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Memorandum

TO: Amanda Loeffen

FROM: Bas Veendrick and Mark Pennington

DATE: 15 February 2011

RE: Document 1 in a series of 4: Memorandum describing the hydrological investigations on HWP irrigation scheme.

1.0 Introduction

The aim of this memo is to give further details of the HWP irrigation/storage scheme detailed in the AEE. Therefore the results given in this memo are based on the same assumptions and the same model run that was used to provide the information in the AEE, which should be used as a reference document to this summary.

All the relevant Figures from the original AEE which have been referenced in this memo are attached in an appendix to this memo. Figure 1 in the Appendix shows a map with the location of the proposed storage, irrigable area, rivers and relevant flow monitoring sites.

2.0 Description of Scheme and summary of effects

2.1 Scheme description

In broad terms the storage scheme consists of two reservoirs located on the North and South Branches of the Hurunui River. It is proposed to construct a 3 m high control gate on Lake Sumner (on the North Branch) and a 75 m high dam on the South Branch, giving potential storage volumes of 27 million and 111 million m^3 respectively. Water is harvested into the reservoirs subject to maintaining minimum flow conditions at the outlets of the reservoirs. Therefore the natural flow regime of both branches of the river would be altered by re-distributing water into storage. Water is then released from the storage sites back into the river to supply water to the irrigation scheme abstraction point that occurs at a downstream location. The natural channels downstream of the reservoirs will be used to convey irrigation water to this off-take point.

Lake Sumner is used as the primary source of storage because it has a faster refill time than the South Branch site and therefore is more responsive to the demand from the irrigation scheme.

For the modelled 42,000 ha scheme the peak daily irrigation demand is up to 31.5 m^3/s or 2.7 million m^3 per day. Table 1 summarises the storage capacity of each reservoir together with the number of days the reservoir can meet the peak demand of 2.7 million m^3 per day.

Table 1: Storage capacity

Storage Reservoir	Storage capacity m^3	Number of days reservoir can meet peak demand
Lake Sumner	27 million	10
South Branch	111 million	40

Table 1 only provides an indication of the storage capacity and is a simplification of the variable storing and releasing of water when the scheme is operating.

In practice Lake Sumner will meet fewer continuous days of peak demand since the amount of water that can be released from the lake will be reduced when the lake level is low. Discharge at the outlet of Lake Sumner will decrease as the lake empties out due to channel constraints downstream of the proposed control gate and to a reduction in driving head.

The amount of storage available for irrigation will also depend on the amount of inflow into Lake Sumner which is highly variable as a result of its dependence on rainfall.

2.2 Summary of effects

The effects of the proposed scheme depend on the operating rules, the irrigation demand and the hydrological conditions. The suggested operating scenario which has been adopted for this modelling exercise is to use Lake Sumner as the primary storage site with the South Branch Reservoir providing supplementary water. The reason for using Lake Sumner as the primary storage site is the large inflow (mean of 28.6 m^3/s) and small storage volume (27 million m^3)compared to the South Branch (mean inflow of 8.7 m^3/s and storage volume of 111 million m^3), indicating that the time to fill Lake Sumner is relatively short. The typical effects on lake levels, outflows and irrigation releases at each storage reservoir are therefore distinctly different as well.

This summary contains clarification and simplification of the original AEE with respect to the effects of the scheme on:

- Lake Sumner lake levels and outflows;
- South Branch lake levels and outflows;
- Flows at Maori Gully.

2.3 Lake Sumner

Effects on Lake Sumner are characterised by short duration irrigation releases and short periods to fill the lake. The larger irrigation releases from Lake Sumner typically start around December- January when run of river availability is low and large irrigation releases (i.e. > 15 m^3/s) need to be made from storage to meet the irrigation demand. These irrigation releases are typically short (i.e. several days) in duration since the outflow of the lake is limited to downstream channel constraints as the water level in Lake Sumner lowers gradually.

Typically the largest effect of the proposed scheme on outflows of Lake Sumner occur when the control gates are closed in August and when large irrigation releases are made from January through to March. In August flows are harvested into storage subject to maintaining an environmental flow condition at the outlet of Lake Sumner resulting in periods of stable river flow at the outlet. In January through to March flow releases are made to meet irrigation demand resulting in higher flows in the river than under natural conditions. Due to the relatively high inflow and short duration irrigation releases the effect on downstream flows are shorter than the South Branch Reservoir. In other words the duration of stable river flows when harvesting water into storage and the period of irrigation flow releases is much shorter.

With the proposed control gates in place Lake Sumner levels will increase by 0.75 m on an average yearly basis and the lake will be held at or above the maximum operating level (543.75 m) for 35 % of the time.

2.4 South Branch

Effects on the South Branch are characterised by irrigation releases of longer duration and longer periods to fill the reservoir after it has been drawn down. The larger irrigation releases from the South Branch typically start in January-February when Lake Sumner lake levels are low and the irrigation release (gradually) switches to the South Branch. Therefore the lowest lake levels in the South Branch are typically experienced at the end of the irrigation season (March-May).

The South Branch has an operating range between 605-630 m RL will only draw down completely 5 years out of the 36 year modelling period. The average lake level is 625.98 m RL with the lake level being higher than 625 m RL for 74% of the time, indicating that the lake is near full for the majority of the time. However, during extremely dry years the lake will draw down completely and the reservoir struggles to refill.

Due to the large storage volume and relatively small inflow the South Branch Reservoir will experience a different change to the natural flows than Lake Sumner. Modified flows are characterised by longer durations of both irrigation release and harvesting of flows, resulting in longer durations of higher (irrigation) flows in the peak irrigation season and longer durations of stable river flows when harvesting water into storage.

2.5 Maori Gully

The main changes to the flows at Maori Gully are in December, January and February and March. The percentage of time when flows are <30 m^3/s are decreased and the percentage of time flows are between 30-60 m^3/s are increased. This is mainly due to irrigation releases. In April and May and August the percentage of time the flow is <30 m^3/s is increased compared to the natural situation and flows between 30-60 m^3/s are decreased. This is mainly due to water being harvested into storage after the reservoirs have been drawn down during the peak irrigation months or the control gate in Lake Sumner is closed (1st of August).

3.0 Lake Sumner

Lake Sumner acts as a natural attenuator of flood inflows. Figure B2 shows the flows at No. 2 Hut, an ECan flow recorder site located some 3 kilometres upstream of Lake Sumner and the flows at ECan recorder site Hurunui at Jollie Brook which is located approximately 12 kilometres downstream of the lake. It can be seen that peak inflows are attenuated, resulting in a subdued outflow hydrographs downstream from the outlet of the lake.

The historical lake level fluctuation of Lake Sumner is around 3.2 m. The idea behind using Lake Sumner is to use the first 2 m for irrigation storage, while flood inflows are managed by using the upper metre to contain inflows. A suggested operating scenario for the scheme which has been adopted for this modelling exercise is for the control gate at the outlet of Lake Sumner to be closed from 1 August whilst water is harvested subject to maintaining an environmental flow of 9 m^3/s. Further releases are made to manage flood inflows and between 1 September and 31 May to meet irrigation demand. The control gate is then reopened on 1 June so that for two months the lake returns to its natural levels.

3.1 Lake Levels

Historical lake levels exist for Lake Sumner over two periods: between 1956 and 1972 and between 1986 and 1992. These are plotted relative to mean sea level in Figure B3 of the AEE. The historical mean lake level is 542.42 m RL while the median is 542.35 m RL. Note that the lows in the second period are 0.21 m higher than the lows in the earlier period, the minimum for the second period is 541.99 m (recorded on 3 May 1988) compared against 541.78 m (recorded on12 April 1971) for the first period. The reason for this difference is expected to be natural changes in the channel geometry between the two monitoring periods. The highest level of Lake Sumner was 544.99 m RL recorded on 14 September 1988 which indicates that the historical range is in the order of 3.2 m.

The proposed design storage level for the maximum storage of irrigation water is 543.75 m RL, some 1.4 meters higher than the historical median lake level, and 1.2 metres below the historical maximum.

