BEFORE THE HEARING COMMISSIONERS APPOINTED BY OTAGO REGIONAL COUNCIL

Under	the Resource Management Act 1991
In the matter	of the proposed Otago Regional Policy Statement 2021 (excluding provisions renotified as part of a freshwater planning instrument)

STATEMENT OF EVIDENCE OF PETER FOSTER (RIVER MORPHOLOGY AND SEDIMENTATION) ON BEHALF OF CONTACT ENERGY LIMITED

23 November 2022

BUDDLE FINDLAY

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1. QUALIFICATIONS AND EXPERIENCE

1.1 My name is **Peter Francis Foster**.

1.2 I am a Principal Engineer (Dams) at Stantec New Zealand.

1.3 I have a BE (Hons) in civil engineering from the University of Canterbury. I graduated in 1976 and have worked predominately in the areas of dam engineering, and hydropower operations.

1.4 I am a Fellow of Engineering New Zealand and a Chartered Professional Engineer. I am a member of the New Zealand Society of Large Dams, the New Zealand Geotechnical Society and the New Zealand National Society of Earthquake Engineering.

1.5 From 1975 to April 2002 I was employed by the Ministry of Works and Development, Works Consultancy Services and when they were privatised, Opus International Consultants. I joined MWH New Zealand Ltd (now Stantec New Zealand) in 2002 as a Senior Civil/Hydro Engineer before becoming a Principal Engineer in 2014

1.6 I am familiar with the Clyde and Roxburgh Dams and their reservoirs and many of the operational issues associated with Contact Energy Limited's (**Contact**'s) Clutha Hydro Scheme (**CHS**). In particular:

(a) I have had a long involvement as a consultant to the New Zealand Electricity Department, then the Electricity Corporation of New Zealand (**ECNZ**) and now Contact with regard to dams, reservoirs and their operations on the Clutha River.

(b) My involvement with Clyde Dam covers the dam site investigations, dam detailed design and construction, lake filling and operational phases of its life.

(c) In addition to the physical works associated with the Clyde Dam I have worked in the following areas:

(i) concept and detailed design for the tailrace deepening downstream of the Clyde Dam - I contributed to the report, *Clyde Power Project: Environmental Impact Report on Design and Construction Proposal* (December 1977), with respect to this aspect of the project; and

(ii) predictions of sedimentation levels and hydraulic calculation of flood levels in the Kawarau Arm and Cromwell Gorge section of Te Wairere / Lake Dunstan, to assist the land purchase requirements associated with construction of the Clyde Dam.

(d) From 1986 onwards I became more involved with the landslide stability issues adjacent to what is now Te Wairere / Lake Dunstan. I ultimately held the position of Deputy Design Manager for the landslide stabilisation works. I continued to be involved by reviewing monitoring data for the landslides when Te Wairere / Lake Dunstan was initially filled1998.

(e) In the 1990s I also began to provide consulting services to ECNZ and then Contact regarding the issues of sedimentation into Lake Roxburgh and the potential flood risk at Alexandra. I project managed and contributed to a pre-feasibility study in 1993 that looked at options to alleviate the flood risk at Alexandra. After the January 1994 flood I project managed the joint study for the Otago Regional Council and ECNZ that recommended investigation and monitoring of operational procedures to encourage sediment migration and flushing in Lake Roxburgh, and flood management strategies that account for storage within Lake Hawea. In 1995 and 1996 I also project managed and contributed to a number of joint studies that Works Consultancy Services and NIWA produced that evaluated the effectiveness of lowering flood levels at Alexandra by flushing activities in Lake Roxburgh.

(f) I project managed and contributed to a number of studies prepared by Opus International Consultants as part of Contact's application for resource consents for the reconsenting of the CHS in the early 2000s.

(g) I have also provided Contact with design services related to both Clyde and Roxburgh Dams. This has included annual inspection reports in accordance with procedures recommended by the New Zealand Society of Large Dams. At Roxburgh Dam I have also been involved in reassessing the Dam foundation stability, and provided recommendations to upgrade the instrumentation at the Dam, project managed the design for the spillway strengthening works and the design for rock removal from the tailrace downstream of the Dam to lower the tailwater level.

1.7 In addition to the above, I have also provided consulting services in dam engineering and reservoir operations to clients such as Meridian Energy, Mighty River Power, Watercare Services and other dam owners in New Zealand and Seqwater and Sunwater in Queensland, Australia.

1.8 I have authored or co-authored some 13 technical papers that have appeared in New Zealand and international journals and conferences. The papers relate to either the Clyde Dam, the landslide stabilisation work adjacent to Te Wairere / Lake Dunstan, or the sediment flushing in Lake Roxburgh.

2. CODE OF CONDUCT

2.1 I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in my brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

3. SCOPE OF EVIDENCE

3.1 In preparing my evidence I have reviewed relevant provisions / parts of:

(a) the proposed Otago Regional Policy Statement (**proposed RPS**);

(b) Contact's submissions and further submissions;

(c) the Regional Council's section 42A report, including the version showing recommendations from the Regional Council's supplementary evidence and additional supplementary evidence (**section 42A report (October version)**);

(d) my council-level evidence (dated October 2002) (**2002 evidence**) and Environment Court evidence (dated 2004/2005) (**Environment Court evidence**), filed as part of Contact's application for resource consents to permit the operation of the CHS;

(e) a number of technical reports, including:

(i) NIWA (2015), *Lake Dunstan Sediment Modelling*;

(ii) WSP (2020), *Lake Roxburgh Sedimentation and Backwater Analysis for 2020 Bed Survey*;

(iii) WSP (2022), *Lake Dunstan Sedimentation and Backwater Study for March 2022 Bed Survey - Kawarau Arm Update* (**WSP 2022 report**); and

(iv) *Contact Energy Clutha Flood Rules 2022*.

3.2 The purpose of my evidence is to provide:

(a) an overview of the Clutha Mata-au and the CHS;

(b) a description of the sedimentation effects of the CHS on the Clutha Mata-au and how it has changed the river morphology of this catchment (including the effects of the CHS on flood levels);

(c) an overview of how sediment (and flood levels) are managed (and could be managed in the future) in regard to the CHS; and

(d) comments on proposed provisions of the proposed RPS relevant to the above matters.

4. EXECUTIVE SUMMARY

4.1 Contact owns and operates the CHS. As part of the CHS, there are two hydroelectric generation facilities located on the Clutha Mata-au River; being the Clyde Dam at Clyde and the Roxburgh Dam located upstream of Roxburgh. These generation facilities are essentially 'run of river' hydroelectricity schemes, with a narrow operating range at Te Wairere / Lake Dunstan (upstream of Clyde Dam) and Lake Roxburgh (upstream of Roxburgh Dam).

4.2 The inflows into the Clutha Mata-au catchment can vary year to year and over periods of a few decades due to the Interdecadal Pacific Oscillation which can affect climate variability in the South Pacific. For example, at Roxburgh, the period 1978 to 2000 had approximately 13% more inflow than other periods between 1930 to 2022.

4.3 Most of the sediment transported by the Clutha Mata-au comes from the Shotover River, which is a tributary of the Kawarau River located above the Clyde and Roxburgh Dams. The sediment flow was originally interrupted by the construction of the Roxburgh Dam. However, since the Clyde Dam's construction, this sediment is now being captured within the Kawarau Arm of Te Wairere / Lake Dunstan.

4.4 Based on the data from cross-sections of Lake Roxburgh that were surveyed pre-construction of the dam and from 1961 to 1992/1993, the average rate of sediment accumulation was calculated to be in the range of 1.37 to 1.42 million cubic metres per year. This indicates that approximately 51 million cubic metres of sediment accumulated in Lake Roxburgh in the period 1956 to 1992/1993.

4.5 An effect of the sediment deposition has been the progressive increase in flood levels at Alexandra. The 1994 flood reached a level approximately 4 metres higher than the level of an equivalent flood that occurred after Lake Roxburgh was first filled.

4.6 In 1994 a partial drawdown of Lake Roxburgh during the 1994 flood was implemented and demonstrated that such a drawdown can redistribute sediment within the reservoir and flush sediment downstream. Such a procedure has been introduced into the Clutha Flood Rules as a mode of operation for Lake Roxburgh and has led to increased flood protection at Alexandra. Modelling by NIWA indicates future increased benefits can be gained and in my opinion the flood drawdown mode of operation for the Roxburgh Dam should continue.

4.7 In my 2002 evidence, I predicted that sediment from the Kawarau River would initially be deposited in the Kawarau and Dunstan Arms of Te Wairere / Lake Dunstan at an average rate of 1.2 million m^3/yr and reach Clyde Dam at year 2105. The Kawarau Arm will develop a riverine appearance as the sediment advances with medial and point bars appearing in this reach. While the character of the Kawarau Arm is much as I predicted, the average rate of sediment deposition has been 0.91 million m^3/yr from 1994 to 2022. The sediment tipping face is not as advanced into the Dunstan Arm below Cromwell as my initial prediction due to the average low deposition rate.

4.8 Letting sediment pass through the Clyde Dam turbines and over the spillway without flood drawdown, combined with use of the sluice with floods, may remain an option for sediment passage downstream of Te Wairere / Lake Dunstan heading into the next century and beyond. I envisage that flood drawdown and flushing will still be the ongoing operating procedure for Lake Roxburgh to promote sediment redistribution downstream of Roxburgh Dam

4.9 Given the significant effect of the CHS on the Clutha Mata-au, I consider that provisions in the proposed RPS that refer to the river being restored to "as natural as possible" should be approached with some caution. In my opinion, the CHS has permanently altered the character of this river, and will continue to do so in the future.

5. OVERVIEW OF CLUTHA MATAU-AU CATCHMENT AND THE CHS

5.1 An overview of the key aspects of the Clutha Mata-au catchment is provided in **Figure 1** below.

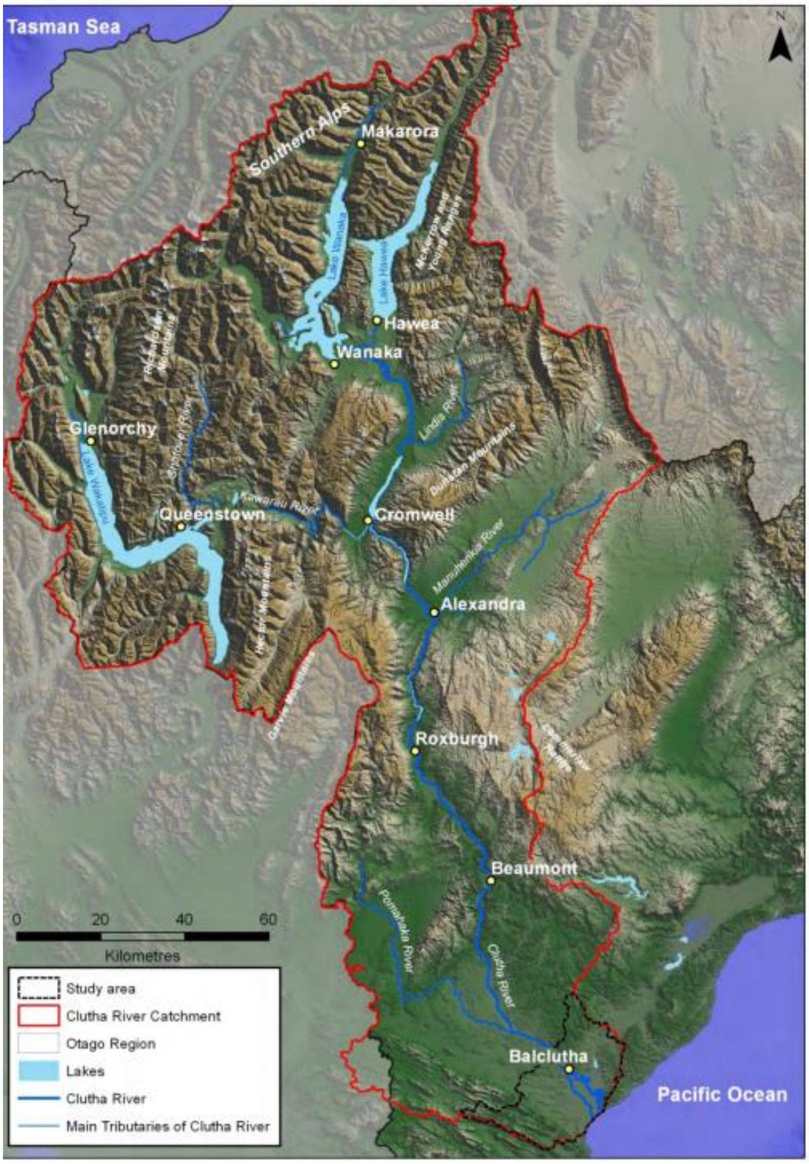


Figure 1: Overview map of Clutha Mata-au (Otago Regional Council)

5.2 Contact owns and operates the CHS. As part of the CHS, there are two hydroelectric generation facilities located on the Clutha Mata-au River; being the Clyde Dam at Clyde and the Roxburgh Dam located upstream of Roxburgh. These generation facilities are essentially 'run of river' hydroelectricity schemes, with a narrow operating range at Te Wairere / Lake Dunstan (upstream of Clyde Dam) and Lake Roxburgh (upstream of Roxburgh Dam).

