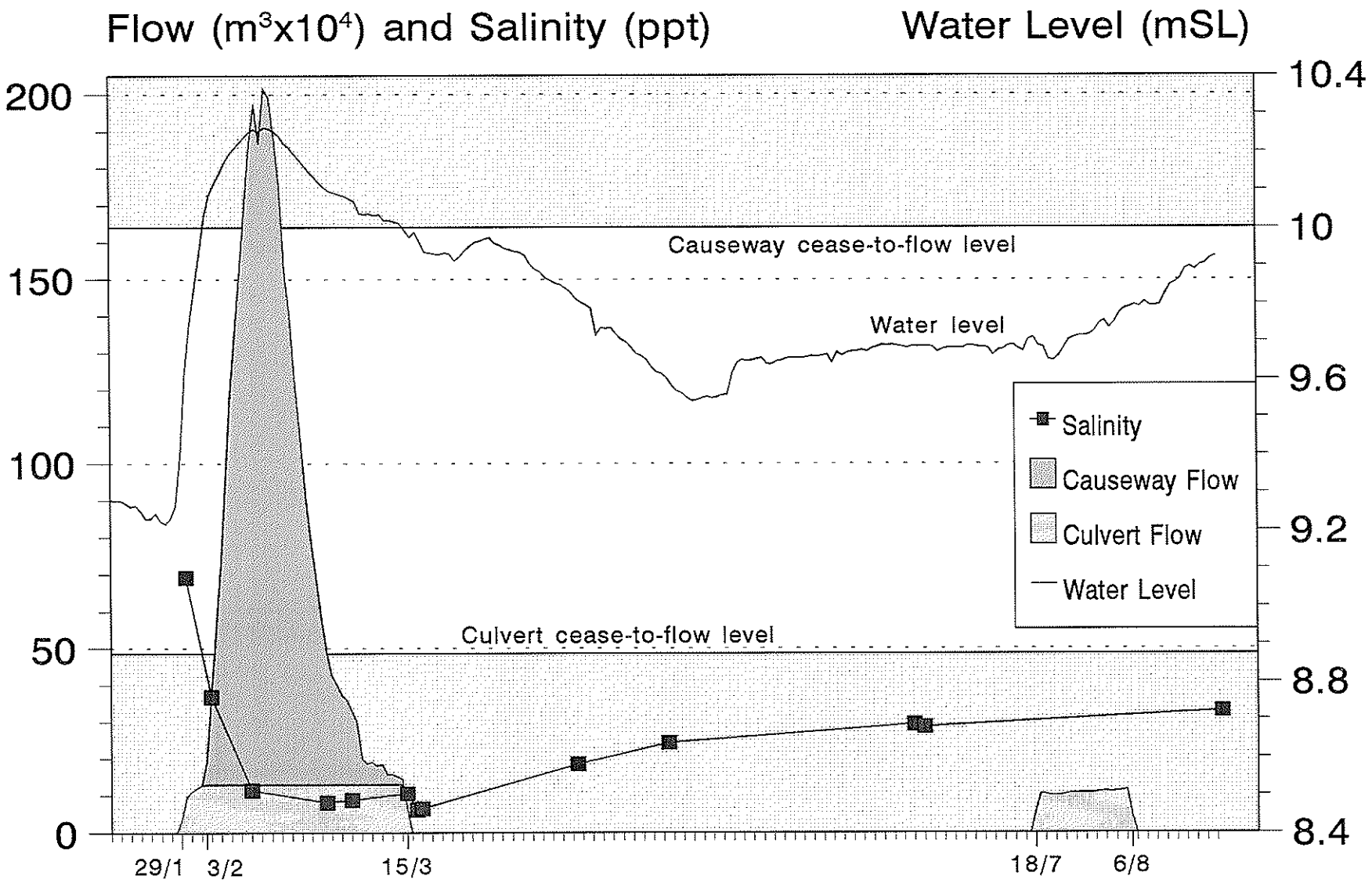


Fig.10 Water levels, outflows and salinities at Qualandary Crossing in 1990.