Figure G2 shows the simulated lake levels over the whole simulation period, while Figure G8 shows an overlay plot of historical and simulated levels between 1986 and 1992. As can be seen in these figures the amount of time the lake level is held at its maximum storage level is highly variable.

Table 2 shows the average monthly lake levels for the natural situation between 1972 and 2008 modelling period and how the lake levels would have changed if the control gate had been in place.

The natural lake levels are modelled for the simulation period (1972-2008) since no continuous record of historical lake levels is available. Therefore the modelled natural lake levels are slightly different than the historical numbers.

Table 2: Natural and modified average monthly lake levels (1972-2008)

Month	Natural	Modified	Increase in average monthly water level (m)
January	542.39	543.04	0.65
February	542.22	542.73	0.50
March	542.18	542.73	0.55
April	542.26	543.15	0.89
May	542.32	543.45	1.14
June	542.40	542.62	0.22
July	542.32	542.33	0.01
August	542.36	543.23	0.87
September	542.44	543.58	1.14
October	542.60	543.65	1.05
November	542.56	543.59	1.03
December	542.47	543.38	0.92
Year	542.38	543.13	0.75

The effect of the scheme on Lake Sumner may be divided into four different periods, based on the operating rules that have been chosen for this modelling scenario:

- June and July: The control gate is open and lake levels are similar to the natural levels.
- August –December: The control gate is closed from 1st of August and inflows into the lake are high and irrigation demand is moderate relative to the availability of run of river water. Average lake levels in this period are approximately 1 m higher than in the natural situation.

- January-March: Lake levels are only 0.5 to 0.6 m higher than the natural situation due to large irrigation releases coupled with low inflow into the lake.
- April-May: Lake levels are approximately 1m higher than the natural situation due to irrigation demand being lower and inflow into the lake being higher than in the peak summer months.

Figure 1 shows the lake level duration curve for the natural and modified situation and Table 3 the associated numbers.

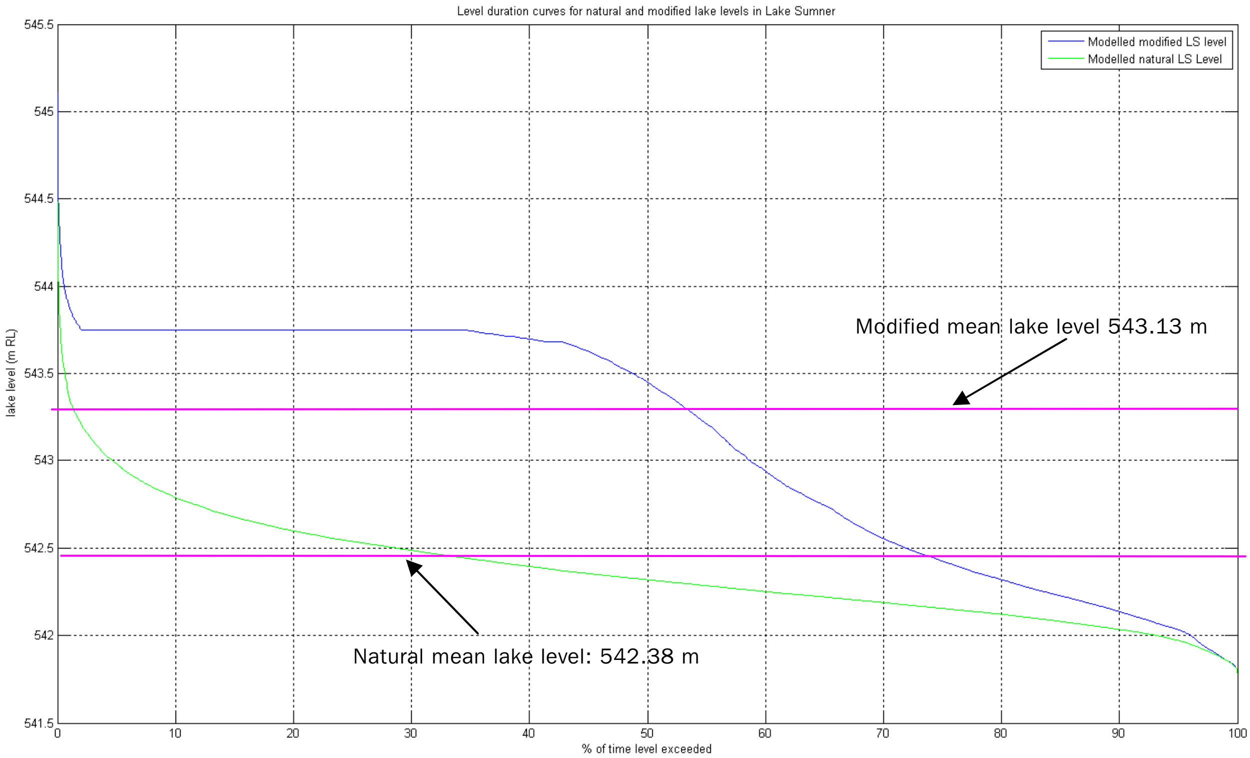


Figure 1: Lake level duration curve for natural and modified Lake Sumner levels

Table 3: Lake Sumner level duration and volumes (1972-2008)			
RL (m)	**Volume (Million m³)**	**% of time level exceeded**	
		Natural	**Modified**
543.75	27.0	0.2%	34.6%
543.50	23.6	0.6%	48.8%
543.25	20.2	1.7%	54.2%
543.00	16.7	4.7%	58.7%
542.75	13.3	11.6%	64.8%
542.50	9.9	28.8%	71.9%
542.25	6.4	60.1%	83.7%
542.00	3.0	93.2%	96.1%

There are considerable periods when the reservoir levels are at the maximum storage level as is clear from Figure 1. In the modified situation the lake is held at or above the maximum operating level of

543.75 m for 34.6 % of the time, whereas for the natural situation this happens 0.2 % of the time. However, the mean lake level over the modelling period is only 0.75 m higher than in the natural situation.

3.2 Time to fill Lake Sumner

The following table summarises the time to fill Lake Sumner to its maximum storage level (543.75 m) from 1st August when the control gates are closed:

Table 4: Time to fill Lake Sumner

	Days
Mean	21
Minimum	2
Maximum	94

The time to fill Lake Sumner depends on the inflow into the Lake. If a large flood flow occurs relatively soon after the gates are being closed the lake is filled to its maximum storage level relatively quickly (i.e. within a few days). Conversely, if the inflow into the lake in August is low and irrigation demand starts relatively early in the irrigation season it may take up to 3 months to fill up completely. In general Lake Sumner fills quickly (average of 21 days) since the flows into the Lake (especially at the start of the irrigation season, August through to December) are high due to snowmelt and the fact that the upper reaches of the catchment receive high rainfall due to its location close to the divide.

3.3 Outflows from Lake Sumner

Outflows from Lake Sumner undergo modification due to

- the harvesting of inflows into storage;
- the containment and release of flood inflows;
- the release of water to meet environmental requirements and irrigation demand.

Changes to the natural distribution of flows may be divided into three periods:

- August (when the control gate is closed and all available water is harvested into storage with an environmental flow release)
- Early irrigation season (September to December), when there is a lower than average demand for water and river flows are relatively high.
- Late irrigation season (January to May) when irrigation demand is at a peak and river flows are relatively low.

In August all flows are harvested subject to maintaining an environmental flow condition at the outlet of Lake Sumner resulting in periods of stable river flow. See Figure M1.

The principal changes in the early irrigation season will be

- Increased frequency of higher flows due to a reduced buffering effect of Lake Sumner (this is related to the lake level being higher than normal so less able to attenuate flood flows (See Figure M1).
- Increased flows to meet irrigation demand

The principal changes in the late irrigation season will be

- Increased frequency of flow releases to meet irrigation demand as the season progresses (i.e. higher flows in the river upstream of the irrigation intake).

3.4 Irrigation releases from Lake Sumner

There is considerable variability in irrigation releases over the irrigation season from Lake Sumner, summarised in the following table: Although there is potential to release up to 31 m^3/s, the release is only a third of this on average, with only 5 days in an average season when the release is close to maximum.

