Department of Conservation & Land Management

Lake Toolibin Evaluation & Design of Outflow Control Works

Feasibility Report : Final

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1. INTRODUCTION

1.1 Background

Lake Toolibin is seriously threatened by salinisation from both rising groundwater levels and surface water inflows from the catchment. This has caused a decline in the species diversity of the lake's environs, with vegetation along and near the Western shoreline suffering significant deterioration. Without considerable, urgent action, the lake will become rapidly salinised.

To protect Toolibin Lake and its environs from further salinisation and to reclaim areas already degraded, the Department of Conservation and Land Management (CALM), the community and other government agencies (Environment Australia, Agriculture Western Australia and Water and Rivers Commission) developed a Toolibin Lake Recovery Plan. This Plan aims to achieve both restoration of the lake itself and restoration of hydrological catchment processes.

The first stage of the recovery program was completed in 1996, with the construction of a large separator and diversion drain to allow the saline initial and end of season flows to be diverted, while allowing the fresher winter flows to be directed into the lake. Groundwater pumping began in March 1997, once the transfer system for groundwater to Lake Toolibin had been completed. A digital groundwater model has recently been completed to assess the impact of current and future pumping programs. The model has made a number of recommendations regarding the extension of the existing groundwater pumping program, of which implementation will begin in 1999.

As part of continuing work on surface water management, CALM has commissioned JDA Consultant Hydrologists to investigate the effectiveness, and prepare a design for lake outflow control at Lake Toolibin.

1.2 Scope of work

The broad objective of this work is to provide a cost-effective means of assisting in protecting the lake by improving the control of lake salinity and regeneration conditions on the lake bed. Temporary increase in outlet flows from Toolibin Lake would allow for more frequent flushing of accumulated salt in the lake, thereby reducing the salt load and limiting the maximum salinity reached as the lake dries by evaporation.

The scope of work undertaken as part of JDA's commission includes:

- The evaluation of the effectiveness of an outflow control structure between the lake and the existing diversion channel. The structure will be used to drain low volume, highly saline pools, and to control flooding of the lake floor.
- The provision of a detailed design of the outflow control works.

2. LAKE CHARACTERISTICS & DATA

2.1 Catchment Details

Toolibin Lake lies approximately 30km east of Narrogin (Figure 1), 250 km south-east of Perth at the top of the Northern Arthur River Catchment, which drains into the Blackwood River. The lake is the first in a series of nine lakes and is the only major lake in the chain which has not become saline. It is understood that the occurrence of several dolerite dykes have restricted significant groundwater inflow to the lake from the north.

The lake is an ephemeral wetland located in the middle of a broad valley floor, covering approximately 300 ha. About one in three years it fills and overflows, with a maximum depth of 2m when full. The area receives 375 - 425 mm in annual rainfall and 2000 mm annual evaporation. At least 90% of the 45 000 ha catchment has been cleared and the area and severity of dryland salinity continues to increase.

Toolibin Lake and its environs provide an important breeding habitat for a variety of waterfowl, and it is one of the last inland freshwater lakes in the south-west. It is the only lake which has retained a sheoak/melaleuca association across significant parts of the lake floor. Toolibin Lake has been classified as a "Wetland of International Importance" under the Ramsar Convention.

The nature reserves including and adjoining Toolibin Lake are managed by the Department of Conservation and Land Management (CALM) on behalf of the National Parks and Nature Conservation Authority (NPNCA).

2.2 Study Data

Data used to perform this study is summarised in Table 1. The locations of the salinity monitoring sites and gauging stations presented in Table 1 are shown in Figure 2. Time series plots of inflow, lake volume, and rainfall for the period 1979-1997 are shown in Figures 3 to 5.

This data was used to formulate a salt and water balance model of the lake for the period 1979 to 1997. Establishment of this model and use of the study data is further discussed in Section 3.

TABLE 1: STUDY DATA

Data	Data Source	Period of Record Used	Comments
Inflow Data • Daily Volume (m^3/day) • Daily Salinity (mg/L)	Water & Rivers Commission Station No. 609010 Northern Arthur River	1979 – 1997	Factored to represent total inflow and total salt load into Lake Toolibin.
Lake Volume Data • Daily Water Level (m AHD) • Storage-Area-Elevation Curve	Water & Rivers Commission Station No. 6009009	1979 – 1997	Storage Elevation Curve deemed unreliable by Stokes & Sheridan (1985) below approx 0.5 million cubic metres of storage (297.0mAHD) due to the flat bottomed nature of the lake Lake overflow level assumed at 297.56 mAHD (JDA, 1995)
Lake Salinity Data • Lake Salinity Spot Samples (mg/L)	Water & Rivers Commission Station No. 6009009 Station No. 60091024 Station No. 60091025 Station No. 60091026 Station No. 60091027 Station No. 60091028	1981 – 1985	Data used to estimate the salt load in Lake Toolibin for approx 50 dates. For records 1981-1985 multiple sites sampled and averages determined.
	Department of Conservation & Land Management Station No. 6091024	1990-1994	Single site sampling post 1990 on basis that previous data showed relatively uniform salinity.
Rainfall Data • Daily Rainfall (mm)	Bureau of Meteorology Station No 010 654 Wickepin Post Office	1979-1997	
Evaporation Data • Average Monthly (mm)	Luke et al (1985) Narrogin	-	Based on estimated monthly evaporation from dams in various agricultural areas. Values are dam evaporation and not Class A pan evaporation.

3. OUTFLOW CONTROL EVALUATION

3.1 Development of a Water & Salt Balance Model

A daily water and salt balance spreadsheet model for the lake was developed based on the following equations and using data as specified in Section 2.

$$V_i=V_{i-1}+I_i+R_i-E_i-O_i-P_i-D_i$$

$$SL_i=SL_{i-1}+ISL_i-OSL_i-PSL_i-DSL_i$$

where V_i= Lake Storage Volume at day i (m^3)

V_{i-1} = Lake Storage Volume at day i-1 (m^3)

I_i = Inflow Volume for day i (m^3/day)

R_i = Rainfall Volume on Lake Surface for day i (m^3/day)

E_i = Evaporation Volume from Lake Surface for day i (m^3/day)

O_i = Overflow from Lake for day i (m^3/day)

P_i = Piped Outflow Volume for day i (m^3/day)

D_i = Channel Diversion of all inflow when inflow salinity greater than 1000 mg/L (m^3/day)

SL_i = Lake Salt Load at day i (kg)

SL_{i-1} = Lake Salt Load at day i-1 (kg)

ISL_i = Inflow Salt Load for day i (kg/day)

OSL_i = Overflow Salt Load for day i (kg/day)

PSL_i= Piped Outflow Salt Load for day i (kg/day)

DSL_i = Channel Diversion Salt Load for day i for inflow salinity greater than 1000 mg/L (kg/day)

At any time the water within the lake was assumed to be uniformly mixed (ie uniform salinity). When the lake was empty it was assumed salt contained in the lake was stored in the bed of the lake and mobilised at the next inflow event.

Infiltration and groundwater influences were neglected in the water balance model.

For the initial calibration of the model piped outflow was set to zero. The diversion channel was constructed in 1995, its effect was only included from 1996 onwards.

The diversion channel was modelled assuming all inflows with salinities greater than 1000 mg/L would bypass Lake Toolibin.

3.2 Model Calibration

3.2.1 Initial Calibration

Model calibration was performed over the period 1979-1997, with the following calibration parameters :

- Initial Salt Load in Lake Toolibin (at 1 January 1979). This parameter was set to 430 tonnes to achieve a match to the initial historical salt load estimate of 854 tonnes in the lake on 1 July 1981.
- Evaporation. A reduction factor of 0.8 to Narrogin evaporation was applied to account for reduced evaporation due to the salinity of water in the lake and also the existing vegetation cover.
- Inflow. Daily inflow volumes for Water & Rivers Commission Gauging Station No. 609010 (Northern Arthur River) was increased by 15% to represent total catchment inflow.
- Rainfall. No areal reduction factor was applied to rainfall on the lake body.
- Existing Overflow Level. This was set to 298.3 for the period pre 1990 and set to 297.56 (surveyed level) for post 1990. Adopting the surveyed 297.56m value pre 1990 resulted in overflow volumes being too large, and difficult calibration of lake salt loads and volumes.

Model parameter values were selected to provide the best possible match in terms of salt load within the lake over the period of 1979 to 1997. The calibration used existing lake level data to estimate overflow volume and salinity from the lake over the calibration period. The salt load remaining in the lake was then determined at a daily timestep.

Results of the calibration provided good agreement with estimated historical lake salt loads with the majority of calculated lake salt loads to within 20% of historical levels. Times where large differences occurred were typically periods at the commencement of inflow events. It is considered possible that salt stored within the lake bed during these periods may not have been mobilised prior to the salinity readings being taken.

Calibration results are shown in Appendix 1, and presented in time series format in Figures 6 and 7.

3.2.2 Calibration Verification (Final Calibration)

A further check on the calibration was performed by developing a discharge rating curve for the lake overflow based on results from the initial calibration, and rerunning the model to calculate lake volumes.

Similarly to the initial calibration, the results showed good agreement with estimated historical lake salt loads with the majority of calculated lake salt loads to within 20% of historical levels (Appendix 1).

With respect to the influence of the diversion channel, the results indicate the channel as having reduced the extent of salt load increase in the lake for the January 1996 to December 1997 period. The increase without the diversion channel for this period was found to be approximately 2.4 tonnes, while with the diversion channel the increase was found to only be 0.7 tonnes (70% reduction). This effect is shown in Figures 6 and 7.

3.3 Outflow Pipe Modelling

Following from the calibration, the water balance model was modified to allow the modelling of a piped outflow from Lake Toolibin. Equations used to determine pipe outflow rates were based on hydraulic relationships as defined for compensating basins in the WP Software model RAFTS-XP (Appendix 2), and assume free discharge to the receiving channel.

The piped outflow was defined by the variables as shown in Table 2. A range of values for the variables of pipe diameter, pipe number, and pipe invert level were used to perform a sensitivity analysis of the effectiveness of the piped outflow in terms of salt removal.

Based on Stokes and Sheridan (1985), the outlet level was set at 297.0m AHD. Variations in the lake bed elevation below 297.0m AHD make storage-elevation data unreliable, and it is considered that water contained in the lake may not freely drain toward an outlet located below this level. The sensitivity of salt removal effectiveness to outlet level was however tested over a 0.2m variation either side of 297.0m AHD.

TABLE 2: PIPE OUTFLOW MODELLING VARIABLES

Variable	Adopted Values
Pipe Diameter (mm)	225, 300, 375, 450, 525, 600, 675, 750, 825, 900, 1050
Pipe Length (m)	10
Pipe Slope (m/m)	0.01
Pipe Roughness (n)	0.013
Pipe Invert Level (m AHD)	296.8, 297.0, 297.2
Number of Pipes	1,2

The modelling of the piped outflow was performed over the same 1979 to 1997 period as the calibration. Results of the modelling are shown in Figures 8, 9 & 10 for the range of different outflow configurations modelled. Results are also presented in Tables 3 to 5. The effectiveness of salt removal was calculated based on the salt remaining in the lake on 10 November 1994, the most recent date with a recorded salinity reading for the lake. The efficiency of salt removal for the existing diversion structure installed in 1995 was also estimated.

Summarising the results:

- The amount of flow and salt per pipe which can be released from the lake even for a small diameter outlet pipe is significant (Table 3). For a 300mm outlet pipe flowing full (72 litres/sec) and assuming a discharge salinity of 500 mg/L, 6220 m^3/day and approximately 3 tonnes of salt can be removed daily.
- Significant reductions in salt load within Lake Toolibin could have been possible during the period 1979-1997 if a diversion channel and outlet pipe had existed (Tables 4 & 5). For a diversion channel with a single outlet pipe placed at 297.0m AHD reductions of the salt load contained in the lake of typically 80% resulted. Of this reduction 60% is due to the impact of the diversion channel with a further 20% reduction as a result of the outlet pipe. The 80% reduction in salt load equates to an estimated 8000 tonne reduction over the 19 year modelling period.
- Increasing the pipe diameter above 450mm or providing a duplicate outlet pipe of similar size was found to not significantly increase the efficiency of salt removal.
- Another factor affecting the efficiency of salt removal is the level at which the outlet was set. Varying the outlet level by 0.2m was found to vary the efficiency by approximately 5%.