Summer: culvert opened 29/1, closed approx 15/3. Flow over causeway began 3/2.
Winter: culvert opened 18/7, closed 6/8.

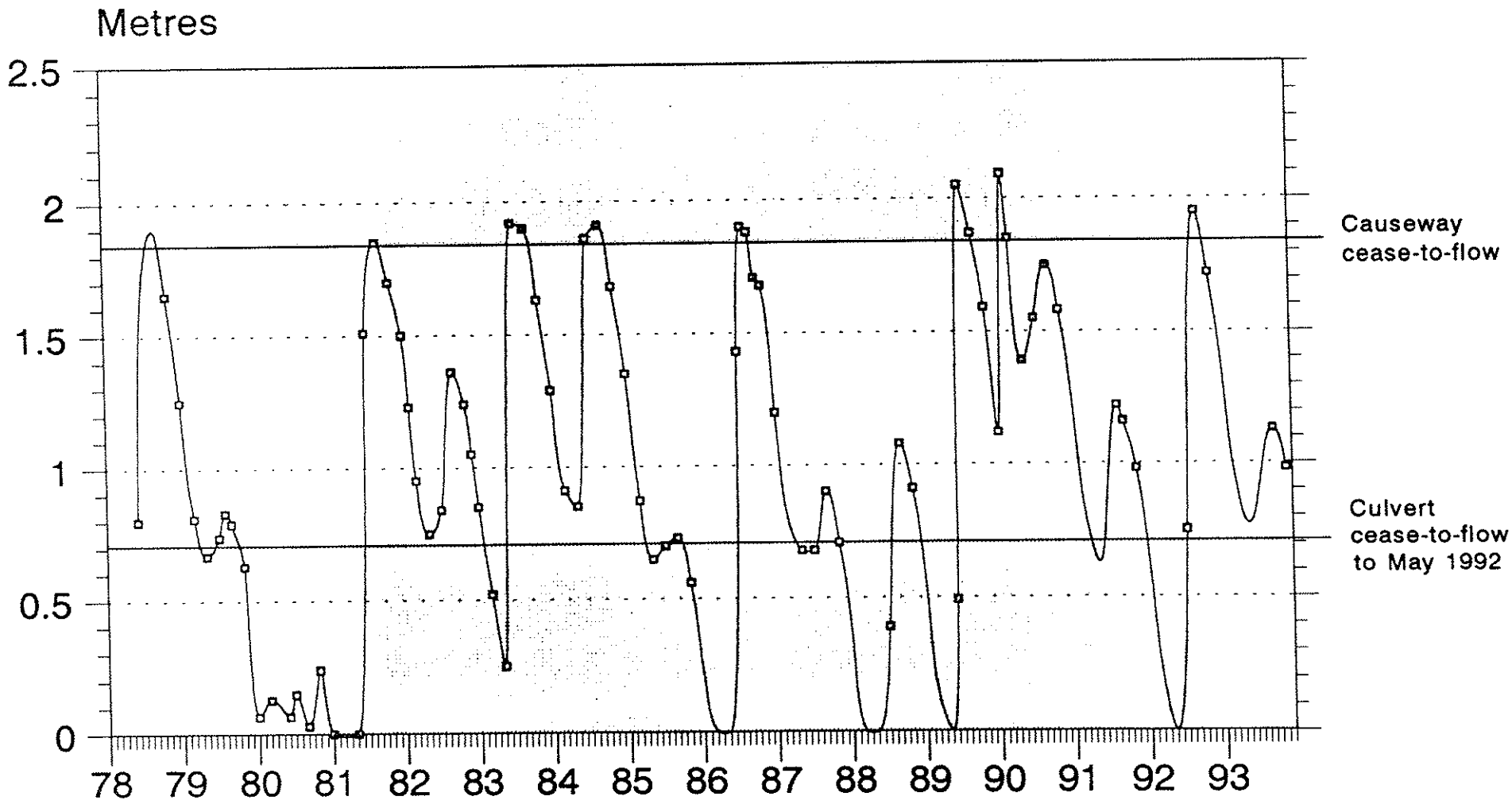


Fig.11 Depth of Yenyenning Lakes, 1978-1993.
Nb: (i) lakes over-topped causeway in 7 winters & 1 summer during 16 yrs.
(ii) lakes reached culvert c-t-f level in 15 of 16 winters.