Table 5: Irrigation releases from Lake Sumner	
Mean irrigation release (m^3/s)	11
Maximum irrigation release (m^3/s)	31

The quantity of water released from Lake Sumner depends on:

- Irrigation demand from command area, therefore a combination of factors relating to temperature, rainfall and soil-type,
- The availability of run-of-river water at Hurunui at Mandamus,
- Lake level in Lake Sumner.

3.5 Duration of continuous releases

An indication of the effects of the scheme on flows at the outlet is given by looking at the duration of continuous irrigation releases, summarised in the following table for releases greater than 15 m^3/s, greater than 20 m^3/s and greater than 25 m^3/s. For comparison the natural mean flow at Lake Sumner outlet is 28.6 m^3/s.

Table 6: Consecutive days irrigation releases made from Lake Sumner

	Releases >15 m^3/s	Releases >20 m^3/s	Releases >25m^3/s
Mean duration	7	5.3	5
Maximum duration	26	17	16

The number of consecutive days a flow release is made from Lake Sumner depends on the irrigation demand and the level in the lake. As soon as the level in the lake drops the amount of flow that can be released is limited to the conveyance capacity of the outlet channel.

For example there could be an irrigation demand in excess of 20 m^3/s for 20 consecutive days. However, as the level in Lake Sumner goes down the scheme switches to the South Branch and the irrigation demand is satisfied from both Lake Sumner and the South Branch. Lake Sumner will still make irrigation releases but will release water at a lower flow rate. This is reflected in the numbers presented in Table 6 which shows that the mean duration of a large irrigation release from Lake Sumner is only a few days. The only time when a large irrigation release is made for a long period of time is when the inflow into the lake is sufficient to ensure that lake levels are not drawn down.

3.6 Summary of effects on Lake Sumner and outlet

Effects on Lake Sumner and its outlet are highly variable depending on hydrological conditions and irrigation demand, and are best explained by example.

Figure 2 shows overlay plots of the natural and modified outflows from Lake Sumner together with Irrigation Releases and lake levels from January through to November 1981. 1981 is considered an average year (i.e. not extremely dry or extremely wet) with the yearly rainfall around the median.

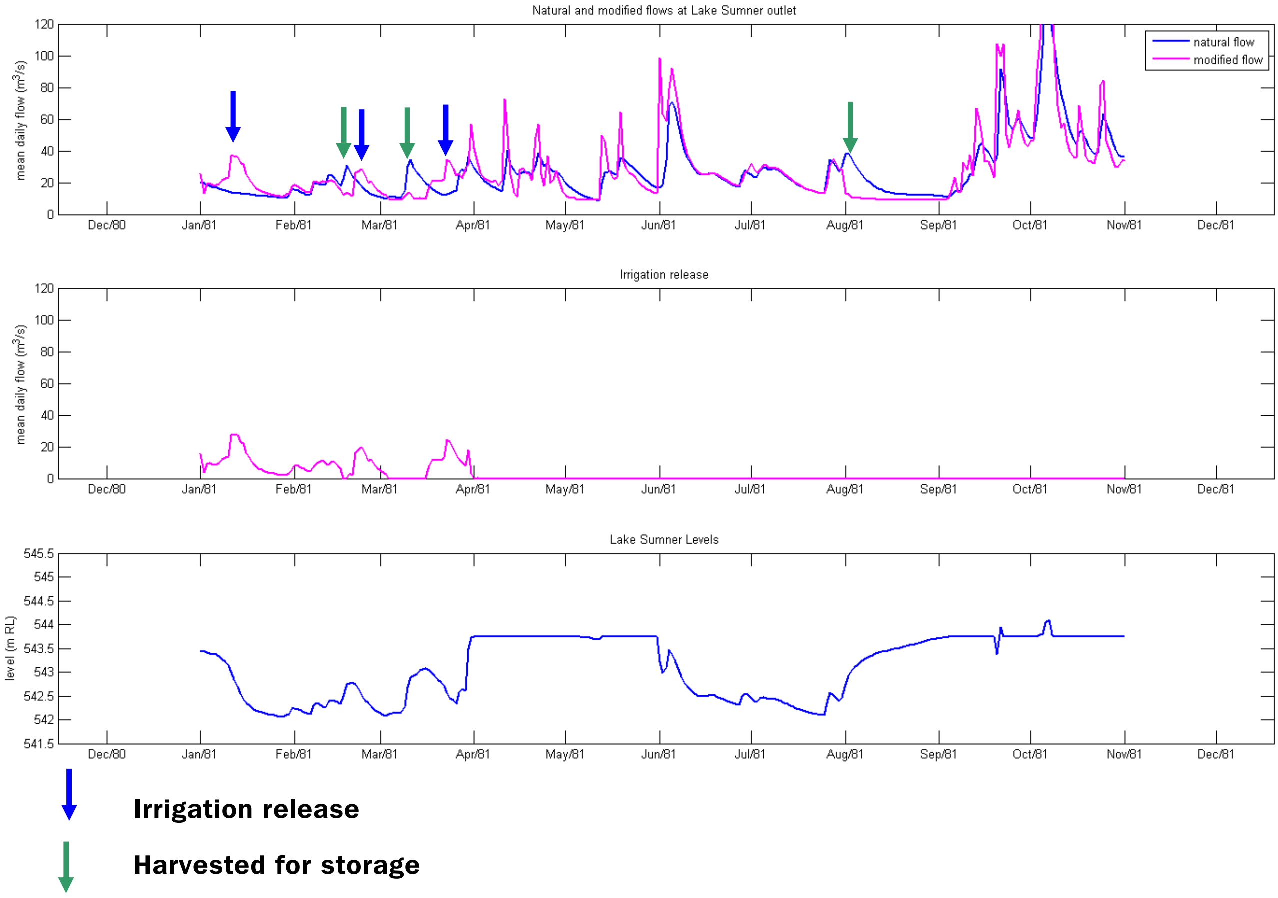


Figure 2: Natural and modified flows, Irrigation release and Lake Sumner levels

In this case, significant irrigation release from Lake Sumner starts from January and, and the irrigation release matches the increase in flow at the outlet. The reduction in water level in the reservoir corresponds to the loss in storage as a result. In February and March periods of irrigation release and harvesting of water into storage are alternating ensuring that flow variability is maintained. By the end of April there is no irrigation release from storage and Lake Sumner quickly refills to its maximum storage level. As a result of opening the control gates beginning of June the water level in Lake Sumner (gradually) lowers and water levels are similar to natural lake levels. The gates are closed again from 1st of August and as a result of relatively low flows in August it takes approximately 1 month to refill.

4.0 South Branch Reservoir

The South Branch reservoir is assumed to have an available storage of 111 million m^3 with an operating range of 605-630 m RL. Over the simulation period there is considerable variability and refill may take up to 18 months after a very dry summer (see Figure G3). Based on the simulation period of 36 years, it is predicted that the reservoir would go completely dry in five years out of 36 years.

Figure G7 shows the lake level duration curve for the South Branch storage reservoir and Table 6 a summary lake levels, durations and volumes.

Table 7: South Branch lake level duration and volumes (1972-2008)		
RL (m)	**Volume (Million m³)**	**% of time level exceeded**
630	110.97	49.2
625	83.20	73.5
620	58.49	84.8
615	36.40	90.1
610	16.95	94.4
605	0	98.4

The graph and the table shows that South Branch Reservoir is completely full for more than 49 % of the time and will be higher than 625 m RL for 74% of the time. Only the extreme dry years draw the lake down completely.

Table 8 shows the average monthly lake levels in the reservoir.

Table 8: South Branch average monthly lake levels (1972-2008)	
Month	**Lake level (m)**
January	627.871
February	625.010
March	622.532
April	622.118
May	622.784
June	624.878
July	626.065

August	627.001
September	627.619
October	628.251
November	628.767
December	628.865
Year	625.980

Seasonally, the lowest water levels in the reservoir will be from February to July which reflects the period where the reservoir is drawn down to meet irrigation demand and for the reservoir to recover. On average the reservoir will be near full from July to the end of January due to low irrigation demand and high inflow into the reservoir.