5.3 Electricity generation is limited by the average inflow reaching the power stations each day. Outflows through the power stations can then be varied to match the electricity demand profiles throughout the day and night. When the power station consented flow capacity is reached, additional flows are then passed via the spillways or sluices located at the dam.

5.4 As explained further in **Mr Hunt's** evidence, the level of generation from the CHS can be controlled to a certain extent to reflect the needs of the electricity system. While the CHS is largely 'run of river' there is some storage capacity (and therefore flexibility) behind the Clyde and Roxburgh dams and in Lake Hāwea. The storage behinds Clyde and Roxburgh dams offers short-term flexibility (eg across a day); whereas the storage in Lake Hāwea offers some seasonal flexibility.

Water inflows

5.5 The inflows into the Clutha Mata-au catchment can vary year to year and over periods of a few decades due to the Interdecadal Pacific Oscillation which can affect climate variability in the South Pacific.

5.6 In my 2002 evidence, I identified the mean inflows and normalised mean flows of water relative to the period 1957 to 1977 across the Clutha Mata-au and across different time periods. I have updated these tables to include the last two decades from 2001 to 2022.[1] This is shown in **Tables 1** and **2** below.

Table 1: Mean inflows of water

	Mean Inflows (m3/s)				
	Roxburgh	Wakatipu	Wanaka	Hawea	Balclutha
1930-1956	484	154	188	62	-
1957-1977	494	171	187	63	535
1978-2000	560	204	218	71	618
2001-2021	502	162	197	60	561

[1] On request, Contact provided me with the data required in order to update **Table 1** and **Table 2**.

Table 2: Normalised mean inflows of water relative to 1957 -1977 period

	Normalised Mean Inflows based on 1957-1977 (m3/s)				
	Roxburgh	Wakatipu	Wanaka	Hawea	Balclutha
1930-1956	0.98	0.90	1.01	0.98	
1957-1977	1.00	1.00	1.00	1.00	1.00
1978-2000	1.13	1.19	1.17	1.13	1.16
2001-2021	1.02	0.95	1.05	0.95	1.05

5.7 The mean inflows and normalised mean inflows identified in **Tables 1** and **2** indicate that:

(a) the period between 1978 to 2000 had a higher average mean inflow compared to the periods between 1930 to 1956 (which was before Roxburgh Dam was completed) and 1957 to 1977; and

(b) in 2001 to 2021 the inflows are similar to those from 1930 to 1957.

5.8 From 1978 to 2000, three of the largest floods at Roxburgh Dam (since 1957) occurred in the period between 1994 to 1999.

Sediment inflow

5.9 Sediment inflow into Te Wairere / Lake Dunstan (and prior to the construction of the Clyde Dam, into Lake Roxburgh) is not at a constant rate but relates to flood activity. The large floods can move higher concentrations of bed load and suspended sediment and result in periods of above average sediment deposition. I discuss the sedimentation characteristics of the Clutha Mata-au, including the effects of the CHS on these characteristics, further below.

6. SEDIMENTATION CHARACTERISTICS OF THE CLUTHA MATA-AU

Overview

6.1 Most of the sediment transported by the Clutha Mata-au comes from the Shotover River, which is a tributary of the Kawarau River located above the Clyde and Roxburgh Dams. The sediment flow was originally interrupted by the construction of the Roxburgh Dam. However, since the Clyde Dam's construction, this sediment is now being captured within the Kawarau Arm of Te Wairere / Lake Dunstan.

6.2 The sedimentation characteristics at the Clutha Mata-Au have developed over time as a result of the impacts of the Roxburgh and Clyde Dams. Generally, sediment flows through waterways, however, where there are structures such as dams, this creates a build-up of sediment in their reservoirs over time. This build-up of sediment increases the bed levels of lakes, and ultimately can result in upstream flood levels if not managed appropriately.

6.3 In this section of my evidence I discuss:

(a) The sedimentation characteristics of Lake Roxburgh, including the effects of this sedimentation on flood levels at Alexandra; and

(b) The sedimentation characteristics of the areas upstream of the Clyde Dam (ie the Kawarau and upstream of Te Wairere / Lake Dunstan), including the effects of this sedimentation on flood levels.

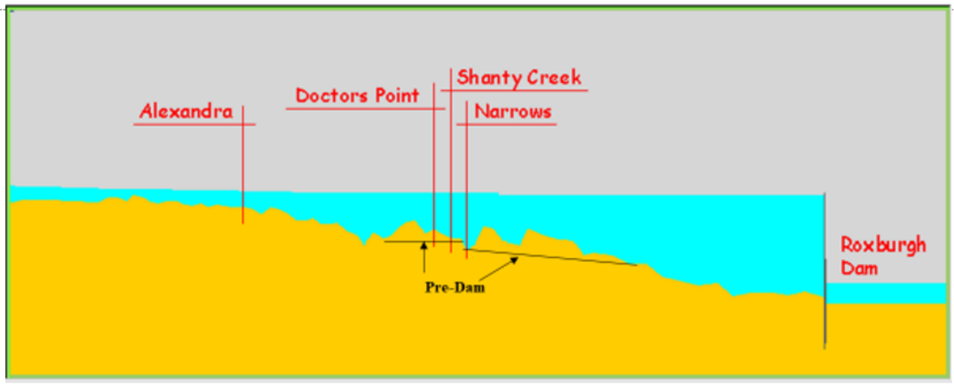
Lake Roxburgh sedimentation

6.4 Lake Roxburgh is a long narrow reservoir within the Roxburgh Gorge. Lake Roxburgh commenced filling in 1956 following the construction of the Roxburgh Dam. It progressively filled with sediment until Te Wairere / Lake Dunstan began filling in 1992 following the construction of the Clyde Dam. After that the sediment supply at Lake Roxburgh was significantly reduced.

6.5 Based on the data from cross-sections of Lake Roxburgh that were surveyed pre-construction of the dam and from 1961 to 1994, the average rate of sediment accumulation was calculated to be in the range of 1.37 to 1.42 million cubic metres per year. This indicates that approximately 51 million cubic metres of sediment accumulated in Lake Roxburgh in the period 1956 to 1992/1993.

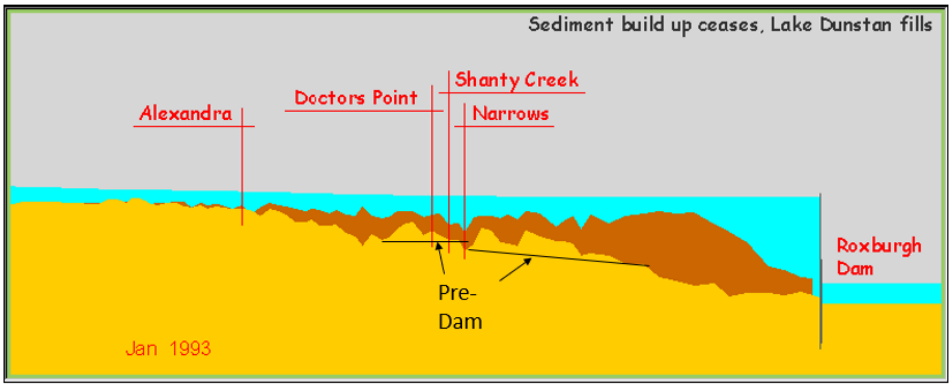
6.6 **Figures 2** and **3** below show the thalweg[2] bed level along the reservoir taken from an initial survey in 1961, and a composite survey from 1992 to 1994, at locations between the Roxburgh and Clyde Dams. The black lines indicate the approximate bed level pre-construction of the Roxburgh Dam. The yellow colour indicates the bed level in 1961; with dark brown representing the bed level in 1992-1994 and blue being the level of water behind the dam.

[2] The thalweg is a line connecting the lowest points of successive cross-sections along the course of a valley or river.



Roxburgh Bed Profile 1961

Figure 2: Bed Profile 1961



Roxburgh Bed Profile 1992-1994

Figure 3: Bed Profile 1992 -1994

6.7 **Figures 2** and **3** show that the sediment tipping front (or tipping face, being the place where most of the bed load and suspended sediment is being deposited) has progressed down the reservoir over time. This would not be seen by an observer on the foreshore of the reservoir, however, has been revealed by the survey of cross-sections described above.

6.8 The sediment and water volumes at the reservoir from the period between 1961 and a survey completed in February 1994 are shown in **Table 3** below. This table shows that the volume of sediment has been increasing, with the reservoir volume concurrently reducing over this period.

Table 3: Lake Survey Dates, Reservoir Volume and Sediment Volume

Survey Date	Reservoir Volume (million cubic metres)	Sediment Volume (million cubic metres)
July 1961	101	0
July 1970	87	14
July 1974	82	19
July 1978	78	23
February 1979	76	25
February 1984	67	34
November 1989	59	42
February 1994	57	44

6.9 The tipping face would have progressed further towards the Roxburgh Dam if the Clyde Dam had not been constructed. However, since the construction of Clyde Dam, the vast majority of sediment that previously accumulated behind the Roxburgh Dam is now being trapped upstream of the Clyde Dam. Some sediment is still coming into Lake Roxburgh via the Fraser and Manuherikia catchments. This would have resulted in further sediment accumulation if the practice of lake drawdown ahead of floods had not been introduced in January 1994 (as I describe below).

6.10 Eventually, if Clyde Dam had not been built, the 'trap efficiency' of the Roxburgh reservoir would have reduced to the point where most incoming sediment would pass through the turbines or over the spillway. The term 'trap efficiency' relates to the amount of sediment that settles out relative to the total amount of sediment input. In my experience from observing reported reservoir sedimentation at some Chinese hydro schemes, a state of equilibrium can be reached after 70-90 percent of the reservoir capacity is lost, whereby the volume of sediment stabilises and stops increasing.

6.11 The effect of sediment accumulation is that it reduces the flow area at each section along the reservoir and increases the velocity of water flow at sections where there has been sediment accumulation. The velocity increase causes a rise in reservoir water levels that can result in flooding, which has been an issue at Alexandra.

Flood management and its effect on sedimentation of Lake Roxburgh

6.12 I began advising ECNZ and then Contact on options to reduce the flood risk at Alexandra in 1992.

6.13 I was involved in studies in 1994 for the Regional Council and ECNZ. In these studies, we found that the sediment accumulation at Lake Roxburgh had caused water levels to rise by 3.4 metres from the first filling in 1956. In my 2002 evidence and Environment Court evidence I produced flood level data for the 1994 flood and included a peak data point for the 1957 flood, which had a slightly higher peak flow than the 1994 flood. I expressed my opinion that a repeat of the 1957 flood would have caused flood levels to rise by 3.9 metres if it had occurred in 1994, based on a peak flow estimate of 2570 m^3/s. The current data is discussed in paragraphs 6.25 and 6.26 below.

6.14 In February 1993 I was involved in a prefeasibility study into options to alleviate the flood risk at Alexandra. The possible options we identified included:

(a) do nothing;

(b) stop bank protection at Alexandra;

(c) dredging with land disposal;

(d) dredging with lake disposal; and

(e) flushing material from the lake.