TABLE 3: OUTLET PIPE DISCHARGE VS LAKE WATER LEVEL

Outlet Pipe Diameter (mm)	Pipe Full Flow (litres/sec)	Discharge for Various Water Levels above Outlet Pipe Invert (litres/sec)			
		0.25m	0.50m	0.75m	1.0m
225	36	40	77	93	117
300	72	55	126	167	204
375	126	64	173	226	305
450	199	73	223	346	424
525	299	78	283	444	576
600	417	82	315	535	733
675	559	86	341	628	865
750	726	90	367	726	999
825	924	93	392	817	1144
900	1142	97	415	865	1283
1050	1697	103	440	967	1607

TABLE 4: EFFECT OF SINGLE PIPE OUTLET ON LAKE TOOLIBIN SALT LOAD

Existing Diversion Channel Modelled	Outlet Pipe Diameter (mm)	Modelled Salt Load in Lake Toolibin at 10 November 1994 (tonnes) and % Salt Reduction for Different Pipe Inverts					
		296.8m AHD		297.0mAHD		297.2m AHD	
		tonnes	% redn	tonnes	% redn	Tonnes	% redn
No	No pipe	9874	-	9874	-	9874	-
Yes	No pipe	3625	63	3625	63	3625	63
Yes	225	1053	89	1852	81	2504	75
Yes	300	922	91	1643	83	2246	77
Yes	375	876	91	1551	84	2107	79
Yes	450	853	91	1504	85	2027	79
Yes	525	839	92	1479	85	1982	80
Yes	600	830	92	1466	85	1954	80
Yes	675	824	92	1459	85	1938	80
Yes	750	819	92	1454	85	1926	80
Yes	825	814	92	1451	85	1917	81
Yes	900	810	92	1447	85	1910	81
Yes	1050	803	92	1442	85	1898	81

TABLE 5: EFFECT OF DUAL PIPE OUTLET ON LAKE TOOLIBIN SALT LOAD

Existing Diversion Channel Modelled	Outlet Pipe Diameter (mm)	Modelled Salt Load in Lake Toolibin at 10 November 1994 (tonnes) and % Salt Reduction for Different Pipe Inverts					
		296.8m AHD		297.0mAHD		297.2m AHD	
		tonnes	% redn	tonnes	% redn	Tonnes	% redn
No	No pipe	9874	-	9874	-	9874	-
Yes	No pipe	3625	63	3625	63	3625	63
Yes	225	849	91	1579	84	2171	78
Yes	300	803	92	1474	85	1995	80
Yes	375	784	92	1431	86	1920	81
Yes	450	775	92	1419	86	1888	81
Yes	525	769	92	1414	86	1872	81
Yes	600	765	92	1412	86	1862	81
Yes	675	761	92	1409	86	1855	81
Yes	750	757	92	1407	86	1849	81
Yes	825	754	92	1405	86	1844	81
Yes	900	751	92	1403	86	1840	81
Yes	1050	746	92	1400	86	1834	81

3.4 Modelling of Future Impact

Further modelling using the piped outflow was performed assuming an initial salt load similar to current conditions in Lake Toolibin. An initial salt load of approximately 10,000 tonnes was assumed in the lake with modelling again performed using the 1979-1997 historical data record.

As shown in Figure 11, a large inflow event as that experienced in 1983 would result in large scale salt removal from the lake even without any outflow pipe. In 1983, 16 million m^3 inflowed to the lake between June and September, representing 8 times the lake volume at the overflow level (297.56 mAHD).

The level of salt within the lake at the end of the simulation period even without a diversion channel and/or an outflow pipe remained at approximately the initial condition of 10,000 tonnes. Salt load reduction efficiencies for various pipe diameters, pipe inverts and pipe numbers were similar to those previously shown in Tables 4 and 5.

On the basis of these results a piped outlet will significantly contribute to controlling the rate of salt load increase in Lake Toolibin between flushing events which occur during periods of large relatively fresh inflows.

3.5 Effect of Outlet Pipe on Water Levels

The effect of an outlet pipe on modelled volumes and water levels in the lake is shown in Figures 12 and 13 for 450mm and 900mm diameter outlet pipes.

The outlet pipe will drain the lake more quickly following inflow events which increase the lake storage level above 297.00m AHD (650,000 m^3). Depending on the inflow event, the accelerated emptying of the lake could be by up to several months. The results indicated little difference in the accelerated emptying of the lake for the different pipe diameters modelled.

4. DESIGN OF OUTFLOW CONTROL WORKS

4.1 Location of Outlet Structure

A field inspection of Lake Toolibin was undertaken by Dr Jim Davies and Mr Robert Panasiewicz on 4 May 1999. The preferred location of the outlet structure was identified as immediately adjacent to the existing lake overflow area near the south western corner of the lake. This area was selected based on :

- Its proximity to the existing diversion channel which will be used to transfer the discharged water from Lake Toolibin.
- Minimising the area of construction and construction requirements.
- Providing good access to the site for construction and for any subsequent maintenance required.
- Maximising utilisation of existing infrastructure.

A survey of 5 cross sections of the existing diversion channel and the lake bed near the south western corner of the lake was undertaken by Haines Surveys Pty Ltd in July 1999 (Figures 14 &15).

The results of the survey provided good agreement with outlet pipe levels and lake stage-storage level data used in the modelling of the proposed outlet structure (Chapter 3). The outlet pipe will be longer than that previously modelled in Chapter 3 (refer Figure 15, channel bank width), however similar salt removal efficiencies are expected to be achieved.

The preferred location for the outlet structure is shown in Figure 14, located approximately 200m upstream of the water level gauge located at the natural outflow channel. The proposed outlet pipe invert at this location is 297.0m AHD.

4.2 Outlet Design

Design drawings to enable contracting out of the outlet control works are shown in Figure 16. Pre-cast concrete structures are considered to be most suitable in terms of ease of construction and minimising future maintenance costs.

Key features of the design include :

- A 16m x 450mm diameter outlet pipe with precast standard headwall units. The outlet pipe invert to be set at 297.0m AHD at its upstream end, with a pipe slope of 1%.
- Provision of a 2m x 2m stone pitched apron within the existing diversion channel for scour protection. Discharge velocities through the 450mm diameter outlet pipe at pipe full flow conditions will typically be 1.2 m/s.
- Provision of stop boards to be used to prevent back flow of saline water from the diversion channel into the lake during bypass flow events (refer Figure 15, diversion channel design flow level), and to regulate releases from the lake to the diversion channel as and when required. These boards will require manual operation.

It should be noted that a further 6 % efficiency in salt removal can be achieved if the outlet level is set at 296.8m AHD (refer Table 4) however some excavation within the lake bed would be required (approximately 100m length, 0.2m depth) to allow for water to drain to this outlet level.

5. OPERATING STRATEGY

The proposed operating strategy for the outlet is as shown in Table 6. This strategy should be periodically reviewed and refined following inflow events based on operating experience.

TABLE 6 : LAKE TOOLIBIN OUTLET OPERATING STRATEGY

Timing	Operating Strategy
Prior/following inflow event (no flow occurring through the outflow structure)	1. Stopboards at downstream end[1] reset to closed position. 2. Upstream end[1] stopboards reset to preferred setting.
At commencement of inflow event while initial inflow to Lake Toolibin is diverted to the bypass channel.	1. Stopboards at downstream end reset to remain in closed position to prevent backflow from the channel into the lake. 2. Re-adjust upstream end stopboards (if required).
At closure of bypass channel flow (inflow now diverted into Lake Toolibin).	1. When flow in bypass channel has subsided and while lake level is less than upstream stopboard level setting remove stopboards at downstream end to fully open position.
During an Inflow Event[2]	1. If additional discharge is required, wait until water level in lake has reached the level of the current stopboard setting and remove a further single board. Depth of water in lake at this time will be 450mm maximum.

Notes : 1. Upstream end refers to end of outlet pipe within lake.
Downstream end refers to end of pipe located in diversion channel.
2. Changing of stopboard settings is generally not required during an inflow event. Note that the outlet configuration is designed for discharge without stopboards (ie fully open during storm events).
Stopboards included to provide operational flexibility if required.

6. CONCLUSIONS & RECOMMENDATIONS

- The salt load within Lake Toolibin has increased markedly from the late 1970's until today. From 1979 to 1995 the salt load within the lake has increased from approximately 800 tonnes to over 8000 tonnes. A driving factor for this increase is that large inflow events to flush the lake are rare and evaporation of inflows leaves salt accumulated in the lake bed.
- A large inflow event as that experienced in 1983 would result in large scale salt removal from the lake even without any outflow pipe. However a piped outlet will significantly contribute to controlling the rate of salt load accumulation in Lake Toolibin between flushing events.
- A salt and water balance model has been developed for the lake and successfully calibrated for the 1979-1997 period. This salt balance model was used to determine the potential benefits of installing a piped outflow to remove saline water from the lake and reduce salt accumulation.
- With respect to the influence of the diversion channel, the results indicate the channel as having reduced the extent of salt load increase in the lake. For the January 1996 to December 1997 period, the increase without a diversion channel was found to be approximately 2.4 tonnes, while with the diversion channel the increase was found to only be 0.7 tonnes (70% reduction).
- The amount of additional flow and salt which can be released from the lake even for a small diameter outlet pipe is significant. For a 300mm outlet pipe flowing full and assuming a conservative discharge salinity of 500 mg/L, approximately 3 tonnes of salt can be removed for the lake daily.
- Modelling results indicate that significant reductions in salt load within Lake Toolibin could have been possible during the period 1979-1997 if a diversion channel and outlet pipe had existed. For a diversion channel with a single outlet pipe placed at 297.0m AHD reductions of the salt load contained in the lake of typically 80% resulted. Of this reduction 60% is due to the impact of the diversion channel with a further 20% reduction as a result of the outlet pipe.
- The 80% reduction in salt load equates to an estimated 8000 tonne reduction over the 19 year modelling period.
- On the basis of modelling results it is recommended that the minimum outflow pipe size should be 450mm diameter. Increasing the outlet pipe diameter above 450mm or providing a duplicate outlet pipe of similar size was found to not significantly increase the efficiency of salt removal.
- Based on recent survey data, the 450mm diameter outlet pipe invert should be set at 297.0m AHD. The recommended location of the outlet pipe is 200m upstream of the water level gauge located at the natural outflow channel at the south western corner of the lake. This site is recommended based on its proximity to the existing diversion channel, minimising construction requirements, good access, and maximising utilisation of existing infrastructure.
- A further 6 % efficiency in salt removal can be achieved if the outlet level is set at 296.8m AHD however some excavation within the lake bed would be required (approximately 100m length, 0.2m depth) to allow for water to drain to this outlet level.
- It is recommended monitoring of the piped outflow and lake salinity be conducted during the first flow event following construction to check the effectiveness of the piped outflow against modelled results.