4.1 Number of consecutive days at or below a specified lake level.

There are considerable periods when the reservoir levels are at the maximum storage level as is clear from Figure G3. The following table summarises the number of consecutive days that the reservoir is at or below a certain lake level and also includes a column which shows the number of occurrences over the 36 year modelling period that the level is drawn down below that level.

Table 9: Average, minimum and maximum number of consecutive days at or below lake level (1972-2008)

RL (m)	Volume (Million m^3)	Occurrences (out of 36 year modelling period)	Number of consecutive days		
			Average	Minimum	Maximum
625	83.20	20	165	15	582
620	58.49	11	182	50	280
615	36.40	9	129	3	256
610	16.95	7	91	17	206
605	0	5	35	3	113

The average number of consecutive days that the lake is at or below a certain level provides an indication of the duration of time that the lake level is below a specified lake level before it recovers to that level. For example the lake level is drawn down to below 610 m RL on only 7 occasions. On average the number of consecutive days that the level is at or below 610 m RL is 91 days.

4.2 Outflows from South Branch Storage Reservoir

Outflows from the South Branch Reservoir undergo considerable modification (see Figure M2) due to:

- the harvesting of inflows into storage and consequent periods of stable outflows from the reservoir. This is particularly evident in 1985, as the reservoir is drawn down at the end of the irrigation season (February through to April) and then takes most of the rest of the year to recover fully. However, the addition of water from the North Esk River adds some variability to the downstream river flows in the Hurunui River South Branch, as seen in Figure M3.
- the release of water to meet irrigation demand. Again in Figure M3, the release of water in February, March and April can be seen clearly by the pink line in February, March and April, at a time when the river would otherwise be at low flow.
- Due to the large storage volume and relatively small inflow the South Branch Reservoir will experience longer durations of irrigation release and harvesting compared to Lake Sumner. This is one of the reasons why Lake Sumner is utilised as the primary storage site.

4.3 Irrigation releases from the South Branch

The following table summarises the magnitude of irrigation releases from the South Branch reservoir. For comparison the natural mean flow at the South Branch reservoir is 8.6 m^3/s.

Table 10: Irrigation releases from South Branch Reservoir	
Mean irrigation release (m^3/s)	14.2
Maximum irrigation release (m^3/s)	30.5

The quantity of water released from the South Branch Reservoir depends on:

- Irrigation demand from command area, therefore a combination of factors relating to temperature, rainfall and soil-type,
- The availability of run-of-river water at Hurunui at Mandamus,
- Irrigation release from Lake Sumner. Lake Sumner will be used as priority storage and therefore irrigation demand is met from Lake Sumner first before switching to the South Branch Reservoir.
- Lake level in the South Branch Reservoir.

Irrigation releases from the South Branch Reservoir are at its maximum when irrigation demand is high and Lake Sumner lake levels and run of river availability is low.

4.4 Duration of continuous releases

An indication of the effects of the scheme on flows at the reservoir outlet due to irrigation releases is given by looking at the duration of continuous irrigation releases, summarised in the following table:

Table 11: Consecutive days irrigation releases made from South Branch Reservoir

	Releases >15 m^3/s	Releases >20 m^3/s	Releases >25m^3/s
Mean duration	10.7	8.3	7.4
Maximum duration	47	30	21

As can be seen in Table 11 the number of consecutive days that large irrigation releases are made are longer than Lake Sumner. This is due to the large storage volume available in the South Branch and the fact that the amount of outflow is not limited to downstream channel constraints.

In general the larger irrigation releases from the South Branch Reservoir occur in the second half of the irrigation season when Lake Sumner Lake Levels are low and irrigation demand is satisfied from the South Branch Reservoir.

4.5 Summary of effects on South Branch Reservoir and outlet

Effects on the South Branch Reservoir and outlet will be dominated by extremes:

- significant periods when the reservoir is full,
- periods when the reservoir is drawn down followed by periods when there is no drawdown,
- significant periods of stable river flows on the short stretch just below the outlet when water is harvested into storage.

These overall effects are seen in Figures G3 and I1.

Figure 3 shows detail between January through to November 1981. Again, this year is considered an average year (i.e. not extremely dry or extremely wet) with the yearly rainfall South Branch draw down around the median.

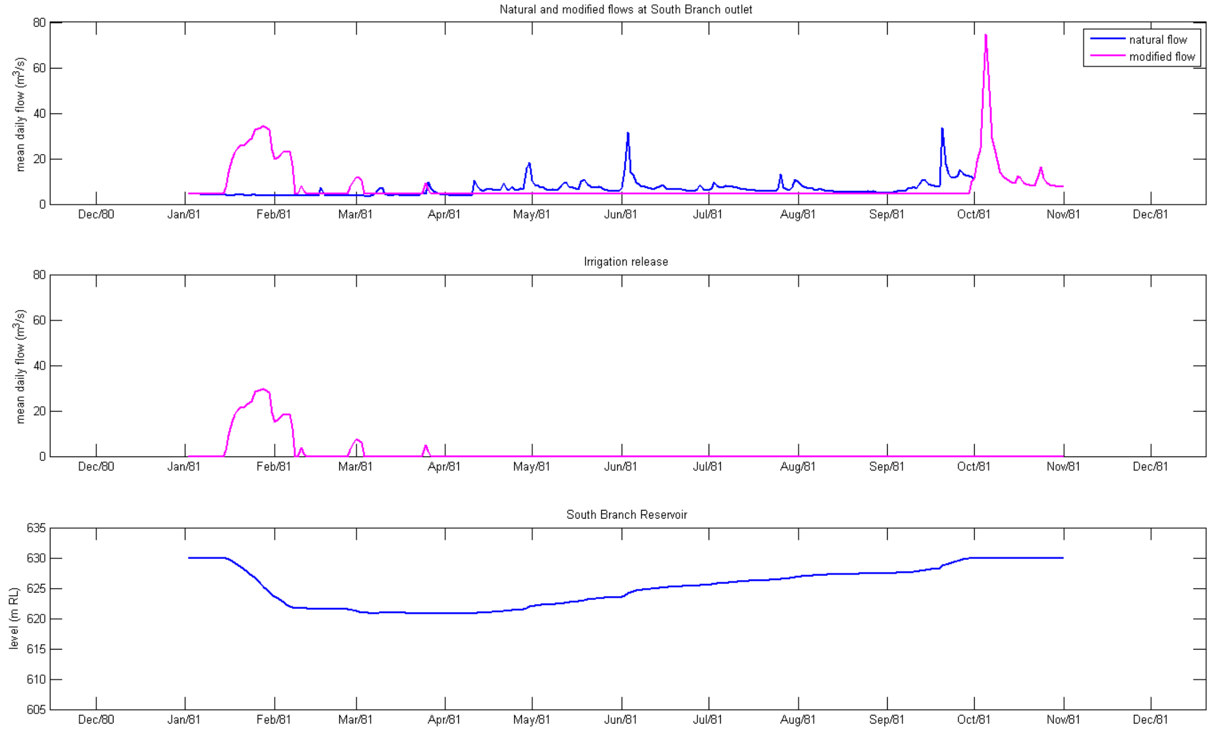


Figure 3: Natural and modified flows, Irrigation release and Storage Reservoir levels for the South Branch

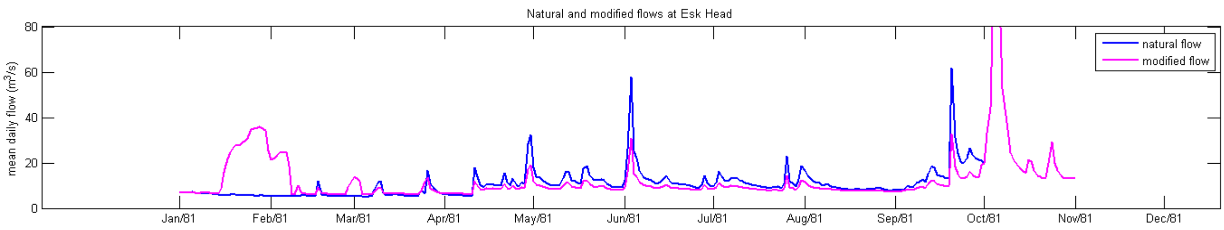


Figure 4: Natural and modified flows South Branch at Esk Head

In this case, from mid-January most of the irrigation release from storage is from the South Branch, and the irrigation demand matches the increase in flow from the South Branch. The reduction in water level in the reservoir corresponds to the loss in storage as a result. In this year it takes 6 months (April through to September) to fill up the reservoir to its maximum level again. As can be seen in Figure 3 and Figure 4 river flows are stable during the refill period in the stretch of the river directly downstream of the reservoir. However, the addition of water from the North Esk River adds variability to the downstream river flows in the Hurunui River South Branch.