6.15 Our feasibility study noted that "*…limited or substantial drawdown of the reservoir through upgraded sluices is a viable option for flushing sediment from the lake…Flood reduction gains may be realised in 10-30 years if operating procedures are modified*."

6.16 The options were then shortlisted down to flushing during floods or as a seasonal drawdown such as from 1 November to 31 January when flood activity was more likely. Sedimentation transport studies completed by NIWA around that time indicated that flushing during floods was the preferred option, and this is now Contact's current practice.

6.17 When flows exceeded 850 m^3/s in November and December 1994, ECNZ partially lowered the lake at Roxburgh Dam using the powerhouse and spillway. ECNZ found they could go lower than 127.4 metres and could operate at an extreme minimum operating level of 125.75 metres. This represents a drawdown of 6.25 metres from normal maximum operating level.

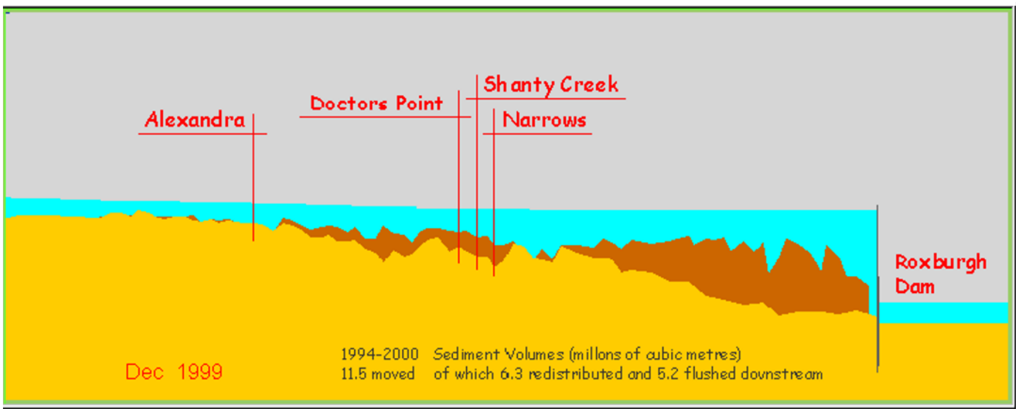
6.18 Since then the lake has been drawn down during floods on numerous occasions. The figure at **Appendix PF.1** shows the lake levels at Roxburgh Dam for the period from 1992 through to March 2022.

6.19 The first trial of a flood drawdown happened in January 1994 and flood drawdown has continued to the present day when flood flows are expected to exceed the trigger levels, provided for in consent conditions for drawdown and operation. The frequency of drawdown was highest in the period of 1994 to 2000 due to greater flood frequency compared to the period from 2000 to 2022.

6.20 **Appendix PF.2** shows the Lake Roxburgh inflows for the period from 1992 through to 2022. The floods in 1994 and 1999 are notable in the period up to 2000, with nothing approaching the size of these floods since 2000.

6.21 The 1994 flood had a peak inflow (3 hourly) of 2343 m^3/s into Lake Roxburgh. The 1995 flood had a peak 3 hourly inflow of 3213 m^3/s and the 1999 flood had a peak 3 hourly inflow of 3623 m^3/s. The 1999 flood and the 1995 flood are ranked 2nd and 3rd respectively as the highest floods at Alexandra since 1878.

6.22 Flooding events affect the bed profile, as I describe below. **Figure 4** below shows the Roxburgh bed profile surveyed after the 1999 flood.



Roxburgh Bed Profile December 1999

Figure 4: Roxburgh Bed Profile December 1999

6.23 In the period between 1994 to 1999 the flushing events had mobilised some 1.5 million cubic metres of sediment, of which 6.3 million cubic metres was redeposited in the reservoir closer to the dam, and 5.2 million cubic metres was flushed downstream of Roxburgh Dam over the spillway and through the turbines.

6.24 **Appendix PF.3** shows a plot provided by Eliot Sinclair of the lake bed profiles from Alexandra to Roxburgh Dam from surveys in 1994, 1999, 2007 and March 2020. This shows that bed levels have been reasonably stable since 1999 with the current sediment flushing regime. There has been a small advance of the tipping face downstream (four sections closest to Roxburgh Dam).

6.25 **Appendix PF.4** shows the 3 hourly measured water levels at Alexandra Bridge and the corresponding Roxburgh inflows in January 1994, November to December 1995 and November to December 1999. It also shows the peak flood levels for the 1957, 1978 and 1987 floods.

6.26 **Appendix PF.4** shows the same data points that I presented in my 2002 evidence, however this now includes peak flood data from floods since 2002 and shows rating curves produced by others that indicate the current situation and predictions of future rating curves if the flushing regime is continued.

6.27 As a result of flushing and lake lowering, the 1999 flood water level at Alexandra was approximately 1.4 metres lower than the 1994 event at a flow equivalent to the peak of the 1994 flood (2343 m^3/s). **Appendix PF.4** also shows a data point for measurements made since the 1999 flood.

6.28 **Appendix PF.4** shows a March 2020 rating curve that is marginally lower than the 1999 flood data for flows <1500 m^3/s, but the WSP 2022 report[3] states that if the 1999 peak flow were to occur now then it would peak with a similar level to the peak in 1999, which is contained now by the stop banks built after 1999. The WSP 2022 report also reported predictions by NIWA as to the rating curves that could occur, projecting out to 2029 and 2059. The accuracy of these projections will depend on the actual flood activity but they do signal that the flushing procedures at Roxburgh should continue into the future to maximise potential flood protection at Alexandra.

[3] WSP (2022), *Lake Dunstan Sedimentation and Backwater Study for March 2022 Bed Survey - Kawarau Arm Update*.

6.29 In addition to the rating curve at Alexandra, Contact's consent conditions require flood maps to be produced for a 1 in 500 AEP flood and the Probable Maximum Flood (PMF). These maps are given in **Appendix PF.5** and **Appendix PF.6**

Te Wairere / Lake Dunstan sedimentation

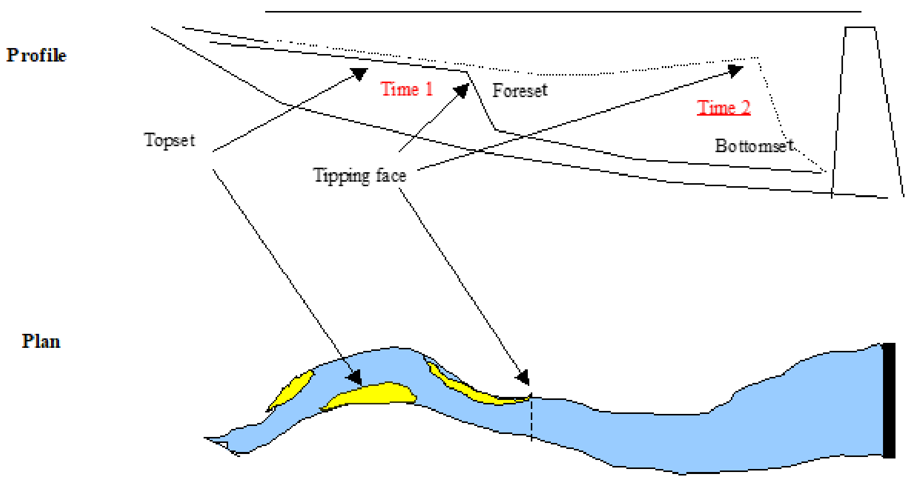
6.30 I started my engineering career in 1976 as an assistant engineer with the Ministry of Works and Development in a team developing concept layouts for a dam in the Cromwell Gorge, initially at Gibraltar Rock (DG7 site) and later at Clyde (DG3 site). By 1978 I was aware of the following from other studies done within the Ministry:

(a) That the accumulation of large quantities of sediment in the proposed Lake Dunstan is inevitable, as has occurred in Lake Roxburgh; and

(b) That by 1977 the bed of Lake Roxburgh had been surveyed in 1960/61, 1970 and 1974 and it had been deduced that between 1956 and 1976 some 34 million cubic metres of sediment had settled in the headpond. It was also known that the volume of Lake Roxburgh was reducing at an average rate of 1.45 million cubic metres per year due to sediment deposition.

6.31 As noted above, most of the sediment entering the Clutha / Mata-au catchment is sourced from erosion within the slopes of the Shotover catchment, which feeds into the Kawarau River. That sediment is now being captured in Te Wairere / Lake Dunstan.

6.32 A stylised pattern of sedimentation into a reservoir that is similar to the Kawarau Arm and Cromwell to Clyde Dam reach of Te Wairere / Lake Dunstan is shown in **Figure 5** below.



Idealised plan and profile of an elongate reservoir receiving sediment (after US Dept of the Interior, Bureau of Reclamation, 1974).

Figure 5: Idealised plan and profile of an elongate reservoir receiving sediment

6.33 The velocity of the water entering the top end of the lake reduces compared to the velocity in the river upstream of the lake. This causes the sand and gravel materials that roll and bounce along the riverbed to settle out and form a delta. The finer suspended sediment also begins to fall from suspension and forms an apron type deposit on the reservoir bed. **Figure 5** shows an initial advance of the delta into the reservoir at 'Time 1' and the establishment of a tipping face.

6.34 As explained above, by 1994, Lake Roxburgh had filled with sediment and reached a similar situation to 'Time 2' as shown above in 'Profile' view in **Figure 5**.

6.35 The Kawarau Arm of Te Wairere / Lake Dunstan has (consistent with the stylised pattern demonstrated in **Figure 5**) transitioned to a morphology more like that of an alluvial river, with 'point bars' growing off the inside of bends and possible 'medial' bars or islands growing mid-stream if the channel is wide enough. This can create a meandering or semi-braided channel pattern. **Figure 5** shows some of these bars in the 'Plan' view of the reservoir.

6.36 The bars can grow higher with raised water levels in floods and emerge to become beaches or islands when floods recede, and the reservoir then reverts back to being a lake. With time, the raised beaches and islands will accumulate finer sediment as “overbank” material and will tend to vegetate as they grow in elevation and are swept by floods less frequently. The beaches and islands will eventually grow above the level of the main channel.

6.37 Over time, the tipping face in the Kawarau and Cromwell to Clyde Dam reach is expected to advance to the dam in a similar manner as for Lake Roxburgh (and as shown in concept at 'Time 2' in **Figure 5**).

6.38 **Photos 1 and 2** below show evidence of Te Wairere / Lake Dunstan evolving in a pattern of sedimentation similar to **Figure 5** expectations. **Photo 1** shows the head of the lake where flow exits from the Kawarau Gorge in 2005.[4] It shows that sand bars were beginning to appear in the lake at that time. **Photo 2** shows the same area in 2010, and shows that these sand bars had developed further.[5]

Photo 1: Sand bars at Te Wairere / Lake Dunstan (2005) (photo courtesy Peter Silvester)

[4] This photo was taken during a helicopter flight over the head of Lake Dunstan that I attended together with Peter Silvester from Contact.
[5] This photo was taken from a helicopter flight over the area by Peter Silvester.

Photo 2: Sand bars at Te Wairere / Lake Dunstan (2010) (photo courtesy Peter Silvester)

Earlier predictions about sedimentation in the Kawarau Arm and Cromwell to Clyde Dam reach of Te Wairere / Lake Dunstan

6.39 In 2002, I made an estimate with NIWA of the likely average rate of sediment accumulation in the Kawarau Arm and Cromwell to Clyde Dam reach of Te Wairere / Lake Dunstan. This estimate was made on the following basis:

Sediment sources/types	Estimate (million cubic metres/yr)
Long term rate into Lake Roxburgh	1.42
Less Upper Clutha sediment	- 0.17
Less other downstream sources	- 0.05
Total	**1.20**

6.40 In my 2002 evidence I noted my opinion that an average sedimentation accumulation rate of 1.3 million cubic metres per year in the Kawarau Arm to Clyde Dam was a long-term upper bound. This higher figure allows for a potentially higher trap efficiency in Te Wairere / Lake Dunstan relative to Lake Roxburgh.