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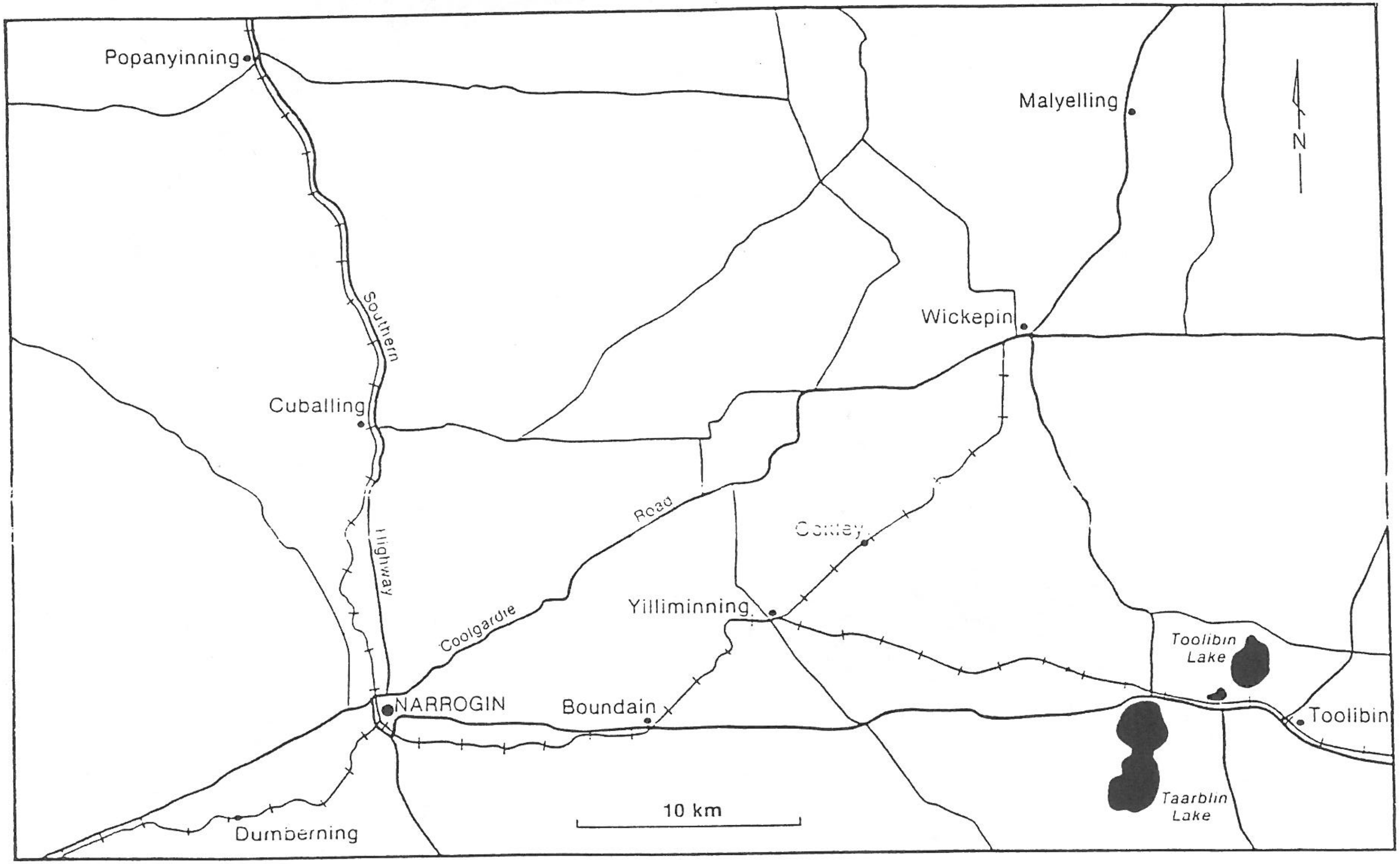

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Figure 1: Location map (from Martin, 1986)

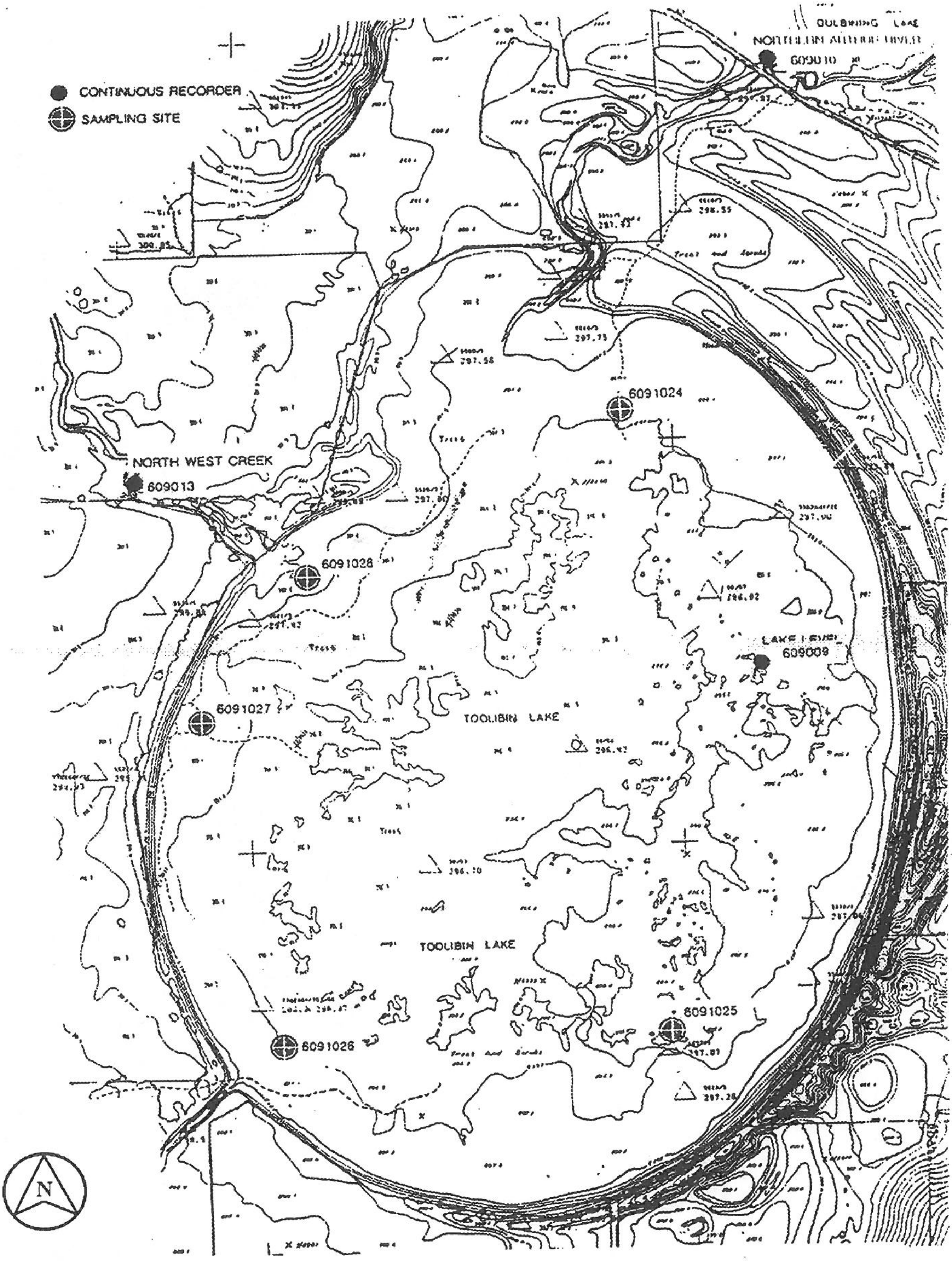

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Figure 2: Lake Detail & Monitoring Stite Locations
(from Froend Bowen & Associates, 1999)

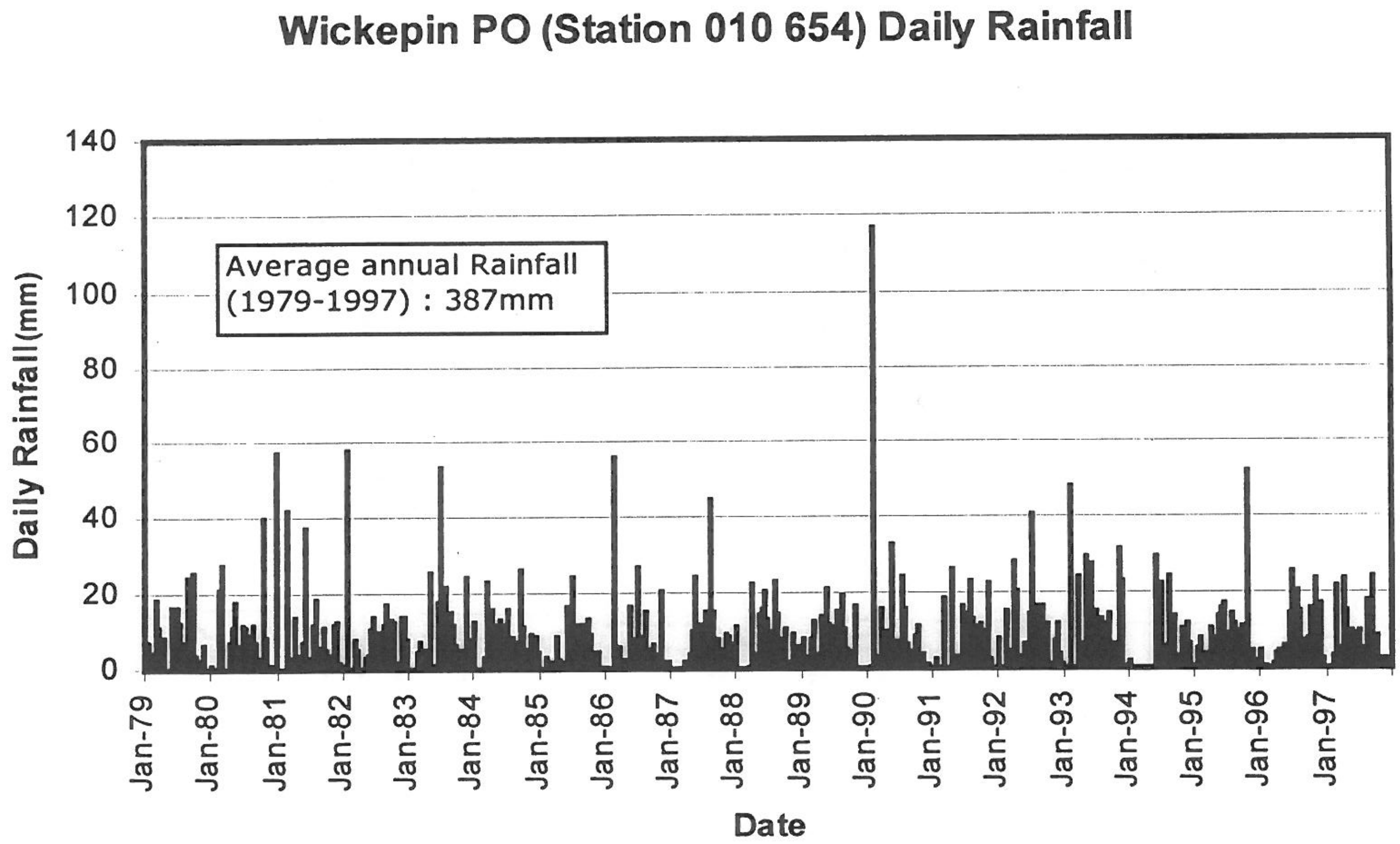

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Figure 3 : Wickepin Daily Rainfall (1979 to 1997)