4.6 Irrigation releases from Lake Sumner and South Branch Reservoir

Figure 5 shows an overlay plot of the irrigation releases from both storage reservoirs together with their lake levels.

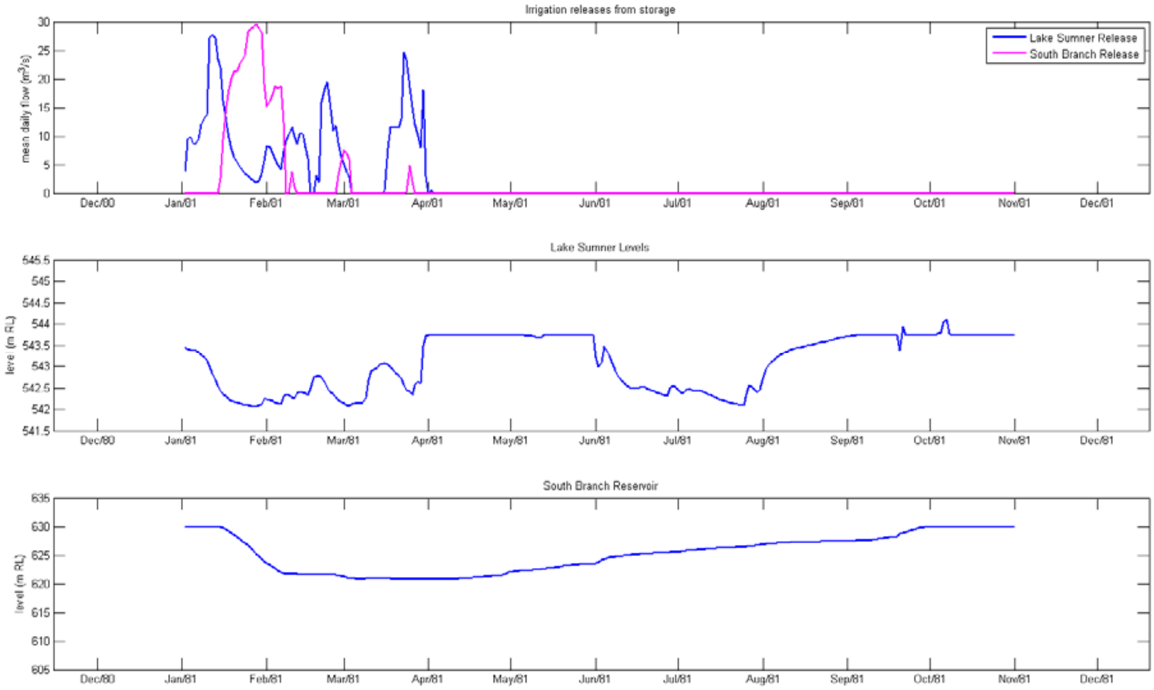


Figure 5: Irrigation releases from storage, Lake Sumner levels and South Branch Reservoir levels

Irrigation demand at the start of the year (until mid -January) is predominantly met by Lake Sumner. As soon as the lake level in Lake Sumner is lowered the supply of irrigation water from storage switches to the South Branch reservoir. From mid-January through to mid-February the main irrigation release from storage is made from the South Branch Reservoir. The refill of Lake Sumner as a result of freshes going into the lake ensures that irrigation demand is predominantly met from Lake Sumner for the remainder of the irrigation season.

5.0 Downstream of confluence of North and South Branches (Maori Gully)

Figure 6 shows detail over the peak irrigation and refill period for 1981 for Maori Gully. The flows shown on this graph are the outflows from Lake Sumner and the South Branch (Esk Head Recorder on the South Branch just upstream of the confluence with the North Branch). It is recognised that additional catchment area is contributing to the flows at Maori Gully (i.e. the catchment between Lake Sumner Outlet and confluence of North and South Branch). Therefore the flows shown on Figure 6 are considered conservative and show a relatively bigger difference between natural and modified flows.

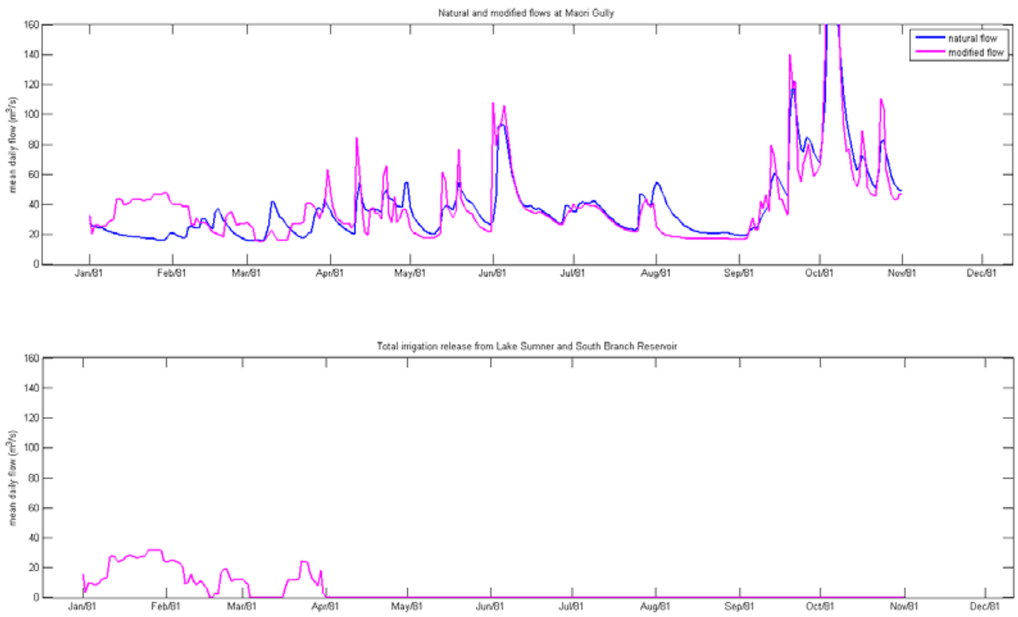


Figure 6: Natural and modified flows at Maori Gully and total irrigation release from both reservoirs

The points to note (for 1981 as an example year) are:

- January has little run of river water available, and large irrigation releases are being made from storage. Therefore, the natural flow is lower than the modified flow.
- In February and March there is significant natural flow variation, which is maintained due to alternating periods of harvesting water into storage and irrigation releases.
- By May, the effect on flows is negligible.

In summary, taking 1981 as a typical year, but given that each year has different flow and irrigation demand patterns, the main conclusions are that:

- Flow variability is maintained, but slightly reduced
- Flows are increased mostly in months when the natural flows would otherwise be low
- The effects are not constant or similar from month to month.

Table 12 shows the percentage of time the natural and modified flow is between a specified flow range by month. The specified flow range is based on the evidence of Ian Malcolm Gill- Fox for the Water Conservation Order. He describes how Maori Gully, and in particular Simon's hole(as one example) changes with varying flow.