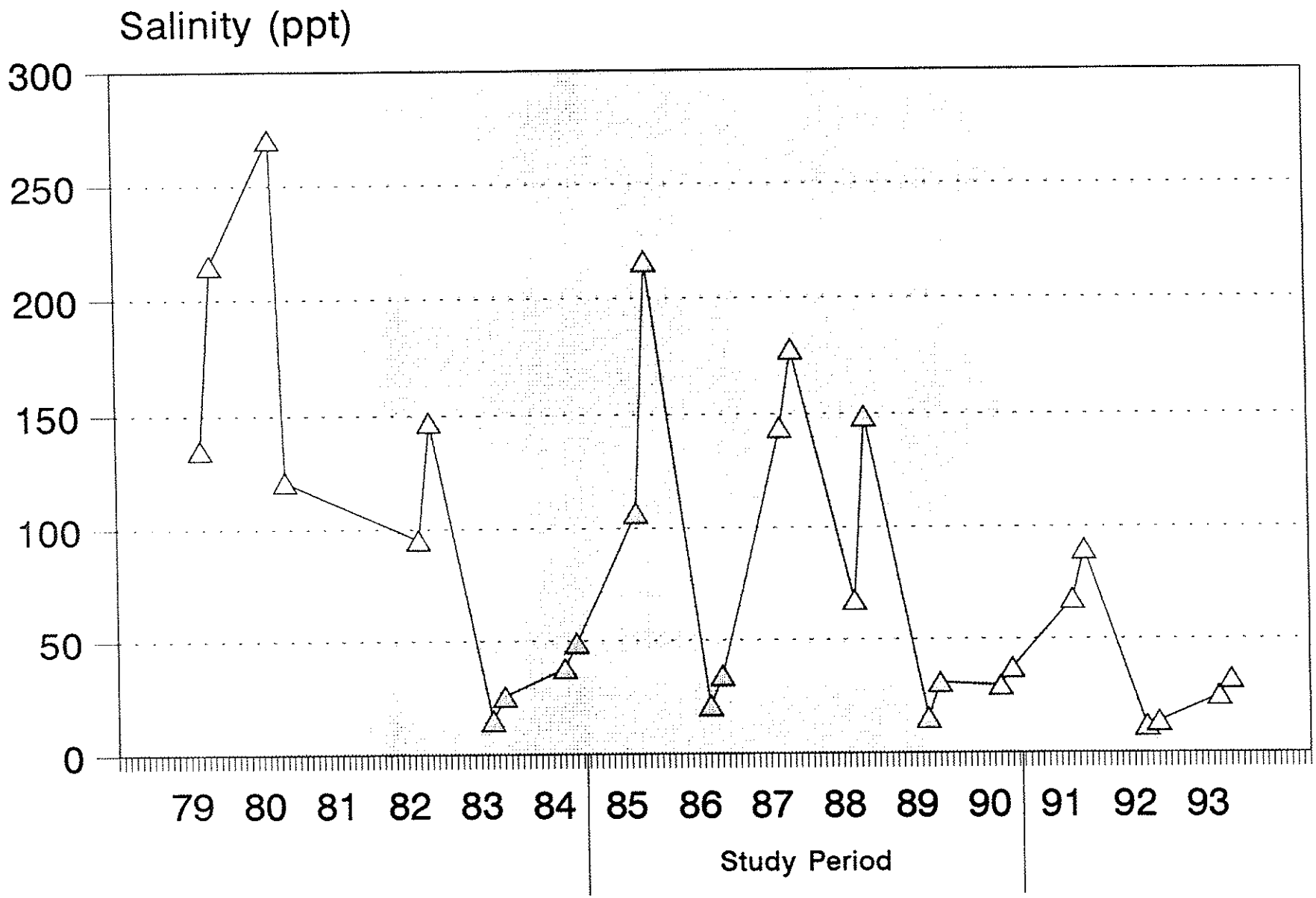


Fig.12 Salinities at Qualandary Crossing, Sept and Nov each year, 1979-93.