6.41 Not all the sediment entering the Te Wairere / Lake Dunstan reservoir is trapped. The finer sediment is still able to remain in suspension and pass through the lake via the penstocks and spillway at Clyde Dam, particularly in flood conditions when sediment inflow pulses occur and the velocities in the reservoir are higher. **Photo 3** below shows sediment-laden water discharging from the Clyde Dam spillway during the November 1999 flood.

Photo 3: Clyde Dam spillway in 1999 flood

6.42 In the Opus report *Lake Dunstan Sedimentation Report* (June 2001) we set out our predictions as to how the sediment accumulation will develop in time in the Kawarau Arm and Cromwell to Clyde Dam reach of Te Wairere / Lake Dunstan. These predictions are provided in the figure at **Appendix PF.7**. I comment below on what this figure shows, also drawing from additional data that was available in 2002.

6.43 The lower half of the figure at **Appendix PF.7** shows how the bed profile is expected to develop with time. Data in 2002 was available from the completion of filling Te Wairere / Lake Dunstan in 1994 through to February 2000 to show how the delta and tipping face was developing. By that time the tipping face had advanced down to about the Bannockburn Bridge, and the finer apron materials were extending down towards the confluence at Cromwell.

6.44 **Appendix PF.7** also shows the tipping face reaching the confluence at about 2010 and then advancing down the Cromwell to Clyde Dam reach of the reservoir. In 2002 I predicted that the tipping face would be getting close to Clyde Dam at about 2105, some 100 years into the future from when the prediction was made based on an annual average accumulation of 1.2 million m^3 per year.

More recent surveys generally confirm my earlier predictions

6.45 More recent surveys by Eliot Sinclair show the bed profile in July 2007 and March 2022 as shown **in Appendix PF.8**.

6.46 **Appendix PF.8** shows that the tipping face has now reached the confluence at Cromwell. In 2002 I predicted it could be approximately 3 km further downstream by 2020. The data is showing that the tipping face is developing much as expected, but suggests the sediment deposition rate has been lower than my average projection of 1.2 million m^3/yr.

6.47 **Table 4** below is taken from the WSP 2022 report[6] and presents the sediment deposition for surveys from April 1994 to March 2022.

[6] WSP (2022), *Lake Dunstan Sedimentation and Backwater Study for March 2022 Bed Survey - Kawarau Arm Update*

Table 4: Sediment deposition April 1994 to March 2022

Table 3-1: Cumulative sediment deposition volumes and average rates in Kawarau Arm.

Survey date	Sediment deposition since April 1994 (Mm^3)	Average annual rate of Sediment deposition since April 1994 (Mm^3/yr.)	Sediment deposition since previous survey (Mm^3)	Rate of sediment deposition since previous survey (Mm^3/yr.)
September 1999	5.69	1.05	1.8	0.51
February 2000	8.48	1.45	2.79	6.67
December 2004	14.96	1.40	6.48	1.34
July 2007	16.25	1.23	1.28	0.50
July 2009	17.56	1.15	1.31	0.65
October 2011	18.81	1.07	1.25	0.56
February 2014 (to cross-section 73)	20.52	1.03	1.71	0.73
February 2014 (Kawarau Arm incl. cross-sections 35-38 and 73 in the Dunstan Arm)	21.6	1.08	1.97 *	0.79 *
March 2016 (to cross-section 73)	21.47	0.98	0.95	0.46
March 2016 (Kawarau Arm incl. cross-sections 35-38 and 73 in the Dunstan Arm)	22.6	1.03	1.07	0.54
March 2018 (to cross-section 73)	22.30	0.93	0.83	0.41
March 2018 (Kawarau Arm incl. cross-sections 35-38 and 73 in the Dunstan Arm)	23.6	0.98	1.01	0.5
March 2020 (to cross-section 73)	22.88	0.88	0.59	0.29
March 2020 (Kawarau Arm incl. cross-sections 35-38 and 73 in the Dunstan Arm)	-	-	-	-
March 2022 (to cross-section 73)	23.68	0.85	0.80	0.40
March 2022 (Kawarau Arm incl. cross-sections 35-38 and 73 in the Dunstan Arm)	25.34	0.91	1.74 (2018-2022)	0.44 (2018-2022)

* Note: For these sediment deposition volumes, it has been assumed that the date of the lake-bed survey of the Dunstan Arm occurred at the same time as the lake-bed survey of the Kawarau Arm.

6.48 **Table 4** indicates that the average deposition rate has been 0.91 million m^3/yr for the 28 years since 1994. However, in the 22 years since February 2000 the average sediment deposition rate was lower at 0.77 million m^3/yr.

6.49 Through the Cromwell to Clyde Dam reach I expect the advancing tipping face to be less visible compared to the Kawarau Arm. This is because the larger combined flow from the Kawarau and Upper Clutha will allow a greater flow area, which still produces sufficient velocity to keep sediment moving. The width of the lake is also narrower than in the Kawarau arm immediately upstream of the confluence. These factors combined cause a drop in bed level. For this reason, medial bars and islands are unlikely to appear. Lake Roxburgh is an example of a similar situation where the narrowness of the reservoir prevented medial islands forming.

6.50 In the Upper Clutha arm at the head of Te Wairere / Lake Dunstan a braided delta has built up (ie the river is braided upstream of the Lake and the braided channel now extends further into the head of the Lake). I expect that this braided delta will advance with a similar form by approximately 4 km over the next 100 years, from sediment sourced from the Lindis and Cardrona tributaries downstream of Lake Wanaka and Hāwea. This relatively slow rate of advance, combined with relatively small sediment inputs (compared to the Kawarau Arm) should result in colonisation by vegetation (willows) and a reasonably stable pattern of channels. I expect to see a braided channel pattern, with several channels passing between stable, vegetated islands. **Photo 4** below shows upstream of Te Wairere / Lake Dunstan in the Upper Clutha arm in 2010, with evidence of the braided delta pattern starting to develop.

Photo 4: Upper Clutha sediment deposition (2010) (photo courtesy of Peter Silvester)

6.51 Further modelling of the sediment deposition and flood level predictions was completed by NIWA in 2015.[7] A schematic of the NIWA model is shown in **Figure 6** below.

[7] NIWA (2015), *Lake Dunstan Sediment Modelling*.

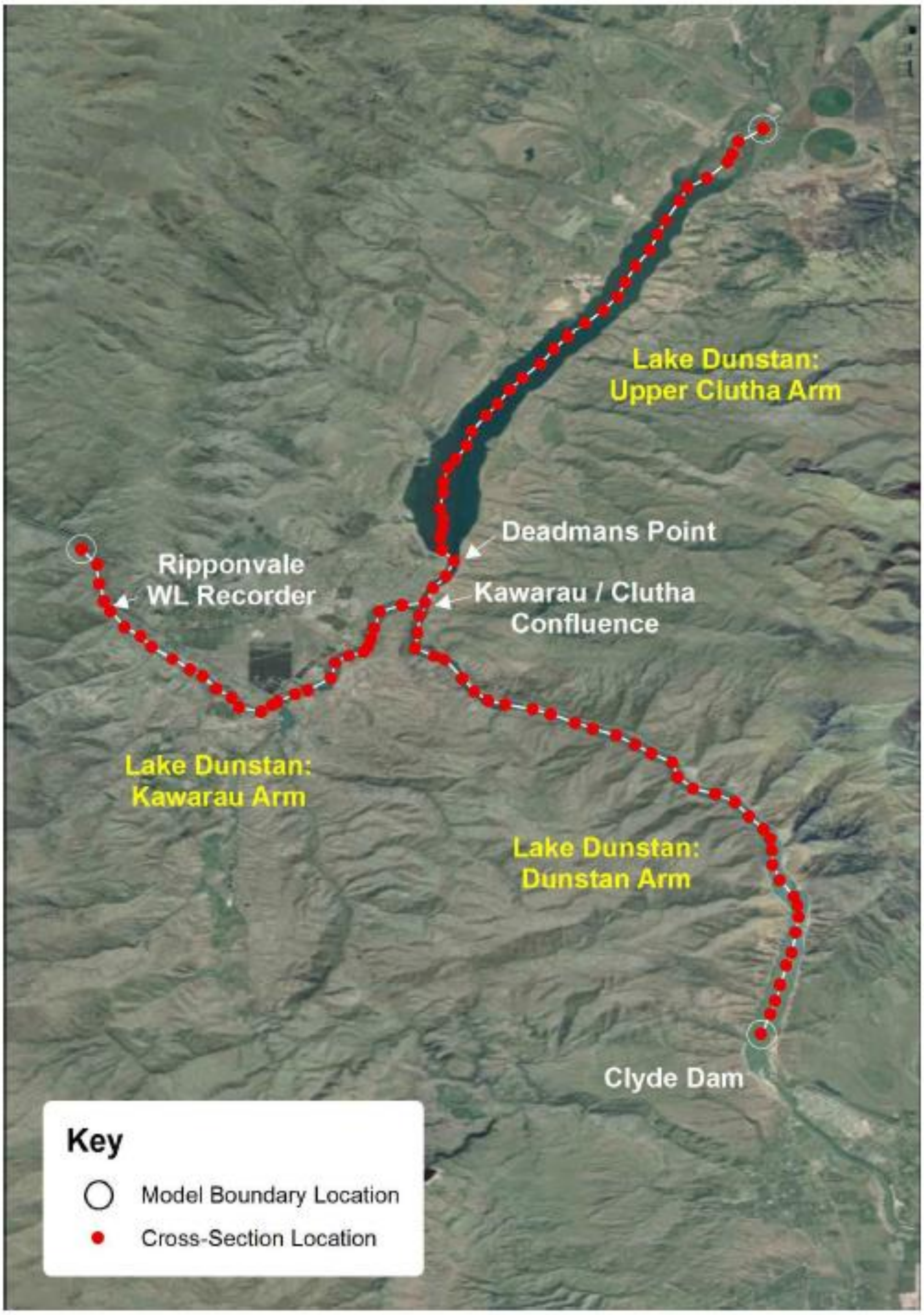


Figure 6: NIWA schematic model representation (NIWA)

6.52 The sediment transport model was calibrated by NIWA using data from the 18-year period between March 1996 to February 2014. NIWA calculated that the average annual deposition in Kawarau arm for the 18-year calibration period was 0.91 million m^3/yr and that the trap efficiency for sediment inflows to the Kawarau Arm was 93%, ie 7% of the sediment was passed downstream of Clyde Dam.

6.53 **Appendix PF.9** shows the NIWA predictions of the sediment bed levels for the Kawarau and Dunstan arms of Lake Dunstan for years 0, 20, 40, 60, 80 and 100 from February 2014. In year 2114 the tipping face is still 3km upstream of Clyde Dam with the thalweg level at a similar level to the intakes at Clyde Dam.

6.54 NIWA predicts the sediment outflow from Te Wairere / Lake Dunstan to increase over time from 168kt/yr for years 0 to 20 to 518 kt/yr for years 80 to 100, with a corresponding reduction on trap efficiency from 91% for year 0-20 to 72% for year 80-100.

7. SEDIMENT AND FLOOD MANAGEMENT NOW AND IN THE FUTURE

7.1 As discussed above, the management of sediment at Lake Roxburgh has been occurring for some time through the flushing regime to address the associated flood risks at Alexandra

7.2 The management of sedimentation into Te Wairere / Lake Dunstan commenced at the design stage of the Clyde Dam. The dam was designed with the penstock intakes set low at an elevation of 169 metres, and a high flow capacity low-level sluice was constructed as well. **Figures 7** and **8** below show those sections at the Clyde Dam.

7.3 **Figure 7** shows that the intakes for the penstocks are set some 25 metres below lake level. I was on the design team for the Clyde Dam and one of the reasons we set the intakes this low (and we could have set them higher) was to limit the eventual height at which sediment could build up in the vicinity of the dam.