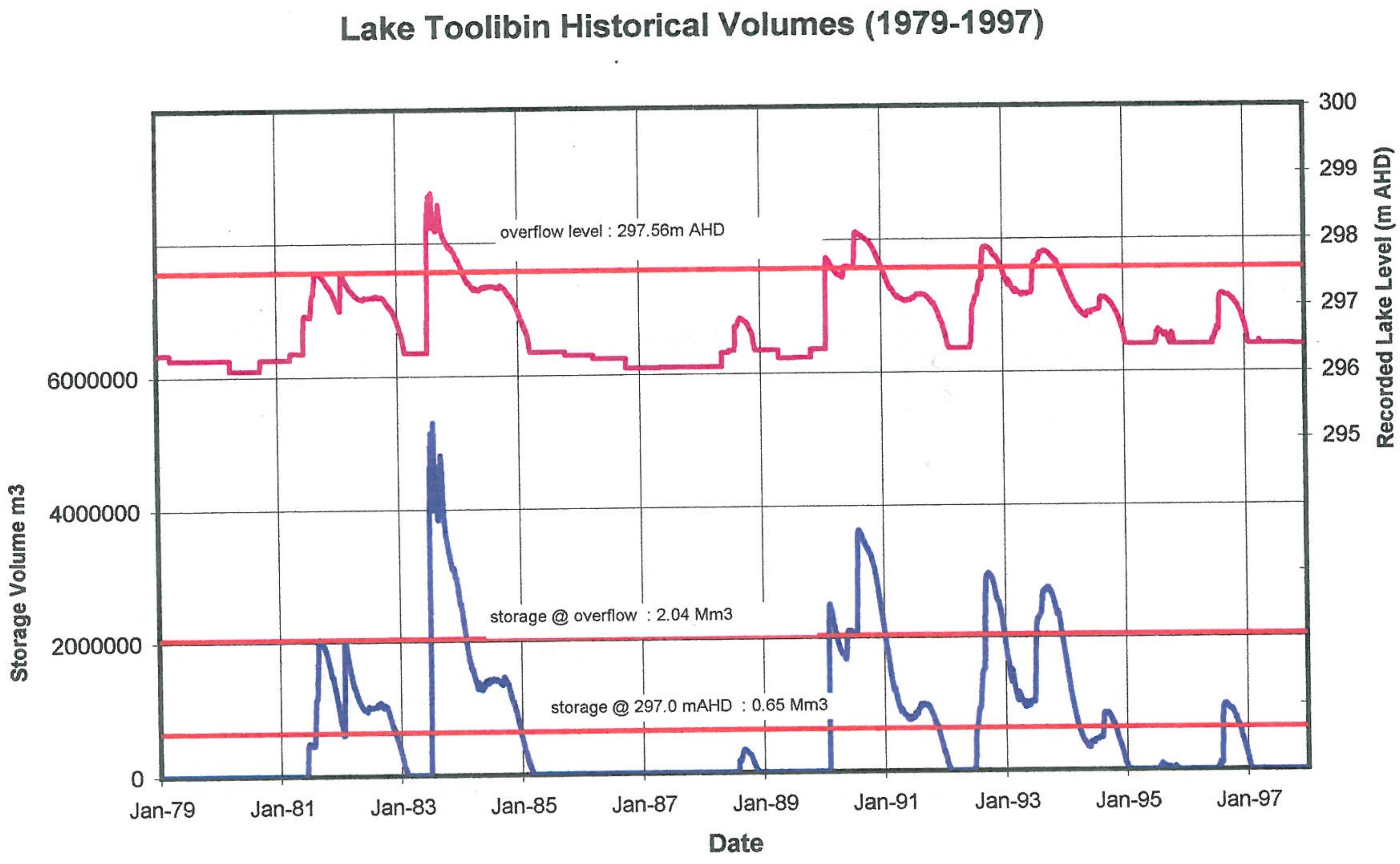

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Figure 4 : Lake Toolibin Storage Volume (1979-1997)

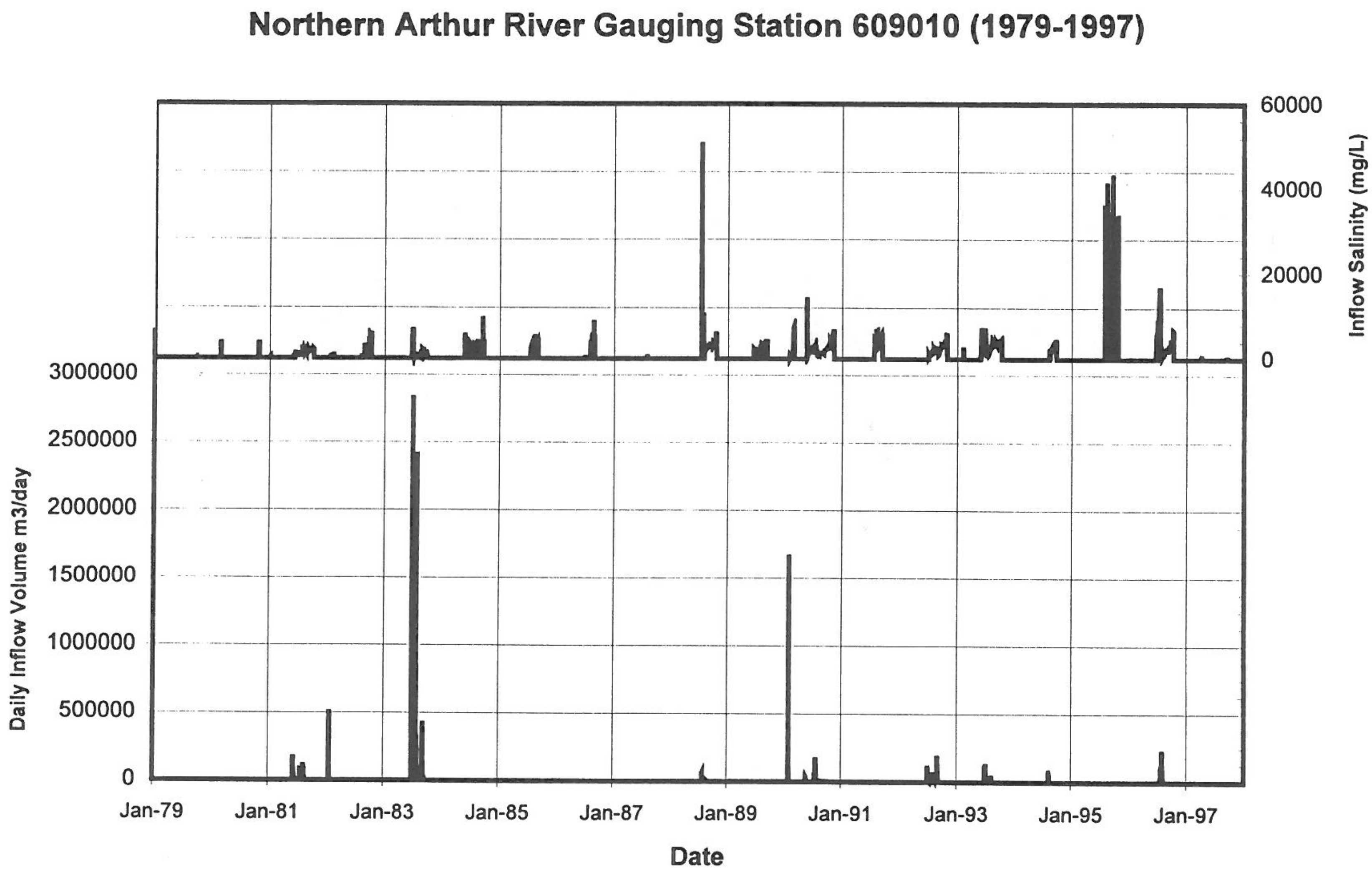

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Figure 5 : Northern Arthur River Recorded Flows 1979-1997

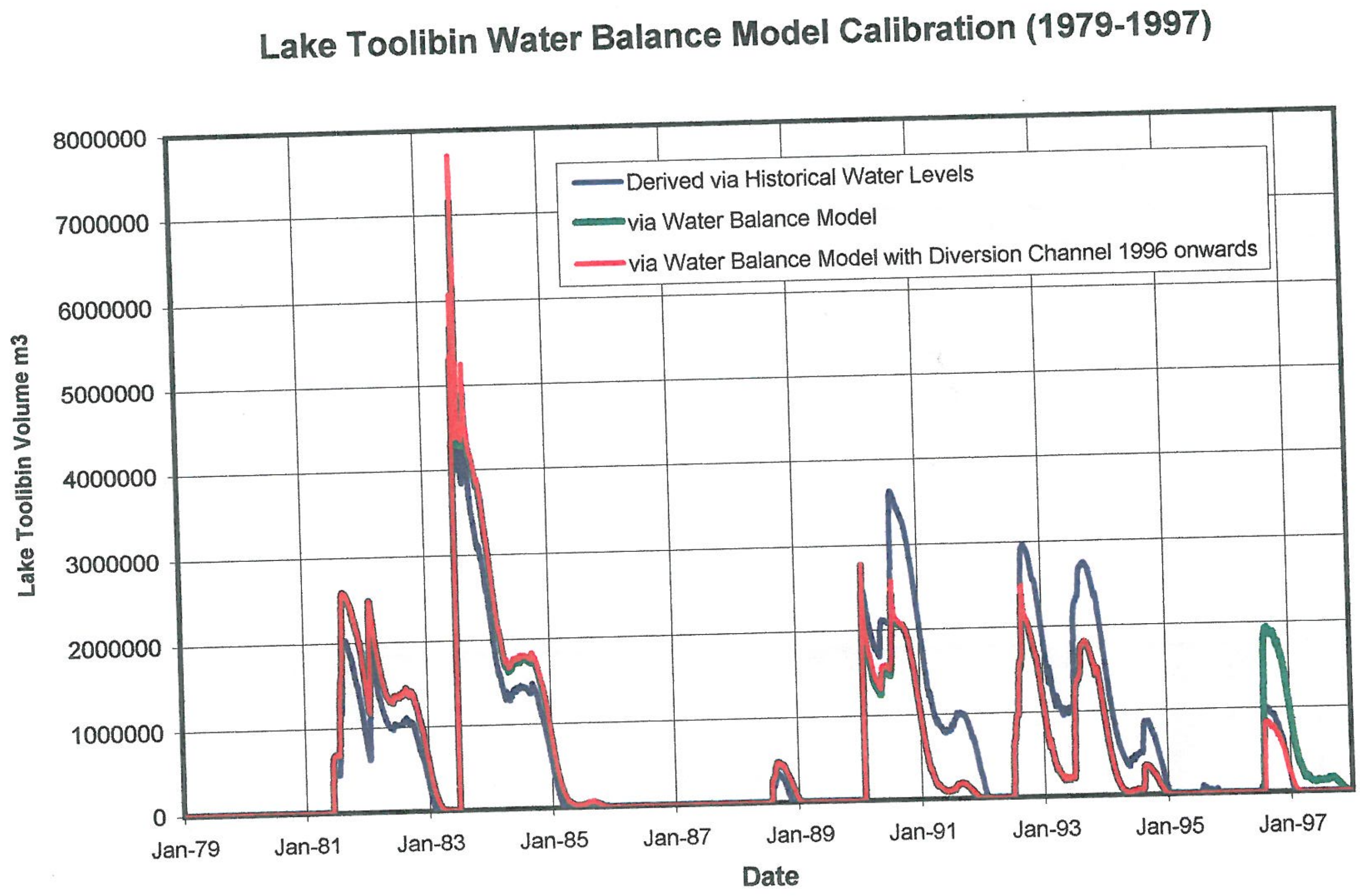

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Figure 6 : Water Balance Model Calibration (Volume)

Lake Toolibin Water Balance Model Calibration (1979-1997)