Table 12: Percentage of time flow is between a specified flow range for the natural and modified situation at Maori Gully

Month	Flow (m³/s)					
	<30	30-60	60-80	80-100	100-200	>200
Jan-nat	43.8%	39.7%	8.2%	3.9%	4.0%	0.4%
Jan-mod	15.6%	70.3%	6.1%	2.2%	5.1%	0.6%
Feb-nat	69.0%	24.2%	4.2%	1.3%	1.0%	0.3%
Feb-mod	38.3%	57.1%	1.8%	1.3%	1.3%	0.2%
Mar-nat	72.8%	22.0%	3.7%	0.4%	1.1%	0.0%
Mar-mod	58.0%	38.3%	1.9%	1.3%	0.6%	0.0%
Apr-nat	57.2%	33.4%	4.0%	2.5%	2.9%	0.0%
Apr-mod	63.9%	29.7%	2.4%	1.0%	3.0%	0.0%
May-nat	52.5%	34.3%	6.3%	2.7%	3.5%	0.7%
May-mod	63.2%	24.9%	5.0%	1.8%	4.6%	0.5%
Jun-nat	35.2%	46.2%	9.0%	4.5%	4.8%	0.3%
Jun-mod	29.9%	46.6%	11.9%	4.9%	6.6%	0.2%
Jul-nat	45.3%	42.3%	6.6%	2.1%	3.7%	0.1%
Jul-mod	46.8%	42.7%	5.6%	2.4%	2.5%	0.0%
Aug -nat	37.5%	46.2%	8.9%	3.7%	3.6%	0.2%
Aug -mod	60.6%	29.8%	4.1%	1.7%	3.3%	0.4%
Sep-nat	29.8%	43.6%	13.7%	6.9%	5.4%	0.6%
Sep-mod	30.5%	45.7%	10.3%	5.7%	7.0%	0.7%
Oct-nat	13.8%	43.0%	16.8%	9.8%	14.7%	1.9%
Oct-mod	15.8%	46.8%	14.3%	5.8%	14.7%	2.6%
Nov-nat	15.3%	52.9%	14.0%	7.2%	8.7%	1.9%
Nov-mod	13.6%	58.0%	11.4%	6.0%	8.6%	2.4%
Dec-nat	26.7%	48.8%	12.3%	5.3%	6.5%	0.4%
Dec-mod	19.3%	59.4%	9.5%	4.5%	7.0%	0.4%
Year-nat	41.4%	39.8%	9.0%	4.2%	5.0%	0.6%
Year-mod	38.0%	45.7%	7.1%	3.2%	5.4%	0.7%

The main changes between the natural and modified flows are shown in yellow. As can be seen from the Table there are hardly any changes on a yearly basis. However, in December, January and February and March the percentage of time flows are <30 m^3/s are decreased and flows between 30-60 m^3/s are increased. This is mainly due to irrigation releases. In April and May and August the percentage of time the flow is <30 m^3/s increases compared to the natural situation and flows between 30-60 m^3/s decrease. This is mainly due to water being harvested into storage after the reservoirs have been drawn down during the peak irrigation months or the control gate in Lake Sumner is closed (1st of August).

6.0 Environmental Considerations

Dr Vaughan Keesing has provided input on environmental issues that may arise from operation of the scheme.

6.1 Flushing Flows

The FRE3 statistic is a measure of the frequency at which flushing flows occur on an annual basis. Specifically, the FRE3 statistic is the mean annual frequency at which the mean daily flow exceeds three times the median flow. The FRE3 statistic is closely linked with periphyton growth and invertebrate density. Flushing flows control periphyton biomass and a flow of around 3 times the median flow is generally required (substrate and flow pattern dependent) to disturb the bed of a river to such an extent that a substantial portion of the periphyton is lost from the reach due to abrasion, dislocation, and/or bed mobilisation. Clausen and Biggs (1977) found that periphyton biomass decreased with increasing FRE3, whereas invertebrate density had an increasing relationship.

Table 13 summarises the FRE3 statistic for natural and modified flows and provides an indication of the change in the frequency of flushing flows as a result of the proposed scheme. It is important to recognise this reflects a particular set of operational rules.

Table 13: FRE3 statistic for natural and modified flows (Period 1972-2008)

	Median natural flow (m^3/s)	FRE3	
		Natural flow	Modified Flow
Hurunui at Mandamus	40.5	6.8	9.1
Lake Sumner Outlet	22.8	5.2	11.0
South Branch at Gorge	6.5	8.9	7.8
South Branch at Esk Head	10.5	10.3	8.8

It is evident from Table 13 that the outlet of Lake Sumner will experience the main increase in the frequency of flushing flows as a result of the proposed scheme. Some of these effects can be mitigated by using temporary storage and making early flow releases in advance of flood flows (i.e. by appropriate management of the proposed scheme).

The South Branch at the Gorge and at Esk Head show a small decrease in the frequency of flushing flows. However, the frequency of flows in excess of 3 times the median flow will increase in the summer months as a result of irrigation releases (when periphyton growth can be an issue) and decrease in winter as a result of harvesting water into storage. Maintaining flushing flows in winter is less of an issue due to less favourable conditions for periphyton growth. As mentioned before the stable flow only occurs in the short stretch of the river between the outlet of the proposed South Branch dam and the confluence with the North Esk River and (some of the) flow variability is maintained further downstream due to the addition of flows from the North Esk River.

Hurunui at Mandamus experiences a higher frequency of flushing flows with the proposed scheme in place. This is mainly due to the proposed operation of Lake Sumner with lake levels and discharges being higher than in the natural situation.

6.2 Environmental Flow Releases from the South Branch

Irrigation releases from the South Branch reservoir, principally between January and April, may substantially augment the natural flows that occur in these summer months creating a regime of flushing flows. In years when irrigation demand is not drawn from the South Branch, environmental flushing flows can be made to meet ecological and environmental requirements. For example, if periphyton levels are observed to be too high an appropriate release can be made.

It is understood that a flushing flow of duration around 6 hours may be required at a flow rate of around 3 times the median flow to remove periphyton from the river bed. For the South Branch Reservoir this would equate to a flow of 20 m^3/s. As mentioned above it is not expected that flushing flows are required when Lake Sumner is close to its minimum operational level and irrigation demand is drawn from the South Branch. In years when the South Branch reservoir is not required to meet irrigation demand and periphyton levels are observed to be high it is expected that the lake is full or near full and the available volume of water can easily accommodate the required flushing of the river system.

6.3 Maintaining Flow Stability in the North Branch

Irrigation releases have the potential to increase the flow by around 30 m^3/s. To minimise the possibility of fish strandings it is necessary to avoid hydro-electric peaking scenarios and maintain flow stability in the North Branch. Around 2 hours is required to ramp up the flow at a rate in such a way to not adversely affect fish habitat. This can easily be achieved with the proposed scheme through release control at the outlet.

6.4 Lake Sumner Inundation and Wave Action

Prolonged inundation of the lake edge above the root zone has the potential to degrade lakeside vegetation. The simulated scheme maintains a typical storage level of 543.75 m RL (which is below the current shore line on which the riparian forests grow and below the surface root zone of the great majority of lake edge trees). Maximum levels of the proposed inundation are within the range of historical lake levels, and while from Table 7 there is an increase in the frequency of lake levels in the upper metre, the increase in frequency and duration are understood to be minor and are unlikely to adversely affect the vegetation at these levels given the trees tolerance to temporal inundation (Keesing pers. comm).

Waves have the potential to increase the inundation area /lake shore of Lake Sumner on top of the proposed new operating level. Wave amplitude (and hence wave run-up) is dependent on fetch and wind velocity. The fetch is the distance over which waves are generated by a wind that is nearly constant in direction and speed. In other words it is the effective distance which waves have travelled in open water, from their point of origin to the point where they break. For Lake Sumner there is no appreciable difference in the fetch of the lake with or without the proposed control gate in place. The slopes of Lake Sumner are relatively steep and the width and length of the lake increases only slightly as a result of the proposed new (higher) operating level. Therefore it is not expected that the wave height will be notably different between the unmodified and modified situations.

In many respects the same relationship between lake level and wave run-up will exist for the modified (proposed) situation as currently exists. With an increased operating level in the lake the area affected by wave run-up will be extended above this proposed operating level.