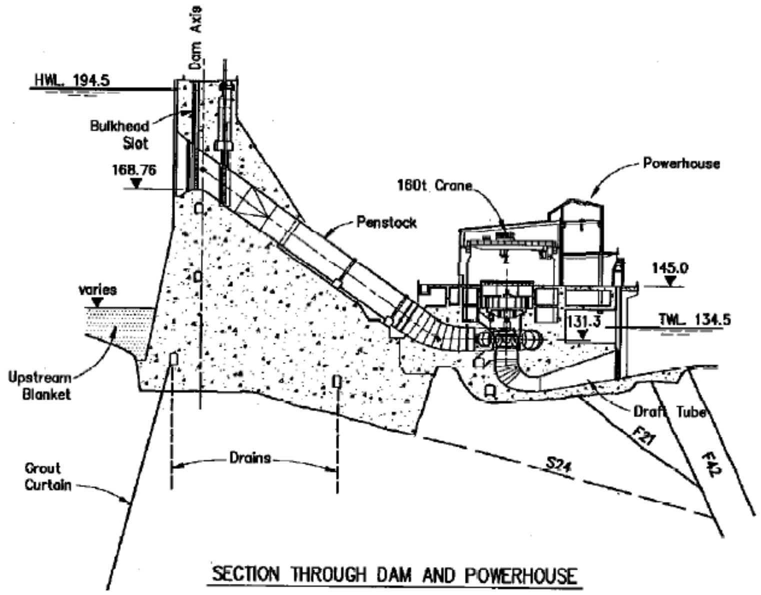


Figure 7: Intake section at Clyde Dam

7.4 **Figure 8** shows the low-level sluice that exists between the intakes and spillway at Clyde Dam. The base of the sluice is set 53 metres below the lake level. The sluice allows the opportunity to locally draw down the sediment levels further and pass this small amount of additional sediment downstream of the dam. Unless the sluice is used to draw the lake well down, such that the river can cut down into upstream sediment beds, the sluice will have only a limited effect on accumulated sediment immediately upstream of the sluice opening.

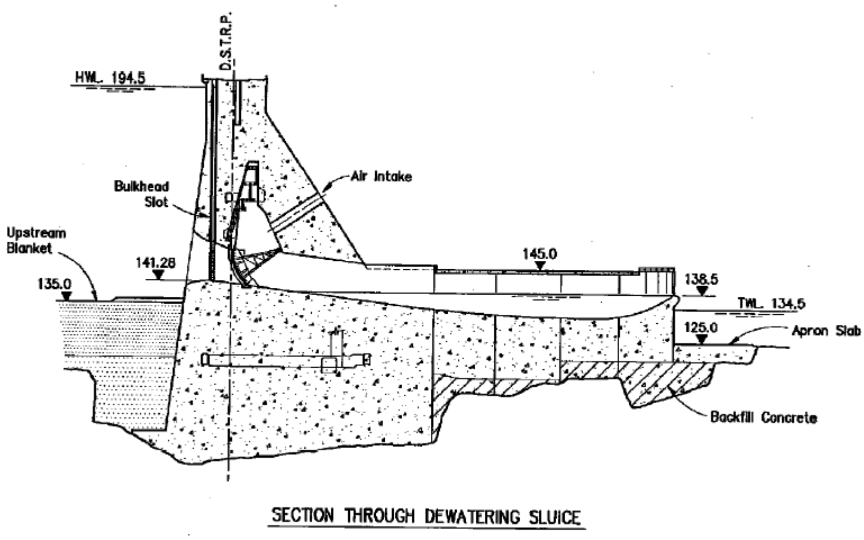


Figure 8: Sluice section at Clyde Dam

7.5 The penstock intakes and low level sluice also allow for the option of sediment flushing to pass sediment downstream of Clyde Dam.

7.6 I also consider it important to recognise that Te Wairere / Lake Dunstan's primary purpose is as the headpond to allow for hydropower generation. The normal operating range is only 1.0 metre. Loss of reservoir capacity at Te Wairere / Lake Dunstan, with sediment going into the dead storage zone below the intakes, is not critical to efficient or sustained energy production in the long term extending into the next century. Excluding the storage at Lake Hawea, the Clutha is a run of river scheme and power generation is a function of flow in the river and the height between reservoir level and tailwater level at the power station, not the water volume in Lake Roxburgh or Dunstan. The sediment accumulation in Te Wairere / Lake Dunstan will affect upstream flood levels, but not power production.

7.7 The approach taken in the past to purchase land around Te Wairere / Lake Dunstan recognises that sediment accumulating in the lake will, with time, give rise to higher flood levels. The land purchased in the Kawarau arm is generally at an elevation of about 220 metres and is well above the 3200 m^3/s flood levels predicted to occur in 100 years time (except for possibly a small area of one property and a small section of road at the Bannockburn inlet).

7.8 In the remainder of Te Wairere / Lake Dunstan, at the confluence and the Upper Clutha, predictions of flood reservoir levels were based on simulations made in 2002. The WSP 2022 report used the March 2022 profile in backwater calculations to update the flood levels in the Kawarau Arm for a flow of 3200 m3/s at Clyde dam as shown in **Appendix PF.10.**

7.9 **Appendix PF.10** also shows a projected flood line out to year 2040 based on the confluence level expected in 2042. As the tipping face progresses further down the Dunstan Arm I expect the backwater model will need to be re-calibrated as surface roughness will be changing due to the bed level rise with sediment. Once the model is re-calibrated for higher flows then further projections for flows as high as 3200 m^3/s can be made.

7.10 Letting sediment pass through the Clyde Dam turbines and over the spillway without flood drawdown, combined with use of the sluice with floods, may remain an option for sediment passage downstream of Te Wairere / Lake Dunstan heading into the next century and beyond. I envisage that flood drawdown and flushing will still be the ongoing operating procedure for Lake Roxburgh to promote sediment redistribution downstream of Roxburgh Dam

7.11 However, if sediment flushing was introduced at Te Wairere / Lake Dunstan now it would not, in my opinion, reduce the sediment accumulation rate. The Kawarau arm bed may deepen a little, but due to the width of the lake, point bars are likely to still form and be unaffected in the long-term. Sediment would still be deposited further down the lake and not necessarily flushed downstream.

7.12 The Clyde Dam has been designed to allow sediment to build up to the level of the intakes. However, it would be desirable to utilise the low-level sluice more frequently in usual flood operations so as to limit sediment build-up near the sluice, as the sluice flow capacity is required for extreme flood passage at Clyde Dam.

7.13 Once sediment starts passing downstream from Te Wairere / Lake Dunstan it will be important to continue the flood flushing regime available under the Flood Rules for Lake Roxburgh in order to maintain the flood level benefits at Alexandra that have been gained since 1994.

7.14 In conclusion, I consider it would be appropriate, over at least the next 80 plus years, to allow sediment to accumulate in Te Wairere / Lake Dunstan without changing any of the operating rules for the reservoir. The opportunity exists to monitor and review the situation every 10 years as sediment accumulates and new measurements are made of the lakebed profile, with updated calculated water levels about the reservoir under flood conditions. Rises in flood level predictions may give rise to further land purchases or flood easements in the Upper Clutha arm of Te Wairere / Lake Dunstan.

8. COMMENTS ON THE PROVISIONS OF THE PROPOSED RPS

8.1 With the above background in mind, I have been asked to consider the following provisions of the proposed RPS (section 42A report (October version):

(a) LF-VM-O2 (noting that this provision has been renotified to go through the freshwater planning process, however, it is useful context to the other provisions that I discuss as set out below);

(b) LF-FW-P13; and

(c) LF-FW-P14.

8.2 These provisions all make reference to the "natural form and function" of the river in some way.

8.3 LF-VM-O2 sets an objective that in the Dunstan, Manuherekia and Roxburgh rohe, flows in water bodies sustain and, wherever possible, restore the natural form and function of main stems and tributaries to support Kai Tahu values and practices. It also sets an objective that in the Lower Clutha rohe, there is no further modification of the shape and behaviour of the water bodies and opportunities to restore the natural form and function of water bodies are promoted wherever possible.

8.4 This objective is echoed in the following policies which related to natural character:

(a) LF-FW-P13 is a policy to preserve natural character. It states that the natural character of lakes and rivers and their beds and margins is to be preserved by wherever possible, sustaining the form and function of a water body that reflects its natural behaviours; and preventing modification that would reduce the braided character of a river; and controlling the use of water and land that would adversely affect the natural character of the water body.

(b) LF-FW-P14 is a policy to restore natural character. It states that where the natural character of lakes and rivers and their margins has been reduced or lost, actions are to be promoted that restore a form and function that reflect the natural behaviours of the water body. Improve water quality or quantity where it is degraded.

8.5 As set out in my evidence above, the CHS has significantly and irrevocably changed the character of the Clutha / Mata-au through the creation of the dams; and Lakes Dunstan / Roxburgh; and the various sedimentation/flooding issues associated with this as I have described. I am therefore not sure how these policies could practically be implemented in relation to this river system.

8.6 If it were considered practicable or possible to remove the dams, consideration must also be given as to how to remove 66 years of sediment stored behind Roxburgh and Clyde Dams and to transport this out of the river system and into the ocean without significant adverse effects to the environment.

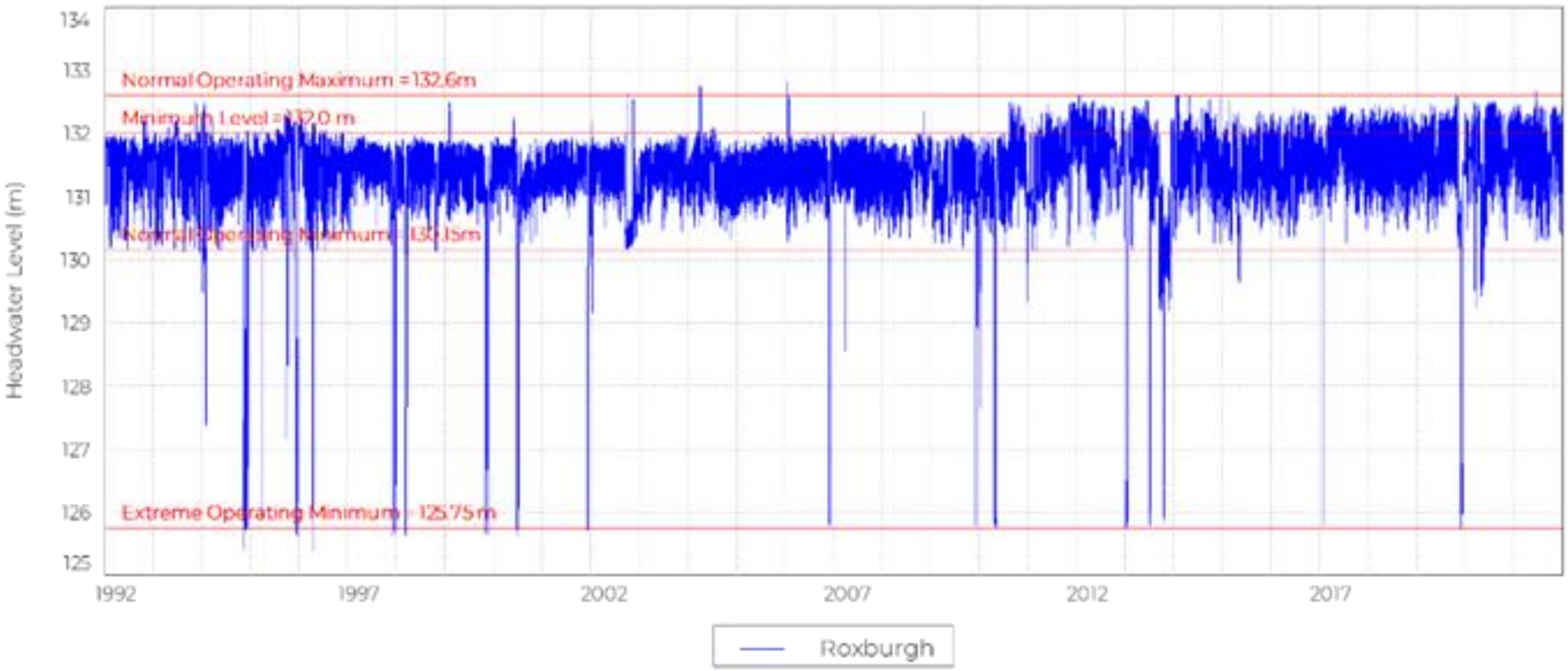
8.7 **Ms Hunter** has recommended amendments to these provisions to reflect that sustaining or restoring the natural form and function of the Clutha River is not practical or sensible in the context of the CHS;[8] and I agree with her recommendations in this respect.