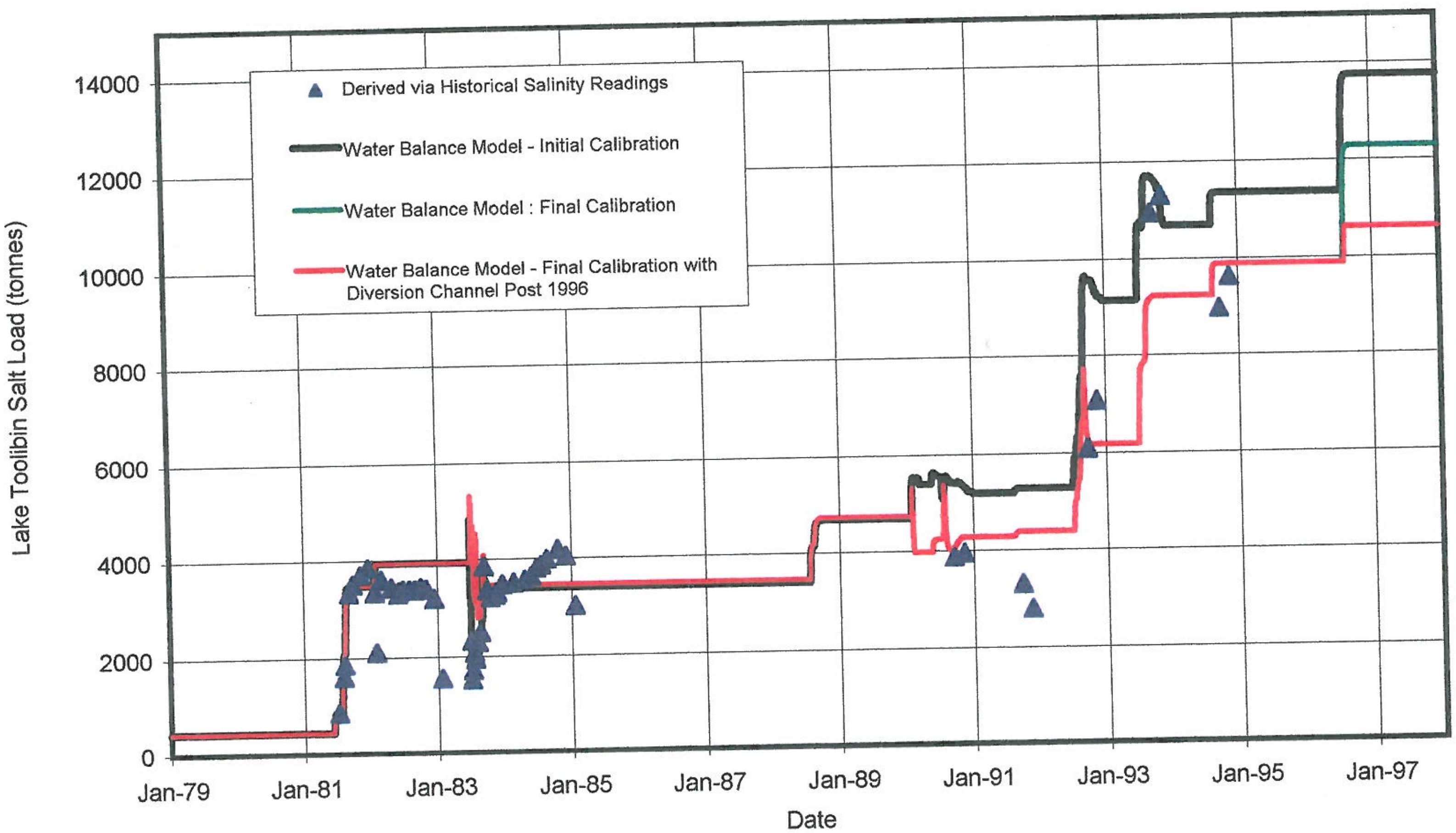

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Figure 7 : Water Balance Model Calibration (Salt Load)

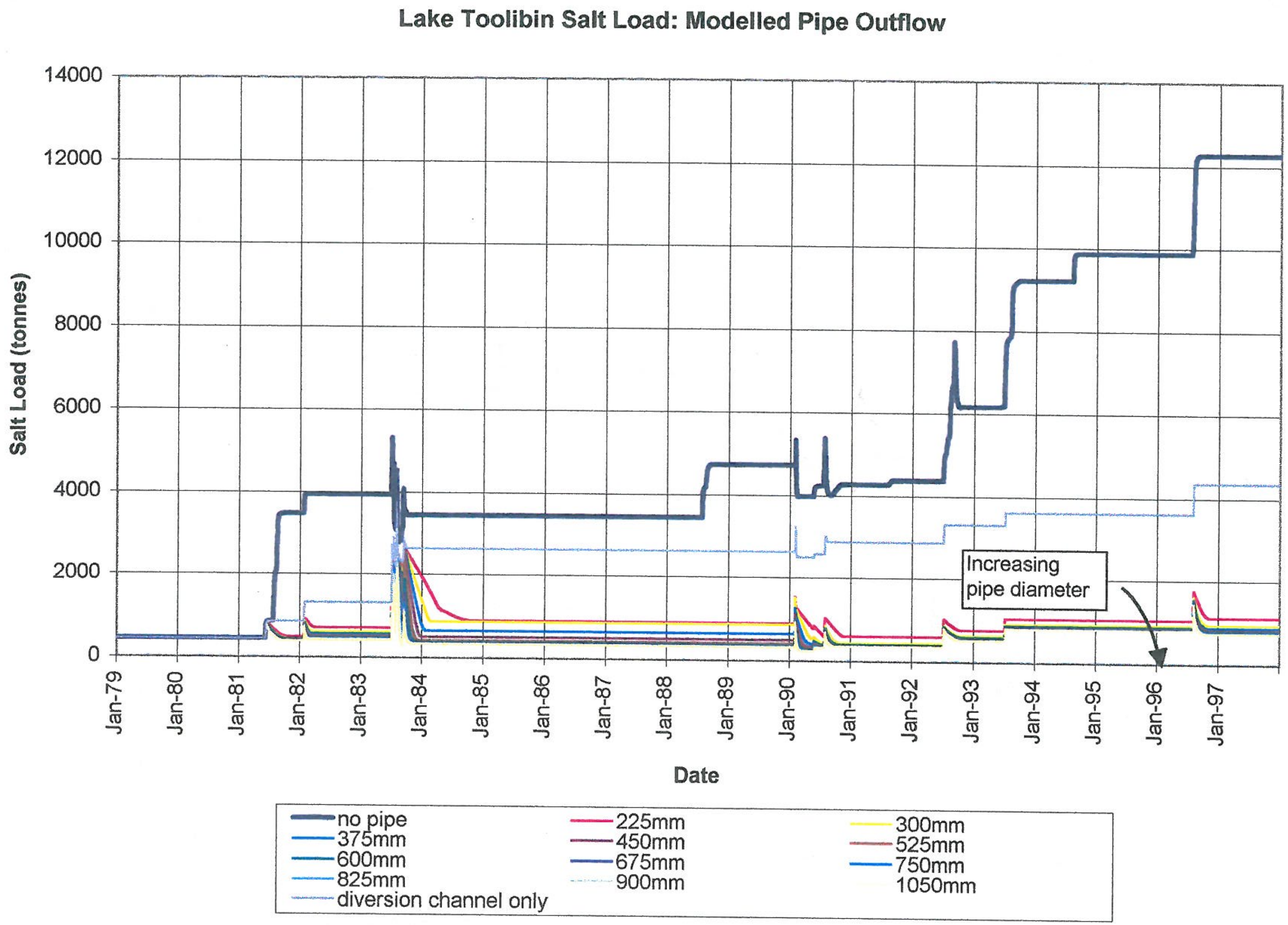

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Figure 8: Salt Load for Various Outlet Pipe Diameters
(Invert 296.8m AHD)

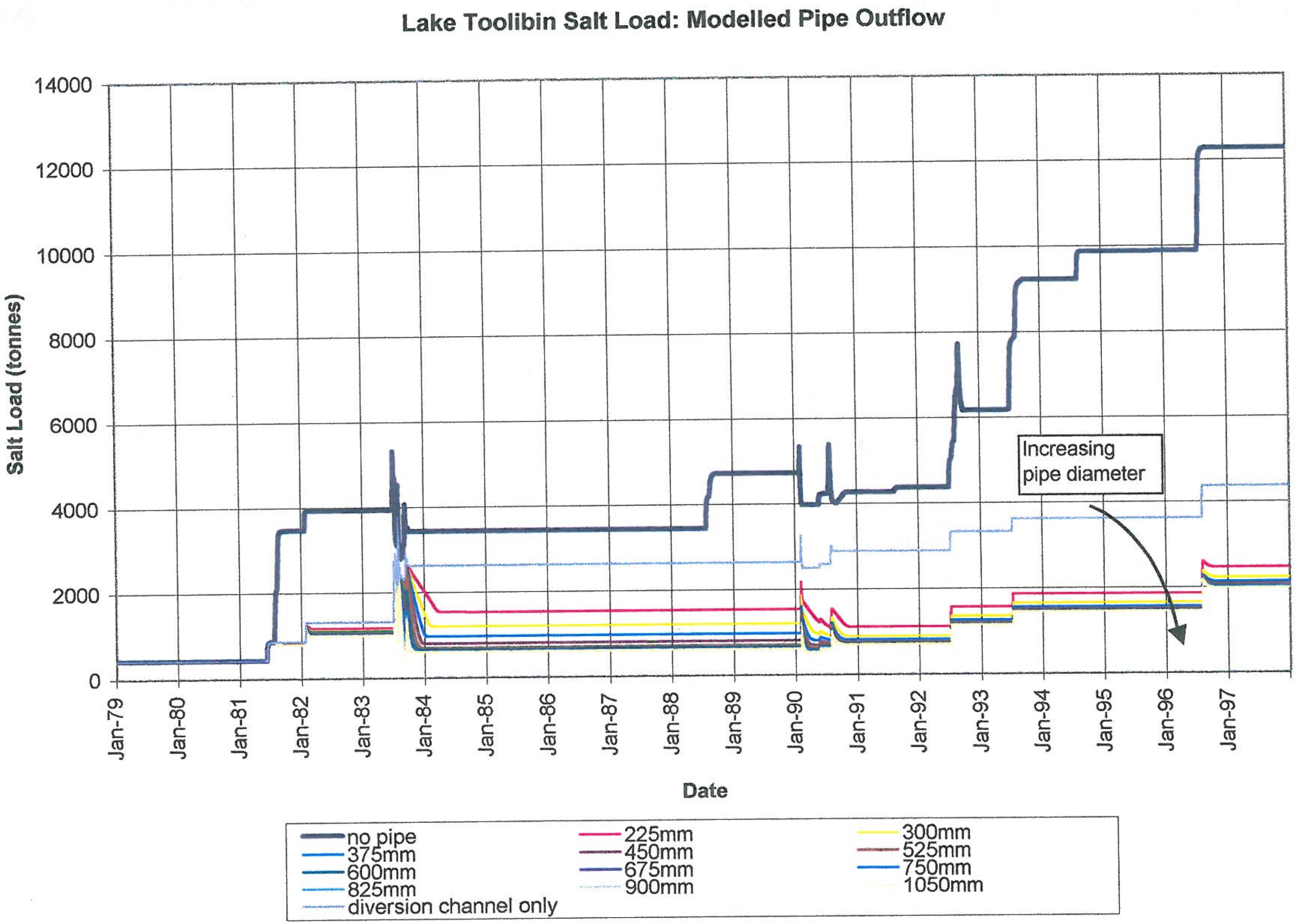

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Figure 9: Salt Load for Various Outlet Pipe Diameters

(Invert 297.0m AHD)