6.5 Lake Sumner Control Gate Operation

The proposed operational rules for Lake Sumner assume that the control gate will be closed at the beginning of August. Closing the gate in August will both ensure that Lake Sumner will be full at the start of the irrigation season while also minimising adverse effects on the environment. Several different scenarios as to when to close the gate have been tested and since September is an ecologically sensitive month it was considered that closing the gate (with an increased probability of flat lining the outflow) at the beginning of September would be undesirable. Maintaining flow variability in September is critical to ensure the migration of fish in this month. The model simulations indicate that closing the gate in October does not ensure that Lake Sumner will be full when water is required for irrigation at the start of the irrigation season. Therefore closing the gate the beginning of August will avoid adverse effects on the aquatic environment while also ensuring that Lake Sumner is full at the start of the irrigation season.

6.6 South Branch Lake Shore

In an average year the South Branch draws down to approximately 618.3m RL which is the lake level that is exceeded 87% of the time (see table 7). In wet years the storage in Lake Sumner may be sufficient to satisfy the irrigation demand and South Branch reservoir levels remain at its maximum level throughout the irrigation season. In order to establish a lake shore between 620m RL and 630m RL which can be used for recreational purposes it is important that the lake shore is free of aquatic entangling submerged or emergent macrophyte. It is therefore proposed to drawdown the lake in wet years to around 620m RL. The lake shore, if desired to be kept clear of abundant aquatic macrophyte, should be dried for 2 months each year with water levels not maintained high and stable for more than 6 months in the growing season (October-April). This can easily be accommodated within the proposed scheme by drawing down the lake in the last few months of the irrigation season. It is not expected that such a drawdown will impact on the reliability of supply since a full or nearly full South Branch Reservoir will have sufficient volume of water available to satisfy the irrigation demand towards the end of the irrigation season. There is sufficient time available to refill the South Branch Reservoir to the maximum level of 630 m RL before the start of the next irrigation season.