Peter Foster

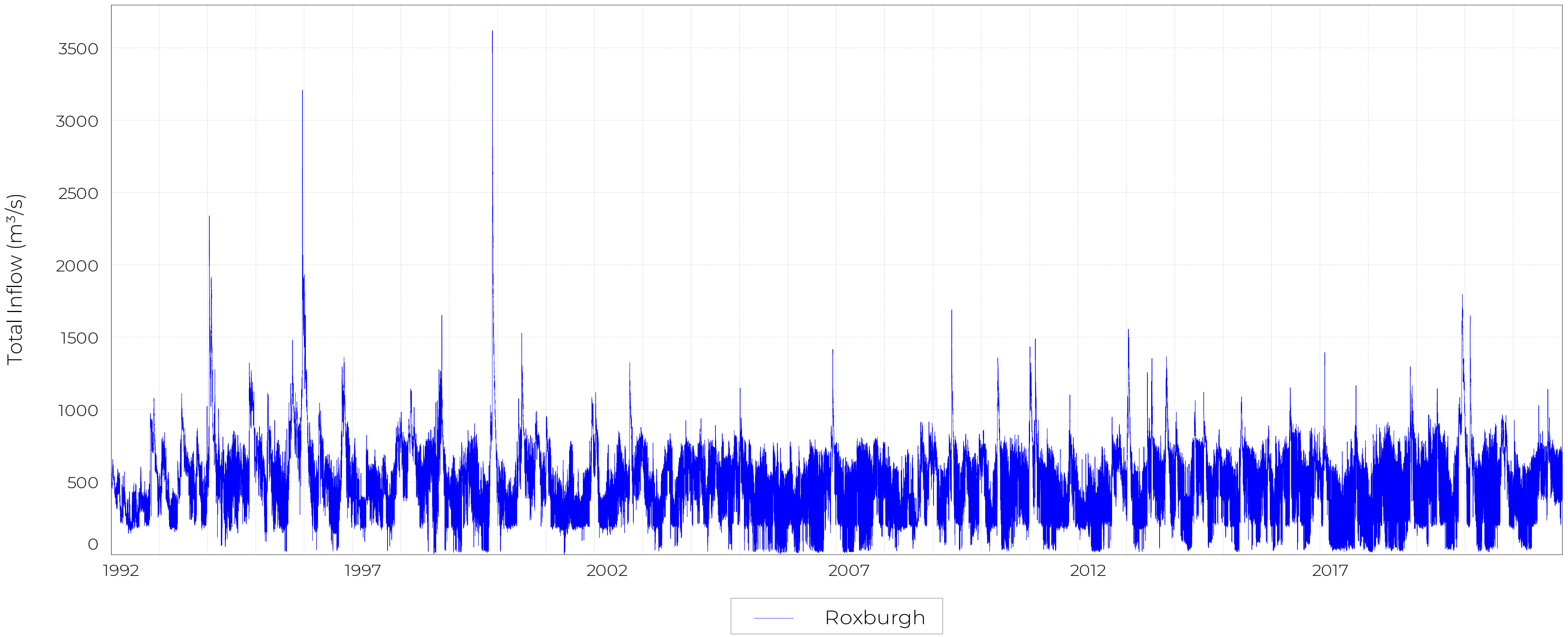
23 November 2022

[8] Hunter EIC, section 9.

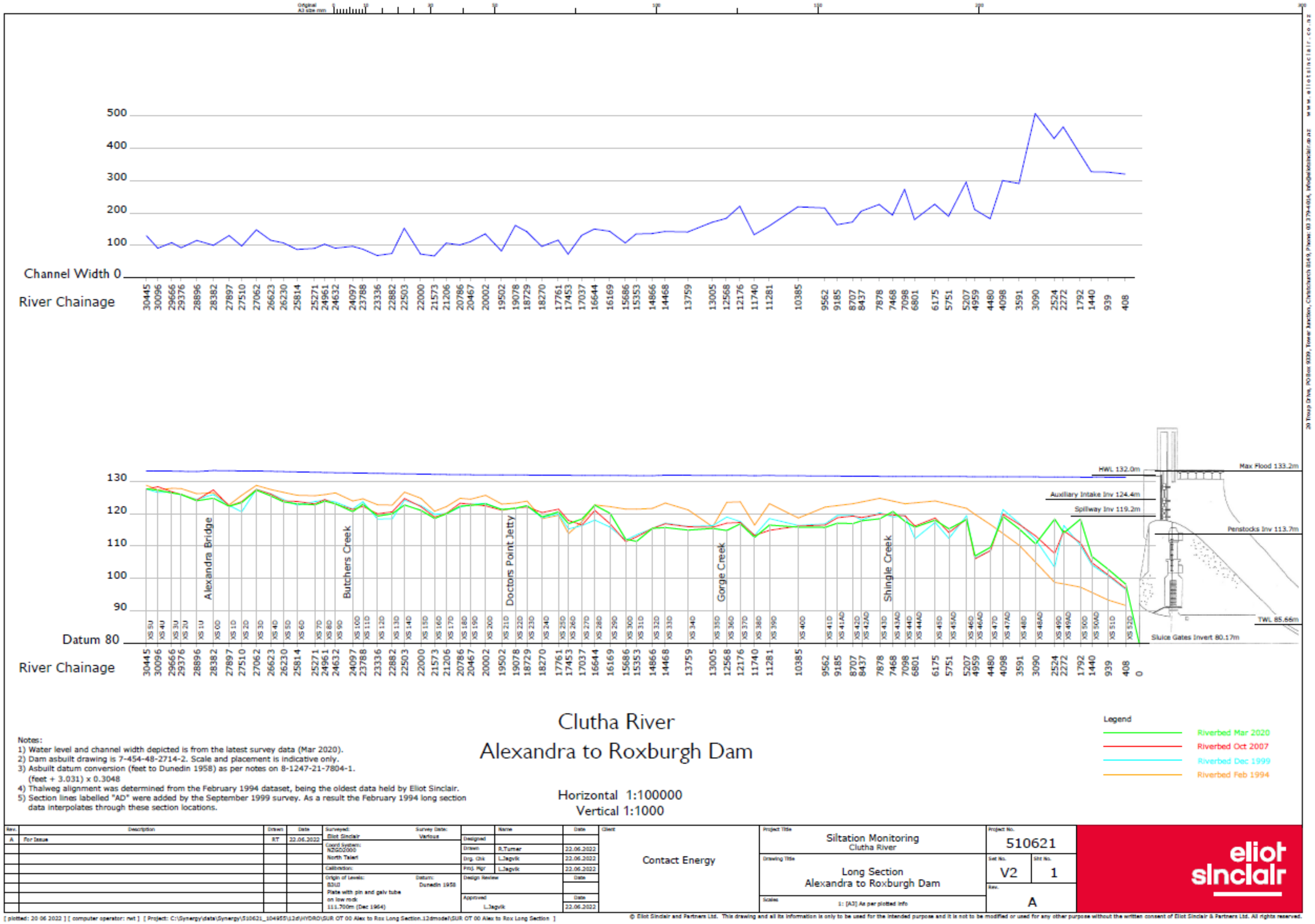
APPENDIX PF.1 – Roxburgh Reservoir Levels 1992 to 2022



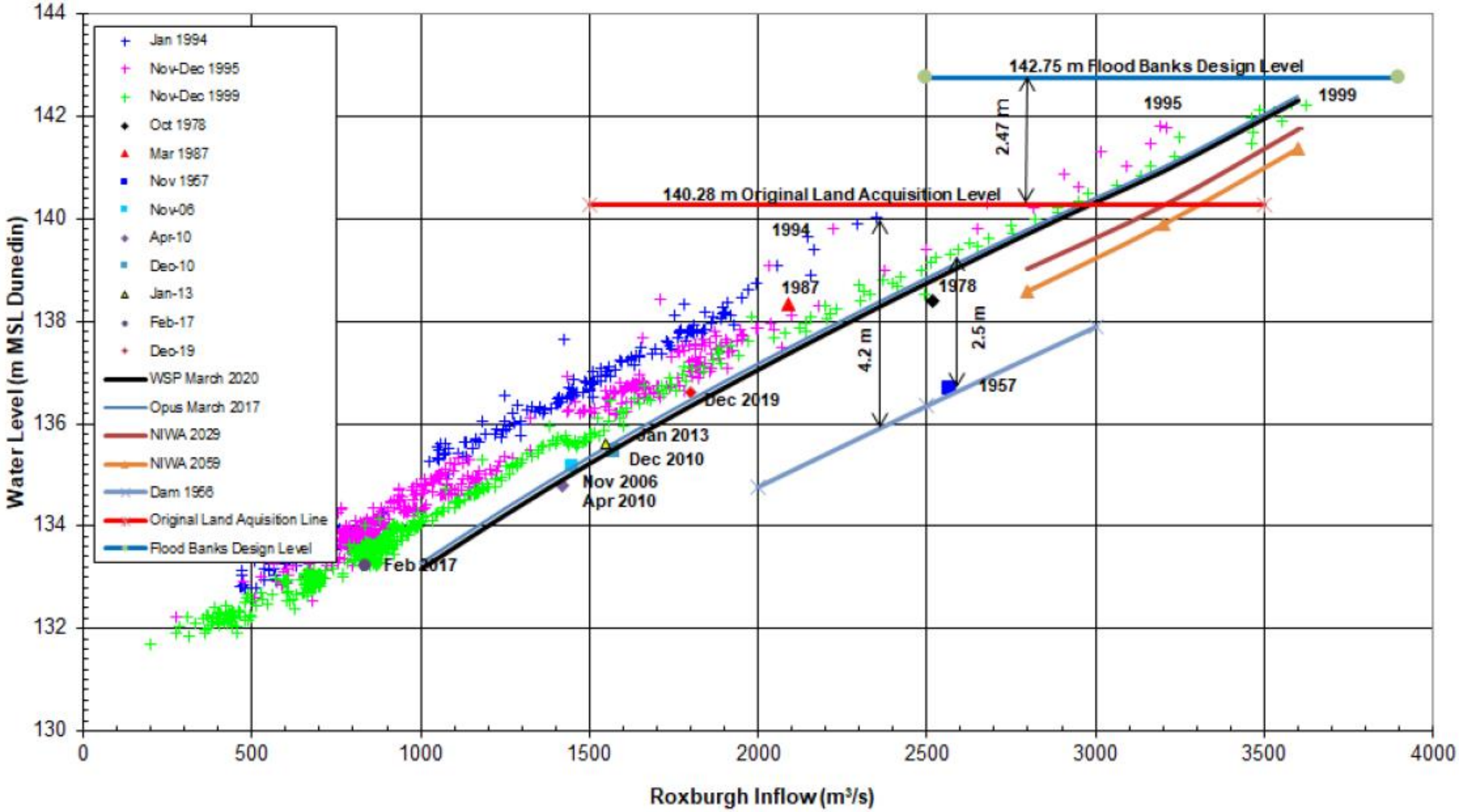
APPENDIX PF.2 – Roxburgh Inflows 1992 to 2022