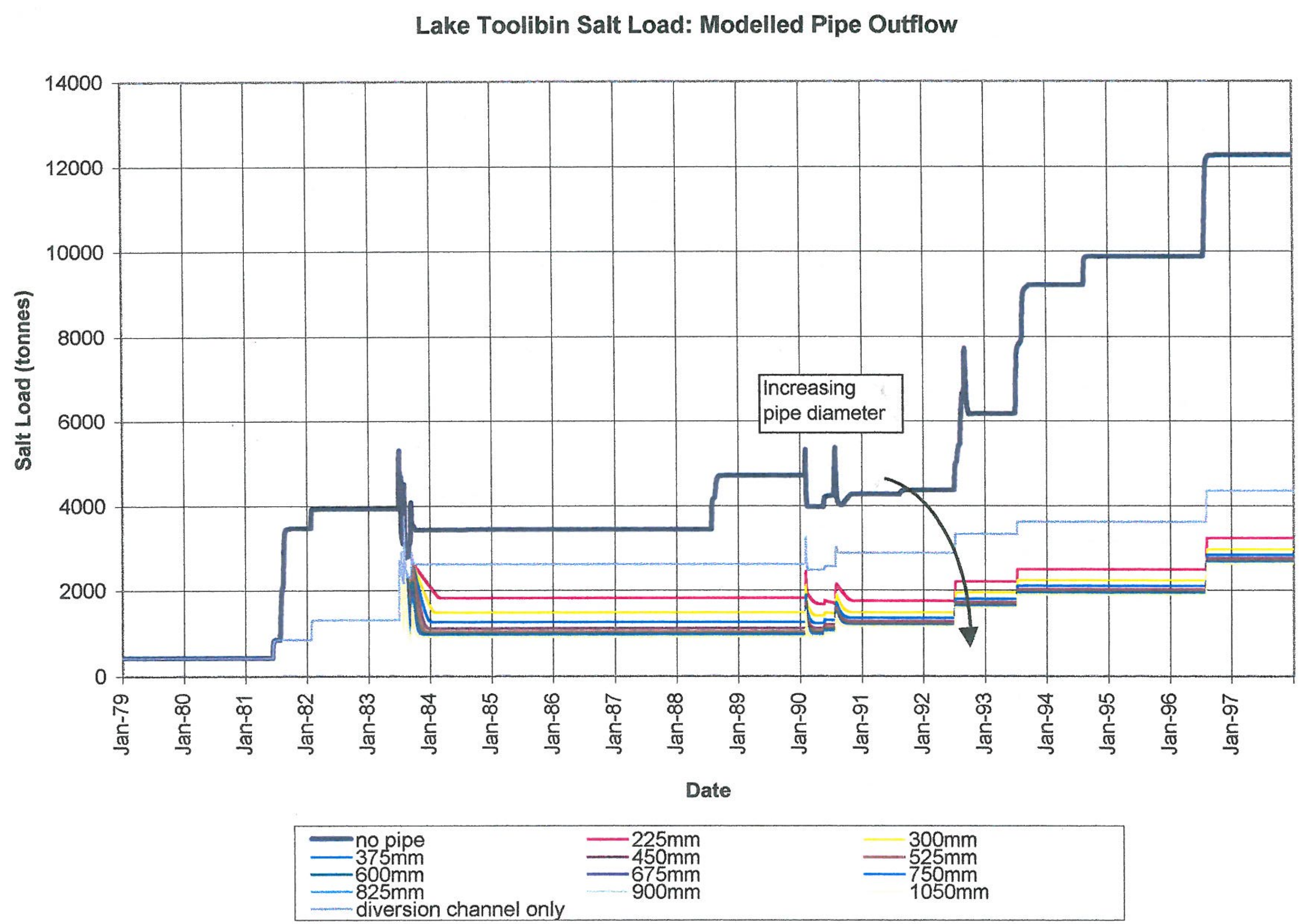

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Figure 10: Salt Load for Various Outlet Pipe Diameters (Invert 297.2m AHD)

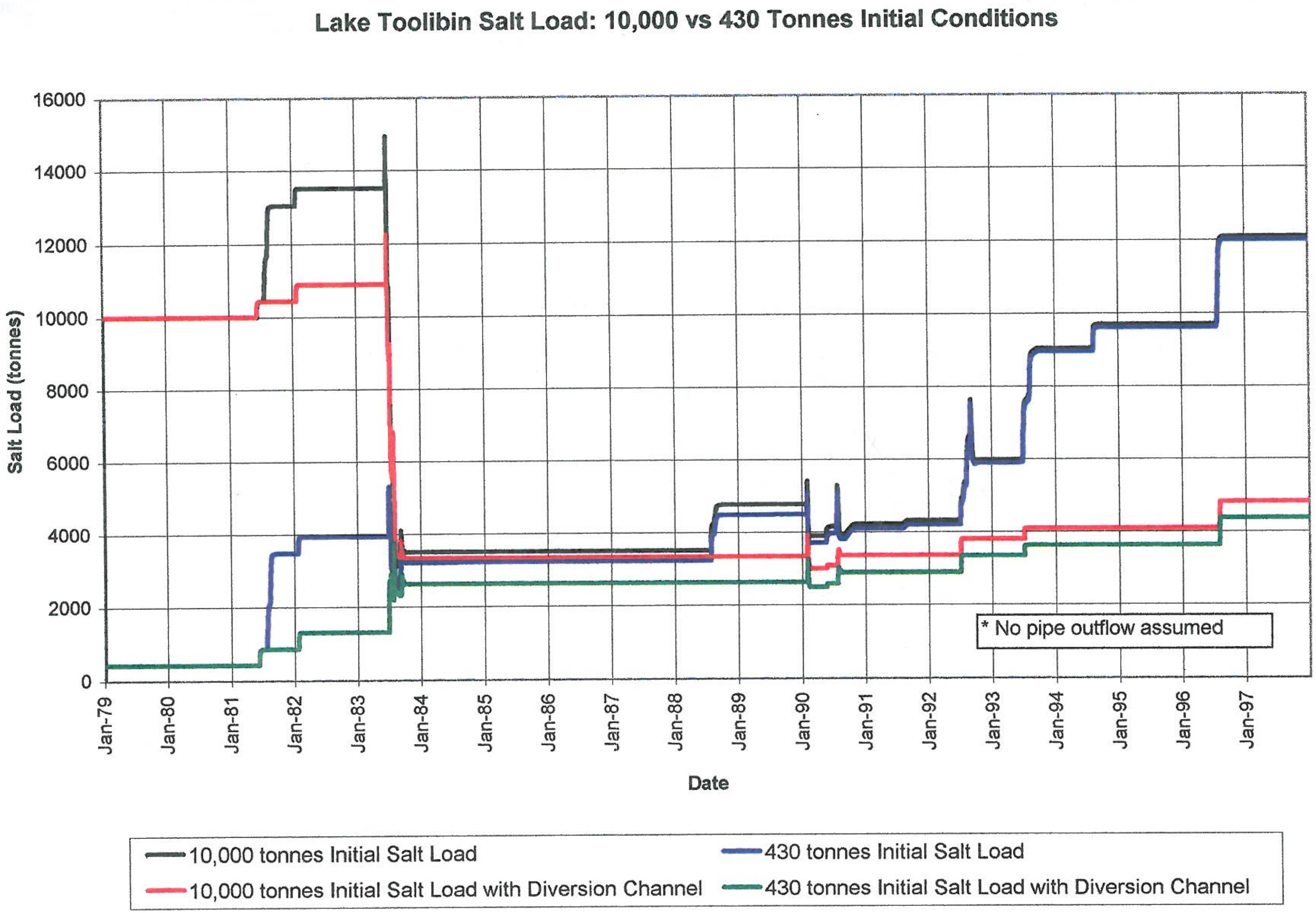

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Figure 11: Water Balance Model Comparison of Initial Salt Loads of 10,000 tonnes vs 430 tonnes

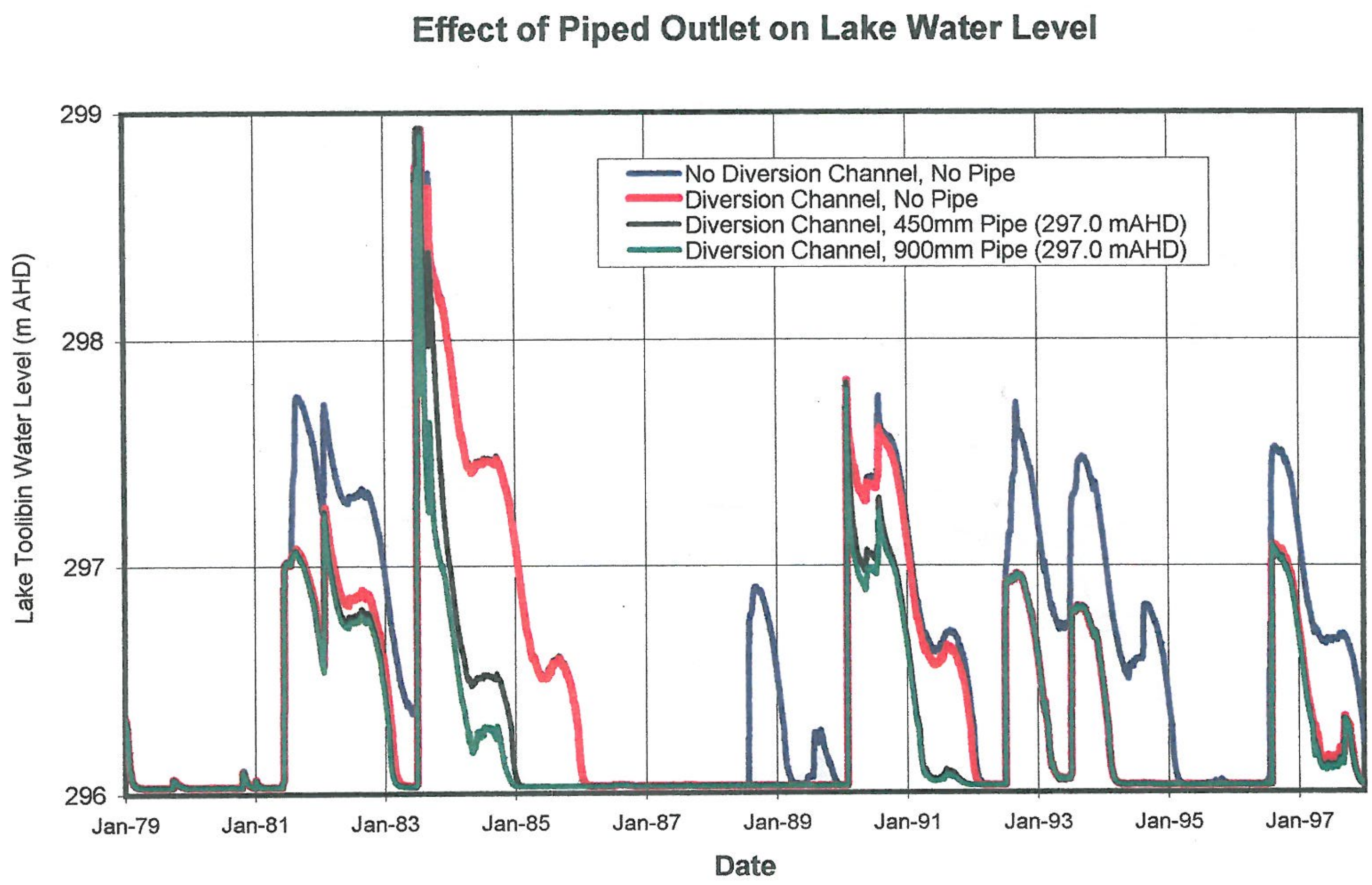

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Figure 12 : Effect Of Pipe Outlet on Lake Water Level