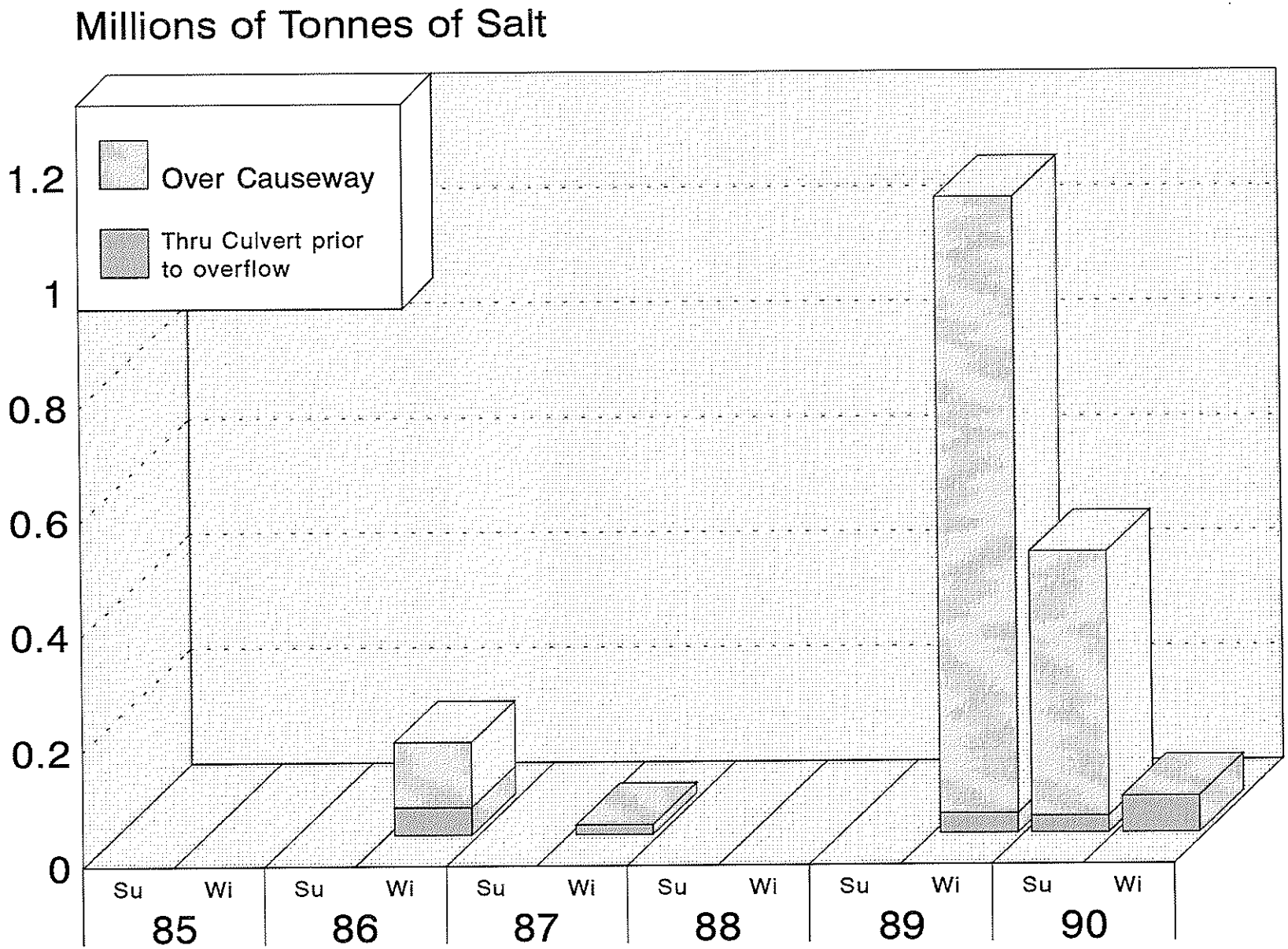


Fig.13 Salt loads discharged at Qualandary Crossing in summer (Su) and winter (Wi) 1985-90.