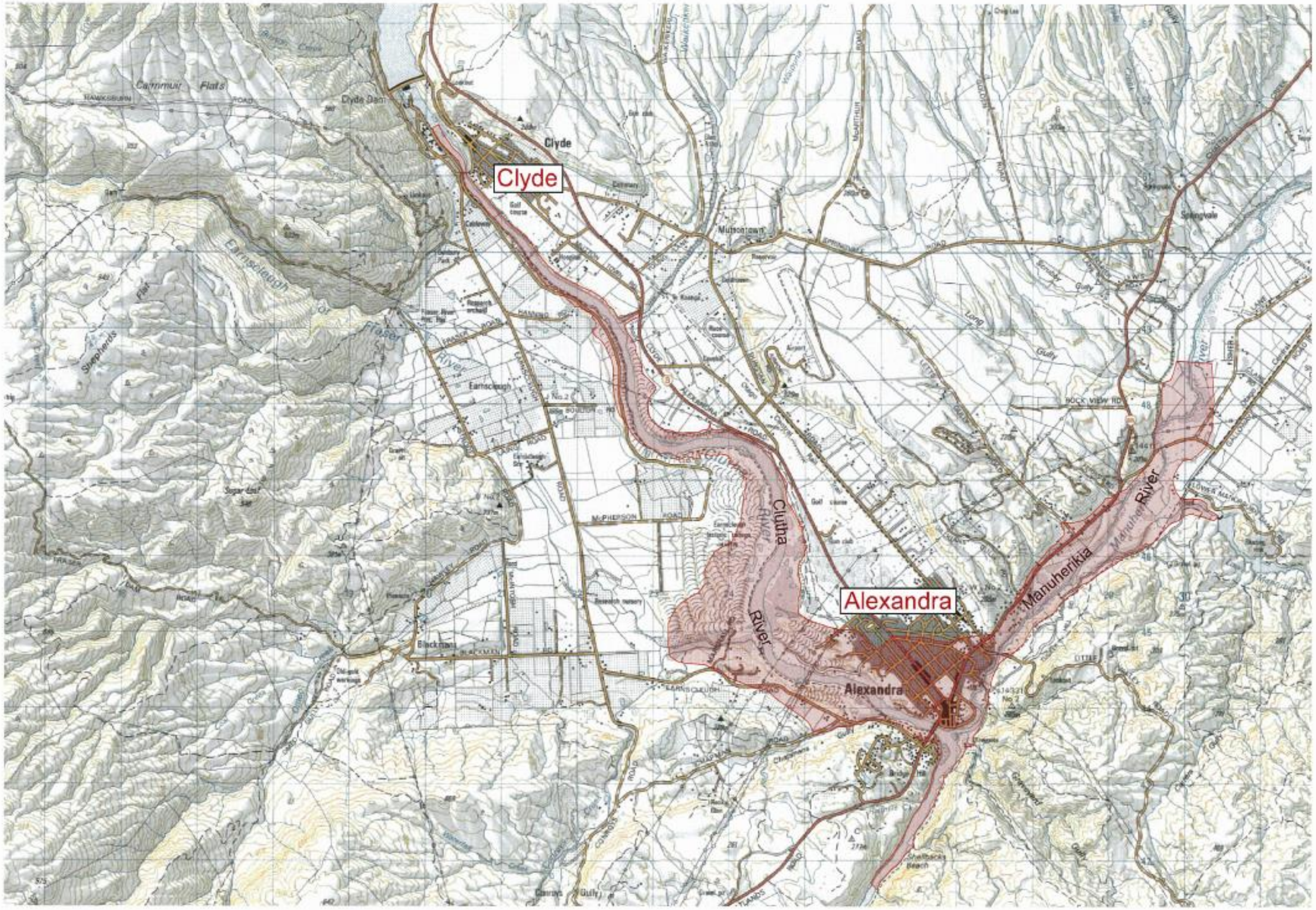
APPENDIX PF.3 – Lake Roxburgh Bed Profiles 1994, 1999, 2007 and March 2020



APPENDIX PF.4 – Alexandra Bridge Rating Curve



APPENDIX PF.5 – Alexandra 1 in 500 AEP Flood Hazard Map



contact.
P O Box 25 Clyde

Note
This plan is derived from interpolated data, via existing mapped contours and therefore accuracy cannot be guaranteed.

N

Scale 1 : 50000 (approx)
0 500 1000 1500 2000 2500m

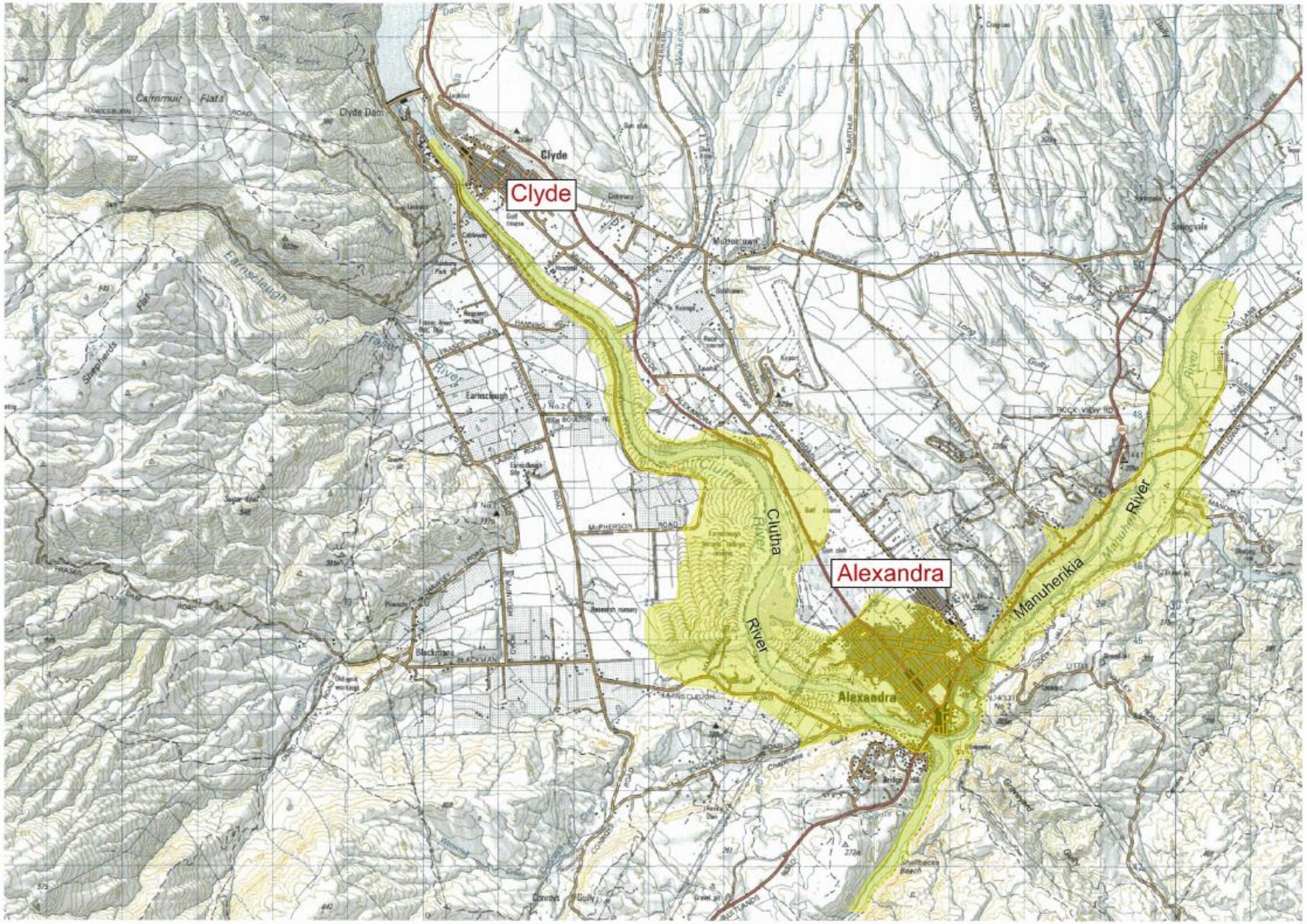
Prepared by :
TL Survey Services Ltd PO Box 901
DUNEDIN

ALEXANDRA
1:500 AEP Flood Hazard Map
Map prepared Feb 2008

LEGEND
—— 145.7m(1:500 AEP)

Changes to the Annual Exceedance Propability (AEP) can occur over time.

APPENDIX PF.6 – Alexandra PMF Flood Hazard Map



contact.
P O Box 25 Clyde

Note
This plan is derived from interpolated data, via existing mapped contours and therefore accuracy can not be guaranteed.

N

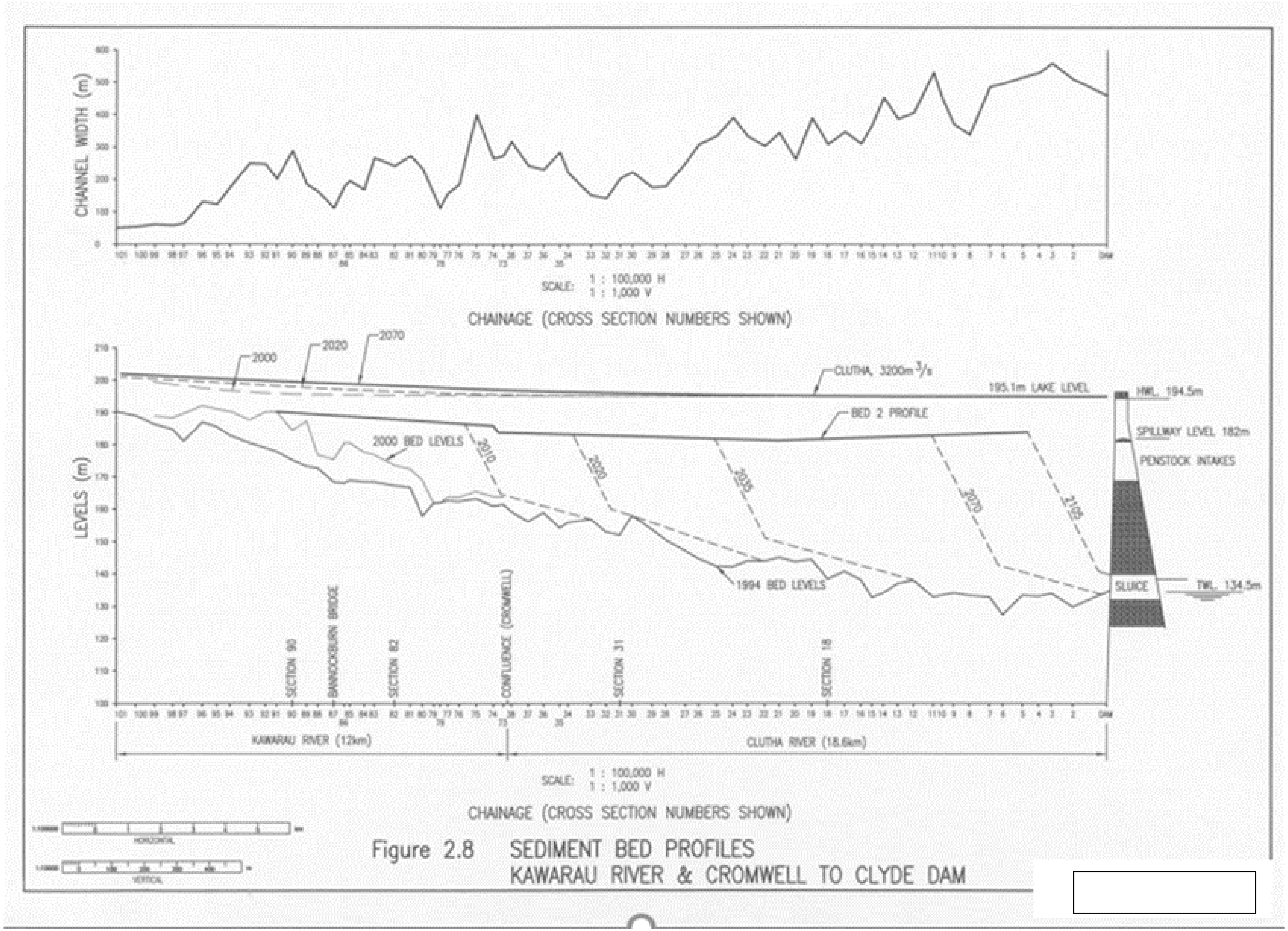
Scale 1 : 50000 (approx)
0 500 1000 1500 2000 2500m