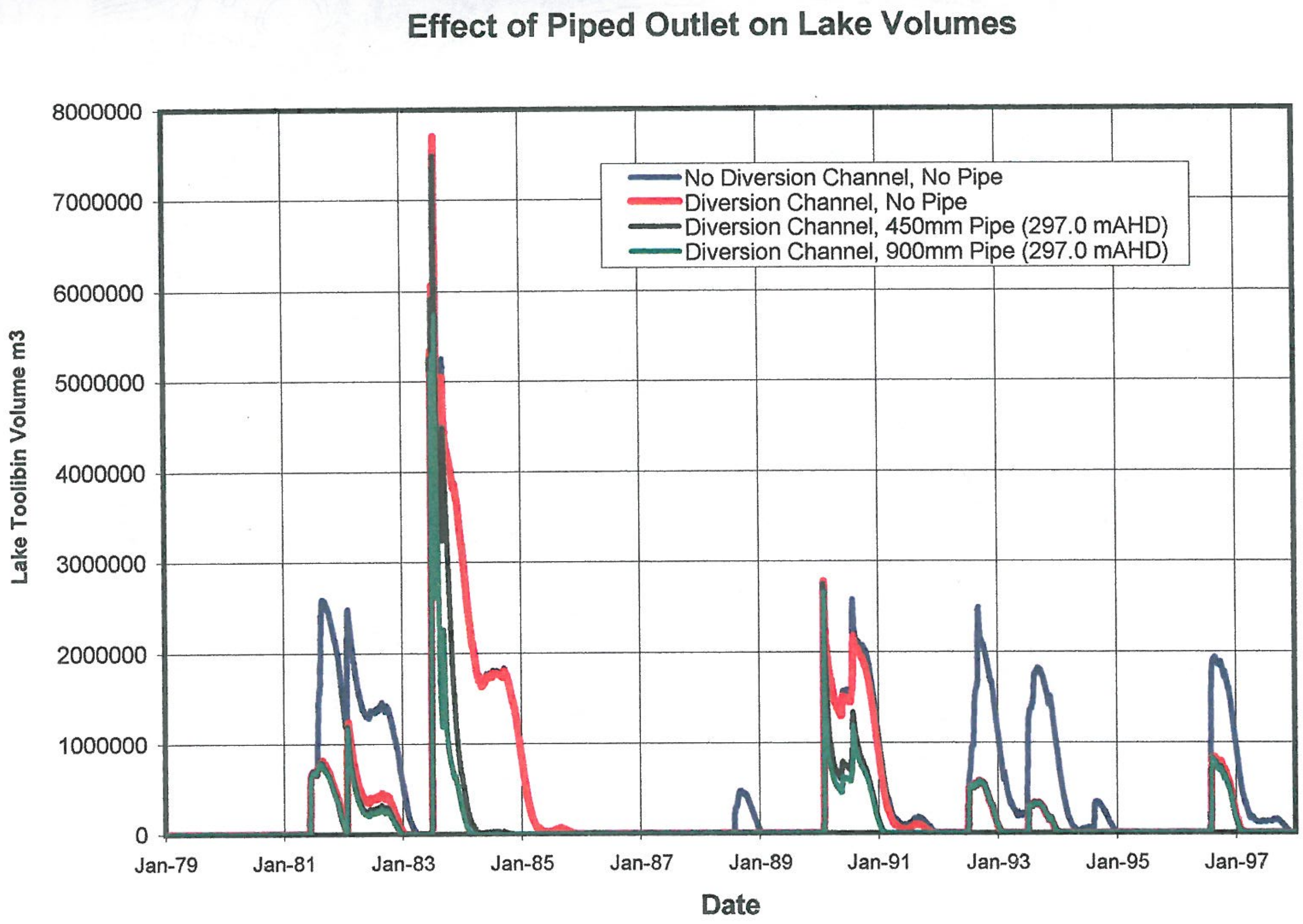

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Figure 13 : Effect Of Pipe Outlet on Lake Volume

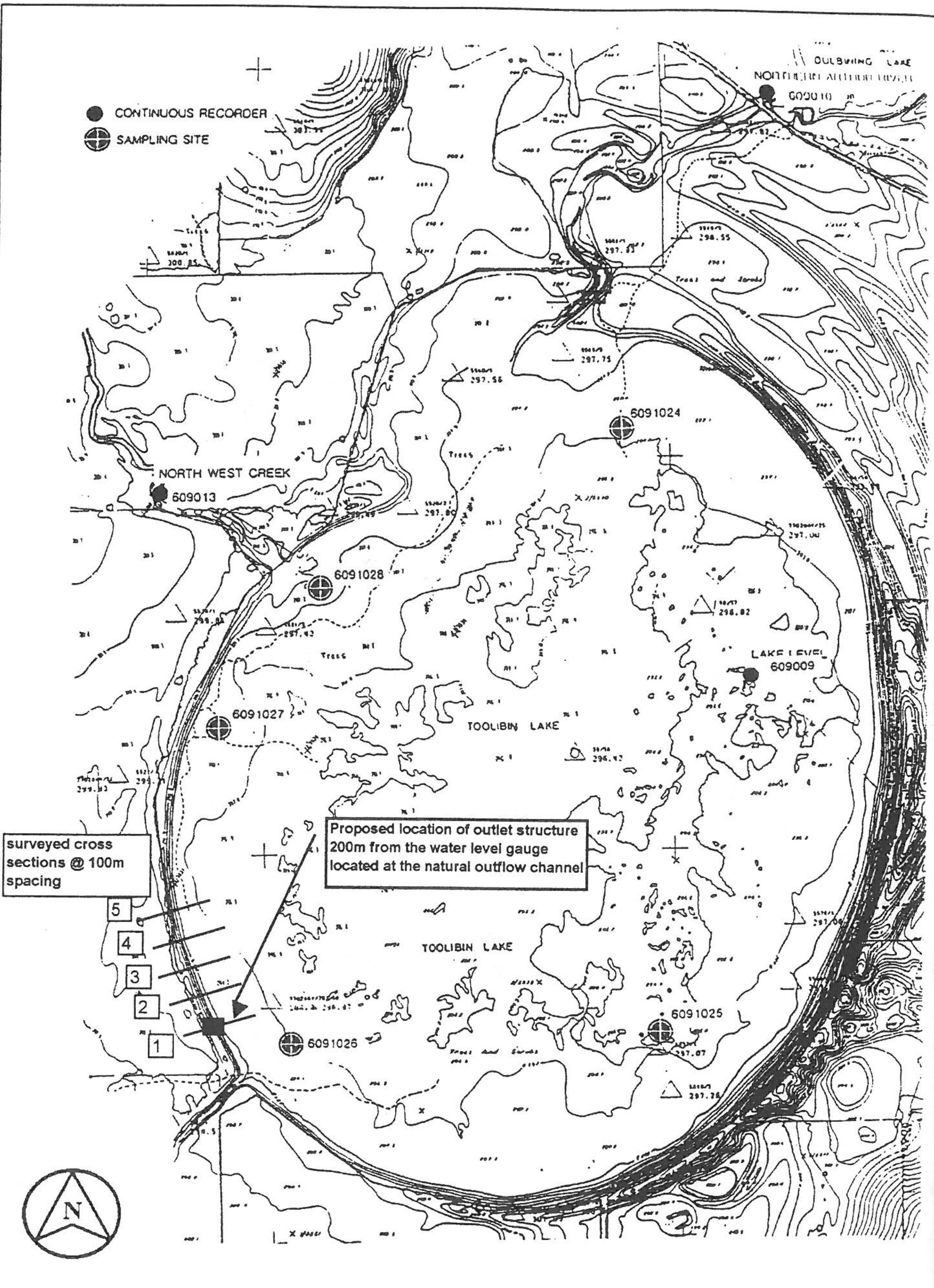

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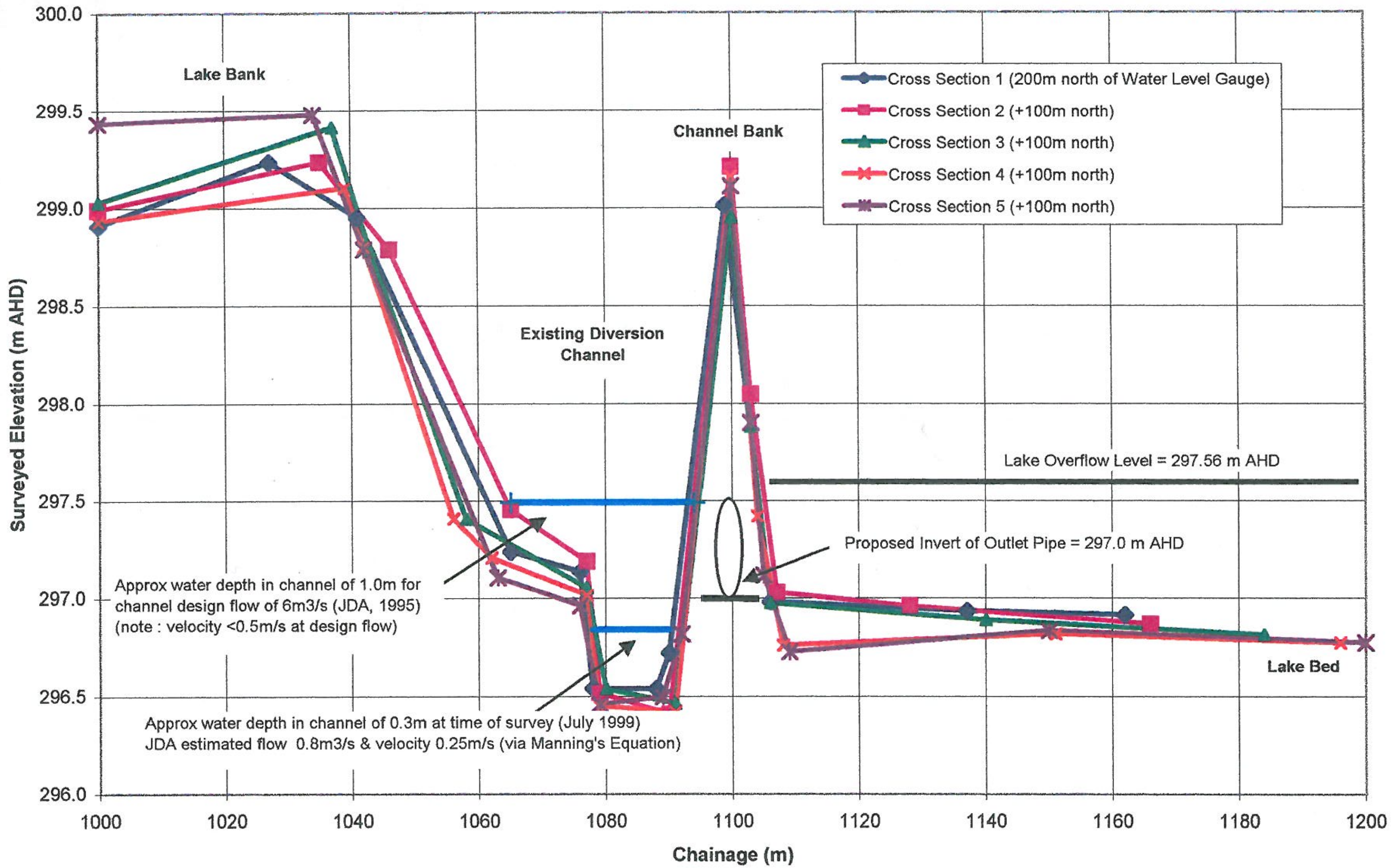
Figure 14: Location of Surveyed Cross Sections & Proposed Outflow Structure



* Survey performed by Haines Survey Pty Ltd (July 1999)