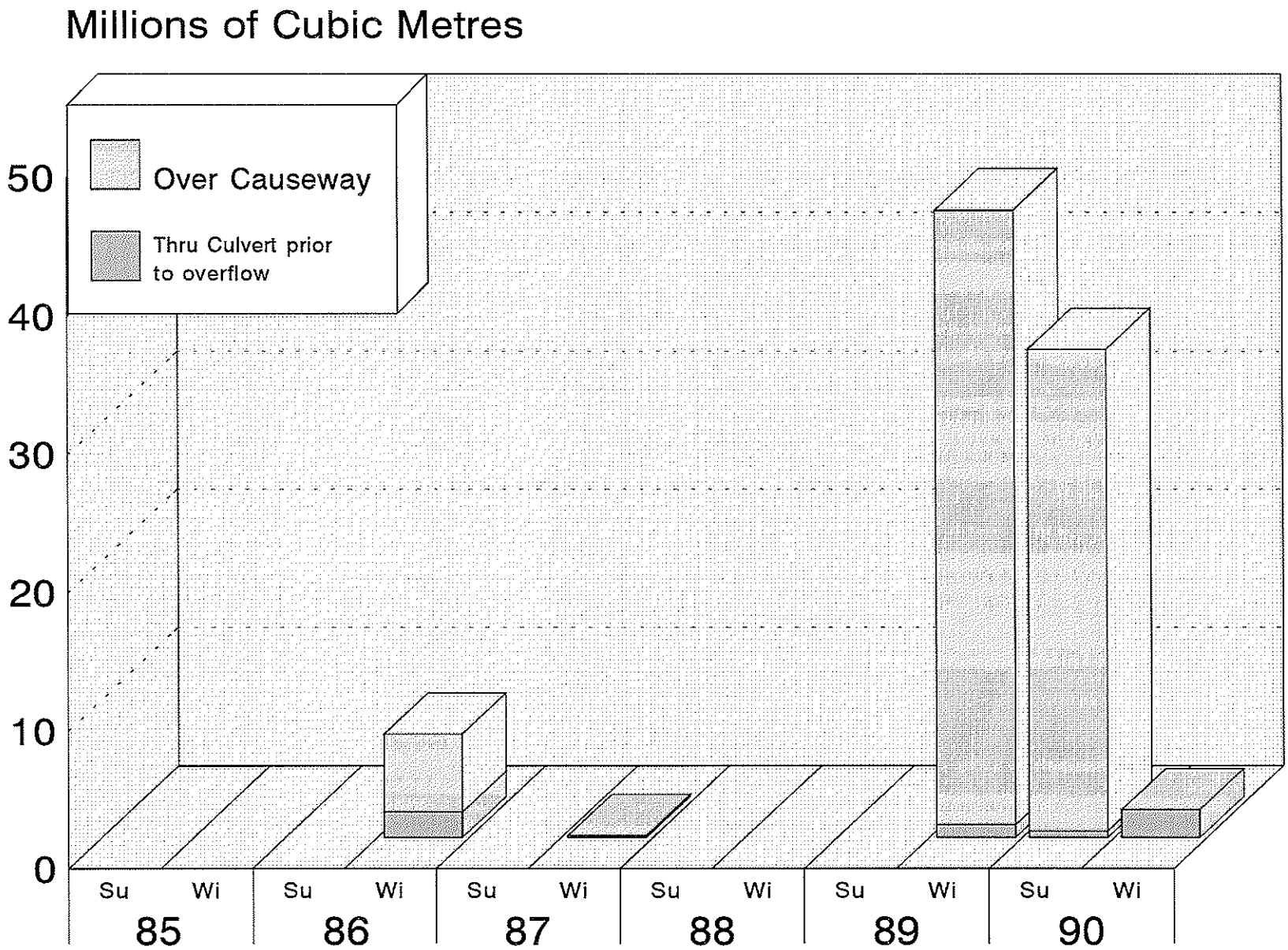


Fig.14 Water volumes discharged at Qualandary Crossing in summer (Su) and winter (Wi) 1985-90.