Prepared by :
TL Survey Services Ltd PO Box 901
DUNEDIN

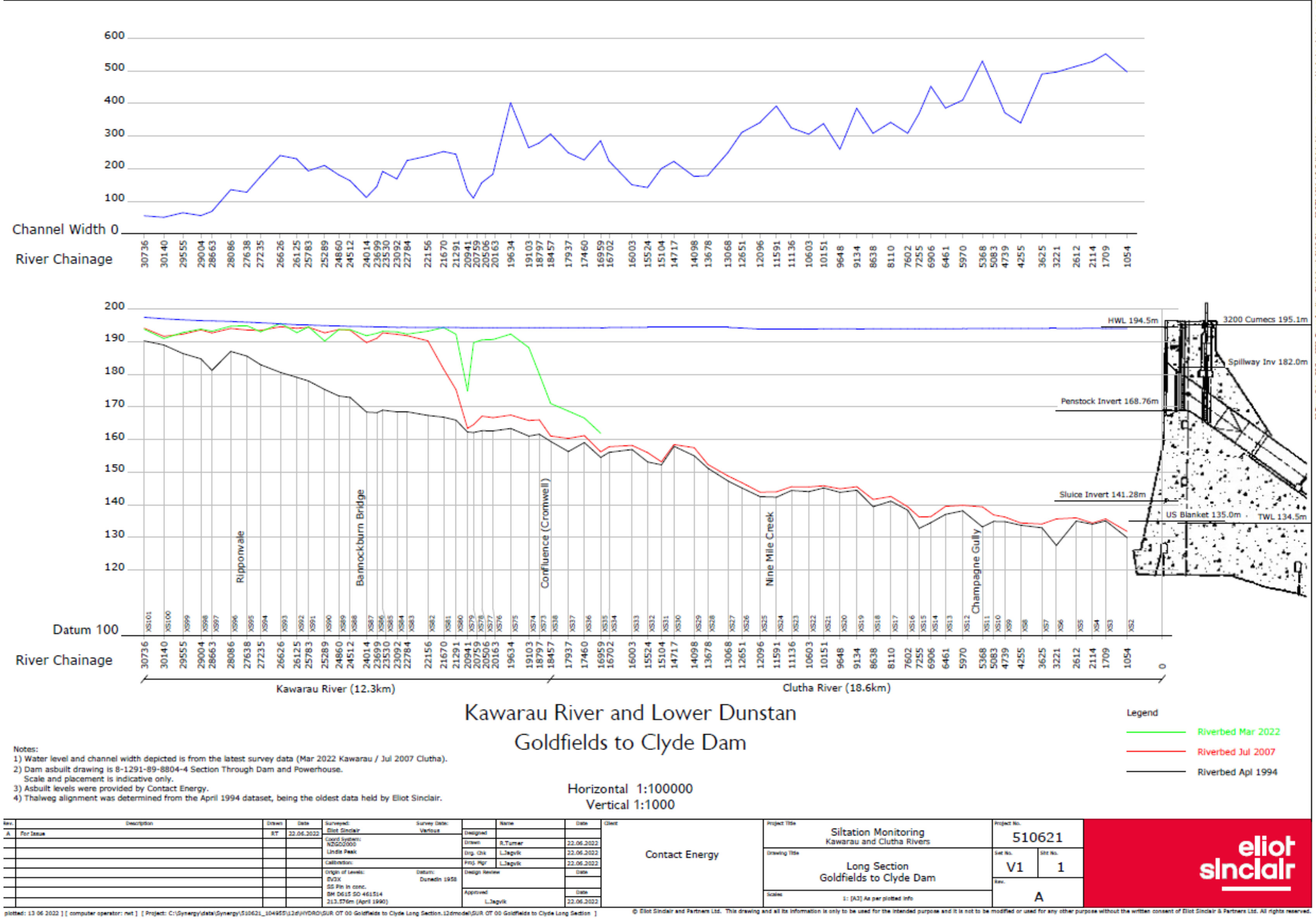
ALEXANDRA
PMF Flood Hazard Map
Map prepared Feb 2008

LEGEND
151.8 (PMF)
Changes to the propable Maximum Flood (PMF) can occur over time.

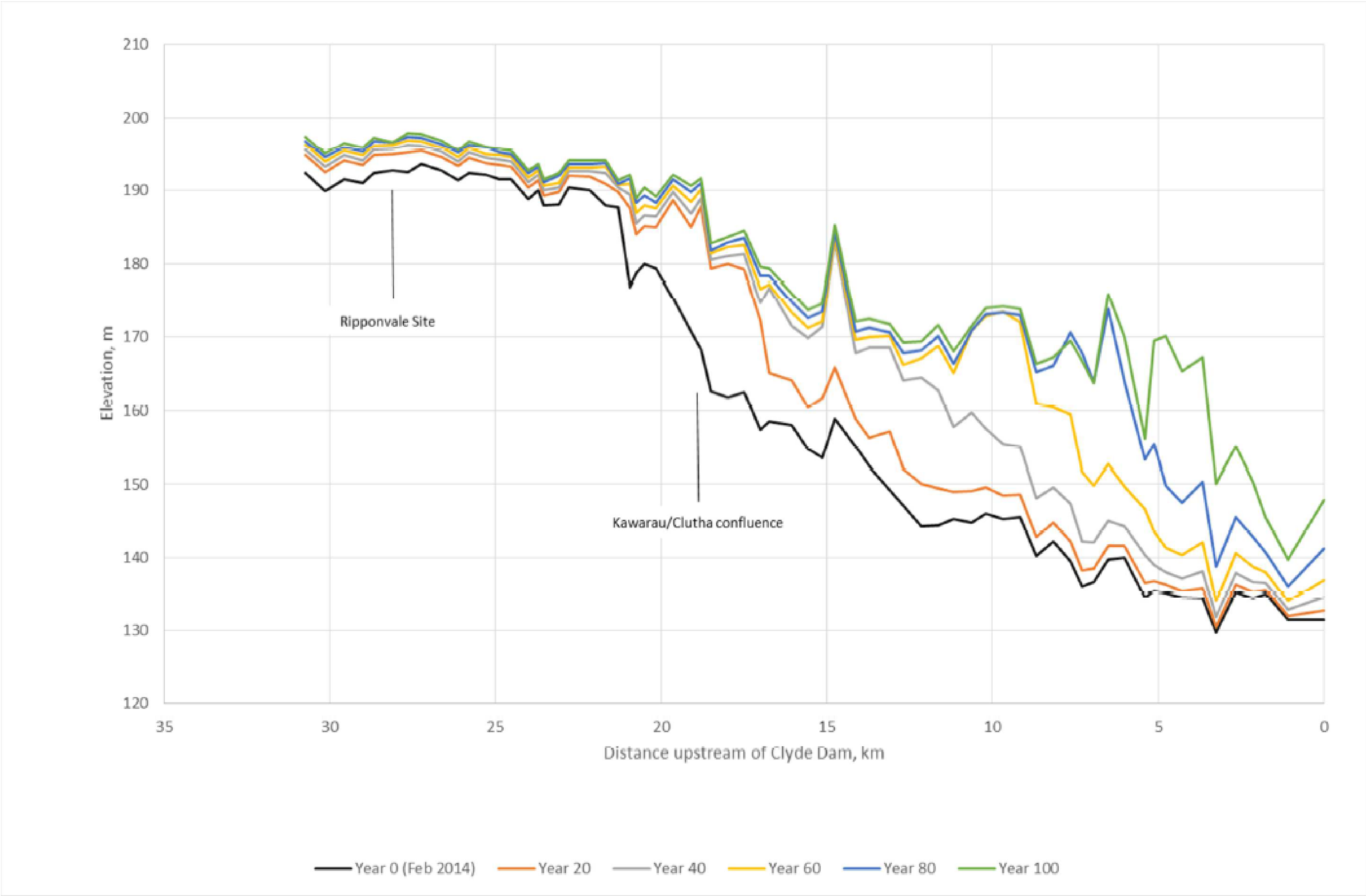
APPENDIX PF.7 – Sediment Profiles Te Wairere / Lake Dunstan 2000 and Projected to 2105



APPENDIX PF.8 – Bed Surveys 1994, 2007 and 2020



APPENDIX PF.9 – NIWA predicted thalweg bed levels Kawarau and Dunstan Arms at years 0, 20, 40, 60 and 80 from February 2014



APPENDIX PF.10 – Kawarau Arm Flood Level Projections

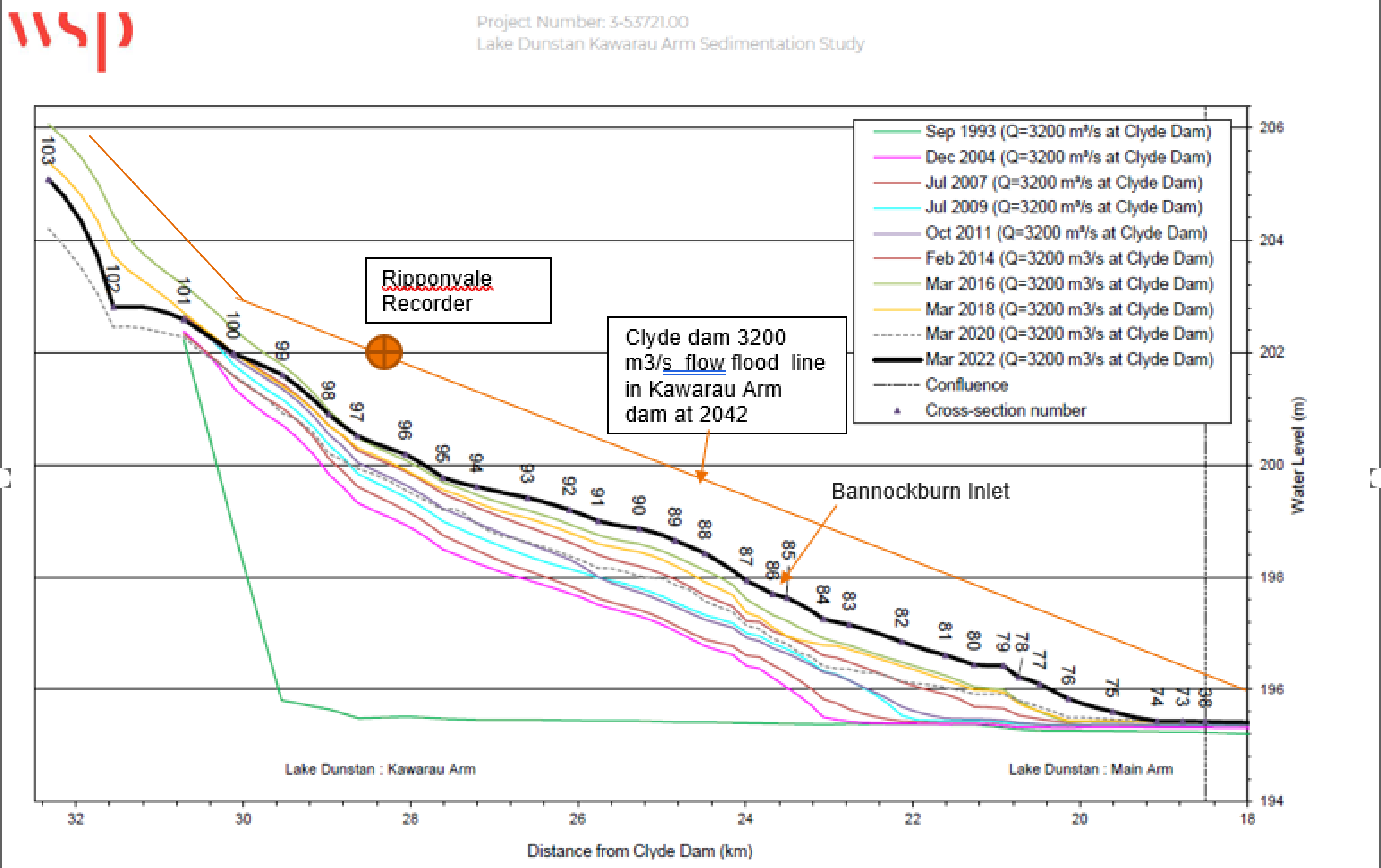


Figure 4-6b: A closer view of the predicted backwater profiles in the Kawarau Arm for the September 1993, December 2004, July 2007, July 2009, October 2011, February 2014, March 2016, March 2018, March 2020 and March 2022 lake-bed profiles, based on a flow of 3200m³/s at the Clyde Dam.