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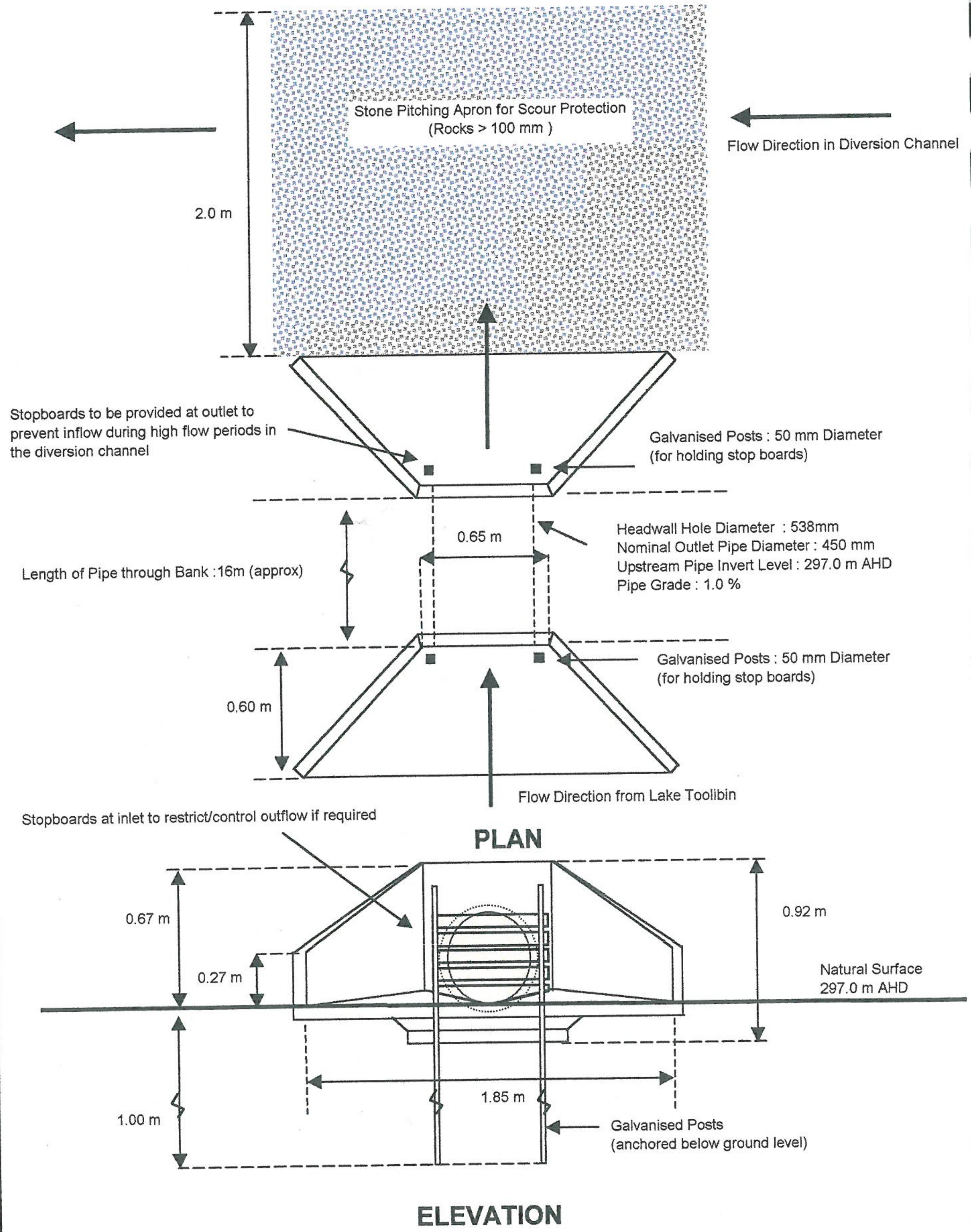
Figure 15 : Surveyed Cross Section Data



Notes

Headwall Dimensions are for a standard precast 450mm diameter pipe headwall via CSR Humes "Headwalls" Catalogue

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Not to Scale

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Figure 16: Proposed Outflow Structure Conceptual Design

Appendix 1 : Water Balance Model Calibration Results

A.S. Martens, JDA Consultant Hydrologists, 21 July 99

"OK" flags shown for all calculated salt loads within 20% of historical records based on measured salinity and lake volume

Calibration Variables and Values Adopted

Inflow Volume Multiplier to Station 609010	1.15
Evaporation Multiplier	0.8
Rainfall Areal Reduction Factor	1.0
Assumed Overflow Level pre 1990 (mAHD)	298.30
Assumed Overflow Level pre 1990 (mAHD)	297.56
Initial Salt Load at 1 January 1979 (tonnes)	430

Calibration Results

Date	Recorded Lake Level 609009 (m AHD)	Derived Lake Volume (m3)	Measured Salinity (mg/L)	Measured Salt Load tonnes	INITIAL CALIBRATION Calculated Salt Load tonnes	Error %		FINAL CALIBRATION Calculated Salt Load tonnes	Error %	
01-Jul-81	296.909	477099	1,790	854	855	0%	OK	854	0%	OK
02-Sep-81	297.551	2013250	1,653	3328	3454	-4%	OK	3453	-4%	OK
22-Sep-81	297.525	1941100	1,805	3504	3469	1%	OK	3468	1%	OK
05-Nov-81	297.364	1502720	2,461	3698	3471	6%	OK	3471	6%	OK
15-Dec-81	297.190	1062093	3,612	3836	3471	10%	OK	3471	10%	OK
19-Jan-82	296.983	614575	5,442	3345	3471	-4%	OK	3471	-4%	OK
26-Jan-82	297.543	1991050	1,060	2111	3902	-85%		3876	-84%	
23-Feb-82	297.410	1625300	2,213	3597	3931	-9%	OK	3931	-9%	OK
20-Apr-82	297.213	1117400	3,072	3433	3931	-15%	OK	3931	-15%	OK
27-May-82	297.164	1000859	3,311	3314	3931	-19%	OK	3931	-19%	OK
03-Jun-82	297.154	977307	3,431	3353	3931	-17%	OK	3931	-17%	OK
24-Jun-82	297.173	1022055	3,305	3378	3931	-16%	OK	3931	-16%	OK
29-Jul-82	297.179	1036186	3,266	3384	3931	-16%	OK	3931	-16%	OK
26-Aug-82	297.204	1095350	3,088	3382	3931	-16%	OK	3931	-16%	OK
28-Sep-82	297.180	1038542	3,301	3428	3933	-15%	OK	3933	-15%	OK
27-Oct-82	297.097	847602	4,002	3392	3933	-16%	OK	3933	-16%	OK
08-Dec-82	296.934	519605	6,156	3199	3933	-23%		3933	-23%	
19-Jan-83	296.649	108083	14,373	1553	3933	-153%		3933	-153%	
30-Jun-83	298.108	3636000	642	2334	1586	32%		4813	-106%	
01-Jul-83	298.427	4590716	331	1520	1900	-25%		5306	-249%	
06-Jul-83	298.336	4323136	395	1708	1920	-12%	OK	4251	-149%	
13-Jul-83	298.478	4664800	446	2081	1960	6%	OK	3681	-77%	
19-Jul-83	298.291	4186600	464	1943	1861	4%	OK	3199	-65%	
03-Aug-83	298.452	4627032	494	2286	2159	6%	OK	3060	-34%	
17-Aug-83	298.221	3975200	627	2492	2275	9%	OK	2846	-14%	OK
08-Sep-83	298.576	4807158	800	3846	3728	3%	OK	4070	-6%	OK
23-Sep-83	298.213	3951040	852	3366	3395	-1%	OK	3532	-5%	OK
12-Oct-83	298.063	3501760	916	3208	3395	-6%	OK	3439	-7%	OK
10-Nov-83	297.928	3100738	1,053	3265	3395	-4%	OK	3439	-5%	OK
16-Nov-83	297.918	3071120	1,080	3317	3395	-2%	OK	3439	-4%	OK
15-Dec-83	297.822	2789288	1,247	3478	3395	2%	OK	3439	1%	OK
16-Feb-84	297.465	1775160	1,976	3508	3395	3%	OK	3439	2%	OK
18-Apr-84	297.312	1366600	2,598	3550	3395	4%	OK	3439	3%	OK
22-May-84	297.317	1379600	2,628	3626	3395	6%	OK	3439	5%	OK
21-Jun-84	297.337	1431600	2,655	3801	3395	11%	OK	3439	10%	OK
17-Jul-84	297.338	1434200	2,688	3855	3395	12%	OK	3439	11%	OK
16-Aug-84	297.326	1403000	2,836	3979	3395	15%	OK	3440	14%	OK
17-Oct-84	297.279	1281760	3,261	4180	3396	19%	OK	3440	18%	OK
29-Nov-84	297.125	910658	4,442	4045	3396	16%	OK	3440	15%	OK
15-Jan-85	296.843	367026	8,230	3021	3396	-12%	OK	3440	-14%	OK
11-Sep-90	298.036	3421300	1,130	3866	5411	-40%		4040	-4%	OK
08-Nov-90	297.884	2970480	1,330	3951	5336	-35%		4268	-8%	OK
18-Sep-91	297.158	986728	3,350	3306	5271	-59%		4366	-32%	
09-Nov-91	297.027	699855	4,000	2799	5271	-88%		4366	-56%	
16-Sep-92	297.871	2932000	2,080	6099	9646	-58%		6358	-4%	OK
10-Nov-92	297.748	2574300	2,750	7079	9310	-32%		6164	13%	OK
15-Sep-93	297.804	2736863	4,000	10947	11705	-7%	OK	9190	16%	OK
11-Nov-93	297.682	2383850	4,740	11299	11171	1%	OK	9218	18%	OK
16-Sep-94	297.096	845350	10,600	8961	11341	-27%		9874	-10%	OK
10-Nov-94	296.917	490441	19,600	9613	11341	-18%	OK	9874	-3%	OK

16.5.2 Basin Stage/Storage Relationships

A stage/storage curve must be derived for the site for use in flood routing computations.

Where investigations are undertaken, using RAFTS, stage/storage co-ordinates would have to be nominated for say up to 10 or 15 points along the curve, based on accurate ground survey, with intermediate points being calculated in the program by linear interpolation.

16.5.3 Basin Stage/Discharge Relationships

Stage/discharge data must be compiled for the normal outlets and emergency spillways. Stage/discharge data may be entered directly in coordinate form, or an option is available to use standard hydraulic equations for preliminary runs only.

Default equations presently used are:

(i) Normal pipe outlet with $h < 1.0 \times$ diameter

$$Q_p = A_p \times R^{0.6667} \times S^{0.5}/n \qquad (31)$$

where:

- h = height of water in basin over invert of outlet pipe
- d = pipe diameter (m)
- Q_p = discharge through pipe at stage h (m^3/s)
- A_p = area of flow in pipe at stage h (m^2)
- R = hydraulic radius at stage h (m)
- S = pipe slope
- n = Manning's roughness (empirically set internally to 0.021) to take into account additional entrance and exit losses.

(ii) Normal pipe outlet with $h \geq 1.0d$

$$Qp = \frac{\pi N d^2}{4}\left(\sqrt{\frac{H}{\left(\frac{(ko + ki)}{2g} + n^2 \frac{L}{R^{1.333}}\right)}}\right) \qquad (32)$$

where:

Q_p = discharge through pipe at stage h (m^3/s)
d = pipe diameter (m)
n = Manning's roughness (presently set to 0.011)
L = length of pipe (m)
H = total hydraulic head (m)
g = acceleration due to gravity
ki = entry loss coefficient (presently set at 0.5)
ko = exit loss coefficient (presently set to 1.0)
N = number of conduits

Equation (32) assumes that the pipe flows under head when the headwater ratio (h/d) exceeds 1.0. The conduit is then assumed to operate under outlet control.

(iii) FHWA - Culvert Procedure

In versions later than 2.8 of RAFTS-XP a limited version of the US Department of Federal Highways Administration's procedure for computing culvert flows is provided. The procedure follows Hydraulic Design Series 5 documentation titled "Hydraulic Design ofHighway Culverts".

Presently wingwall flares are limited to 30° to 75° and the outlet condition is limited to free outlet. Submerged tailwater conditions are still modelled via the interconnected basin option.

(iv) Spillway

The spillway is treated as a normal weir with an equation of the form:

$$Q_s = cwh_s^{3/2} \qquad (33)$$

where:

Q_s = discharge over spillway (m^3/s)
c = coefficient of discharge, default set at 1.7 for a broad crested weir
w = spillway width (m)
h_s = height of water above spillway.

Under basin options the weir coefficient can be set to any specified value or a weir stage/discharge curve may be used to replace the standard equation (33).

At present the program also has the ability to handle spillways, orifice type normal outlets, fuseplug spillways, unrouted low-flow pipes through the basins and can optimise the size of normal outlets for given basin storage volumes or maximum desirable outflow. These aspects are further discussed below.