Appendix

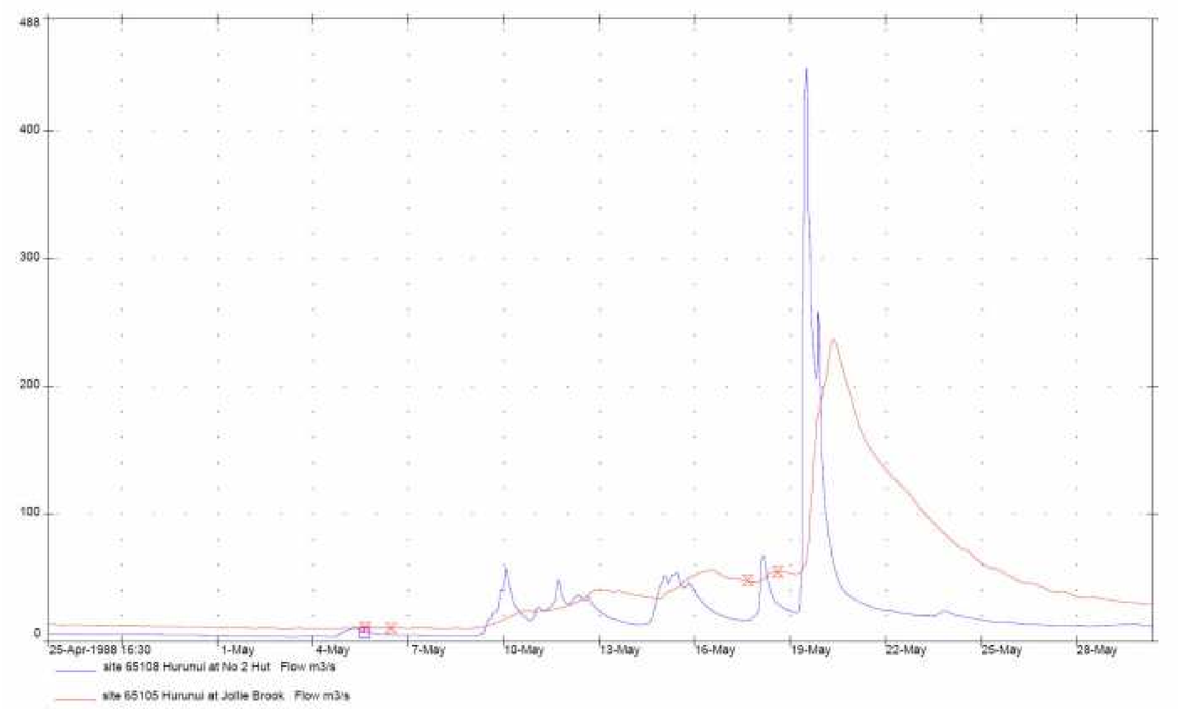


Figure B2: Typical Inflow-Outflow Hydrograph for Lake Sumner

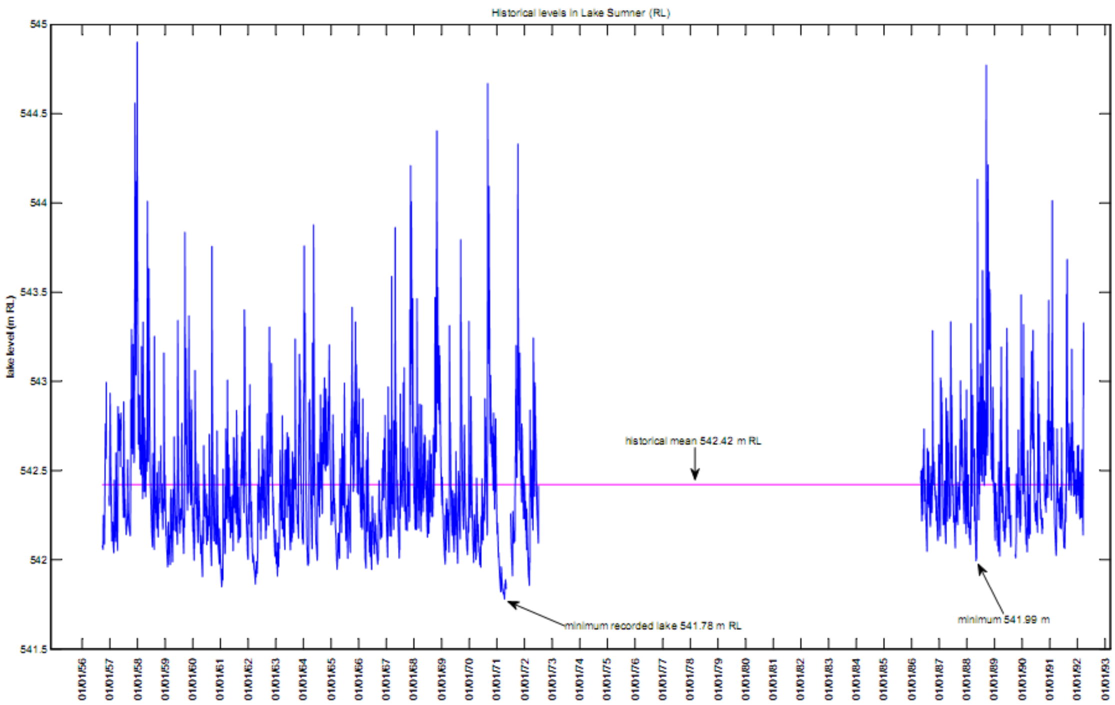


Figure B3: Historical lake Levels in lake Sumner

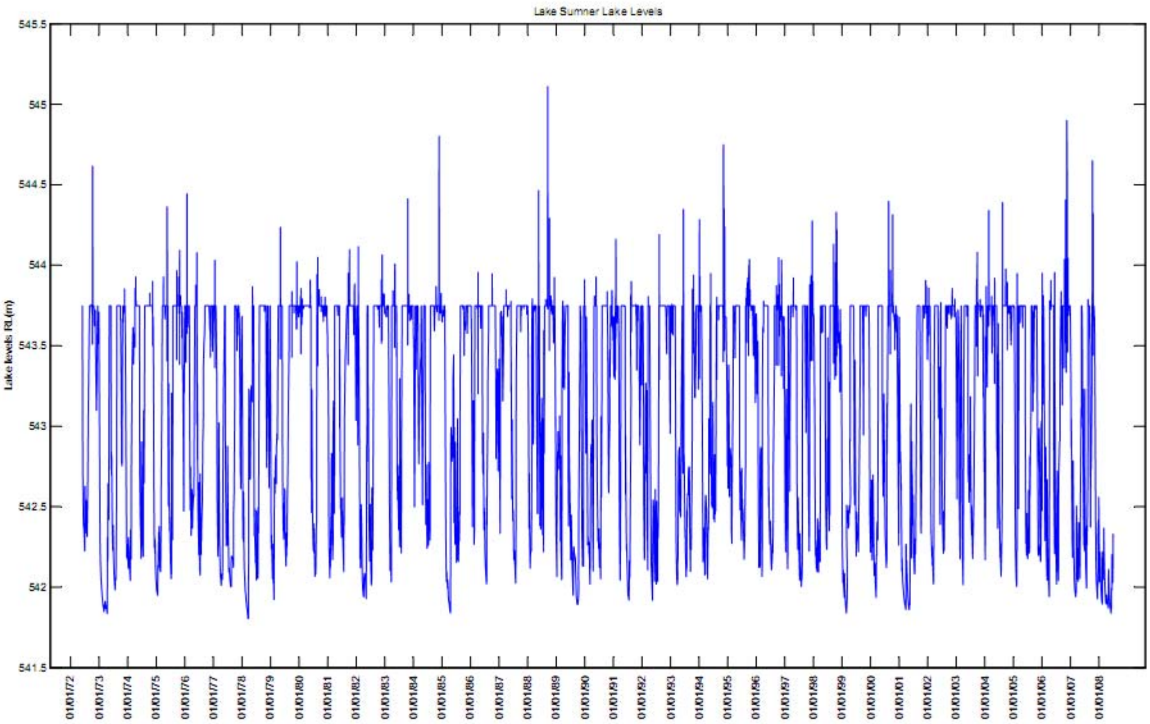


Figure G2: Lake Levels in Lake Sumner during 36 years modelling period

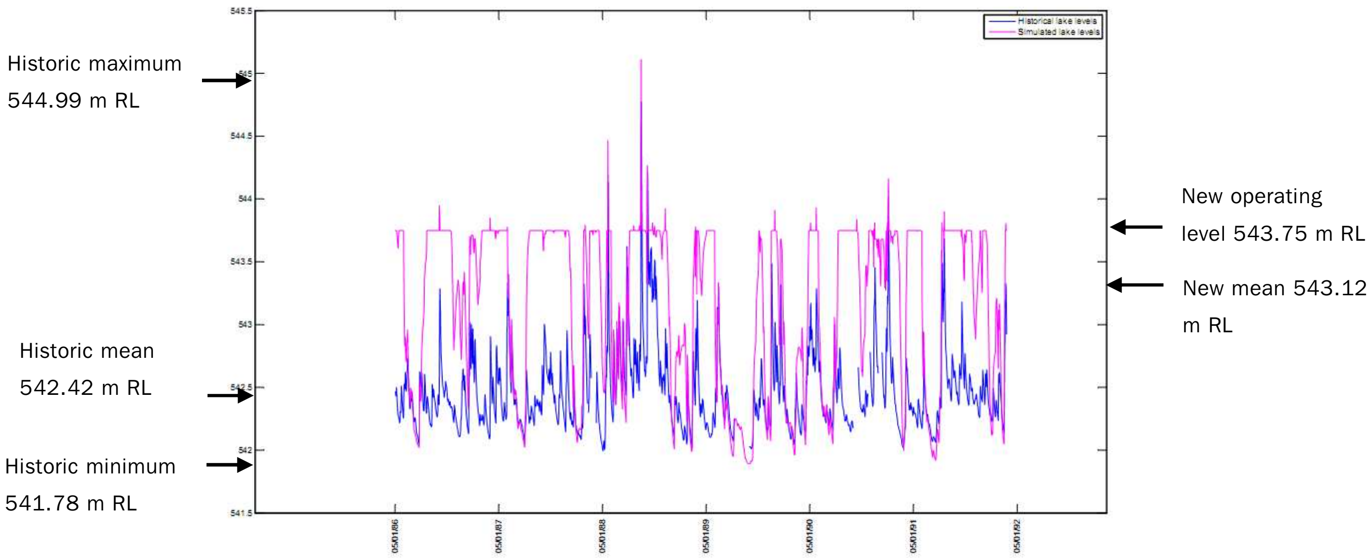


Figure G8: Overlay plot of modified and historical levels in Lake Sumner

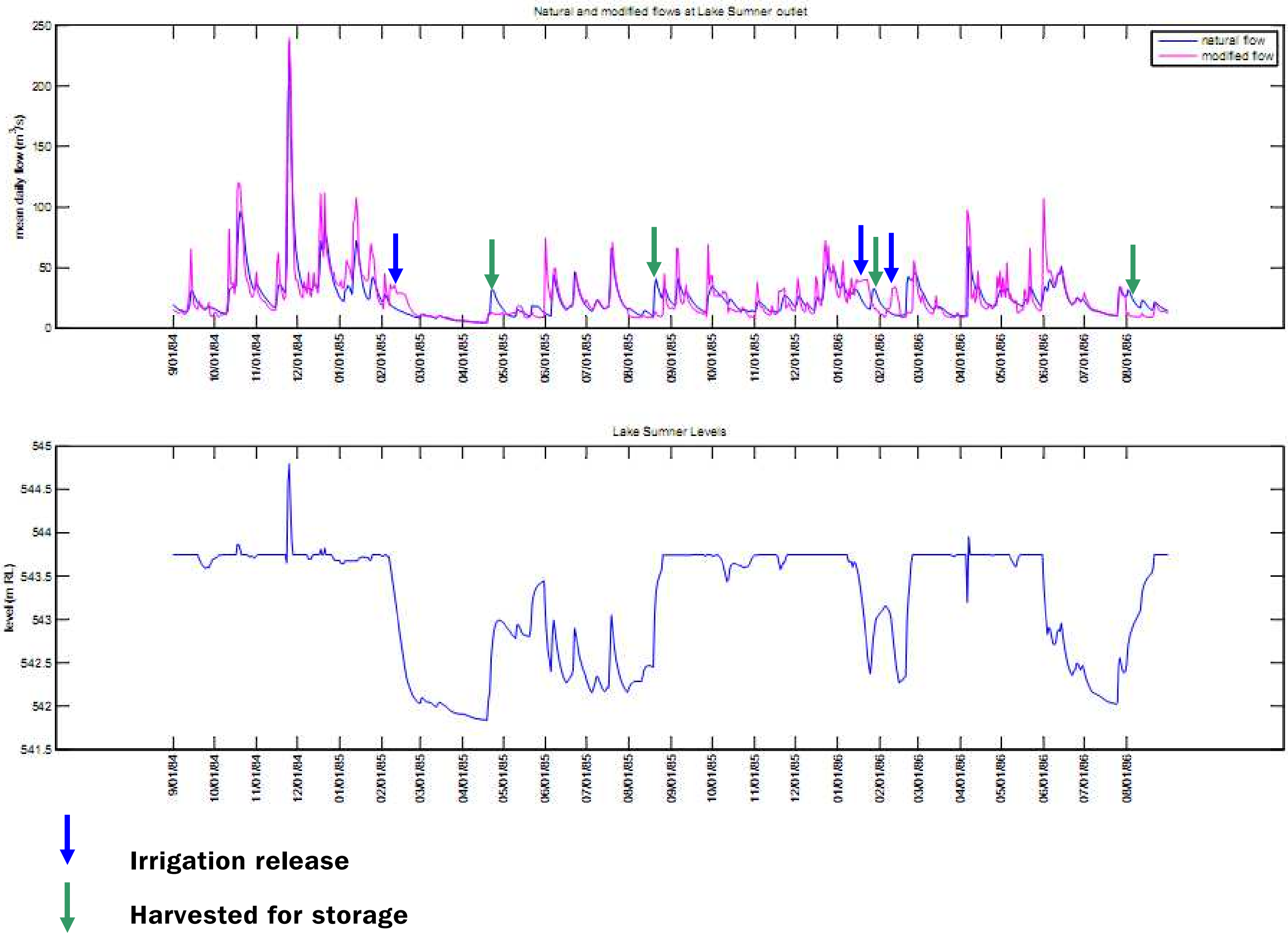
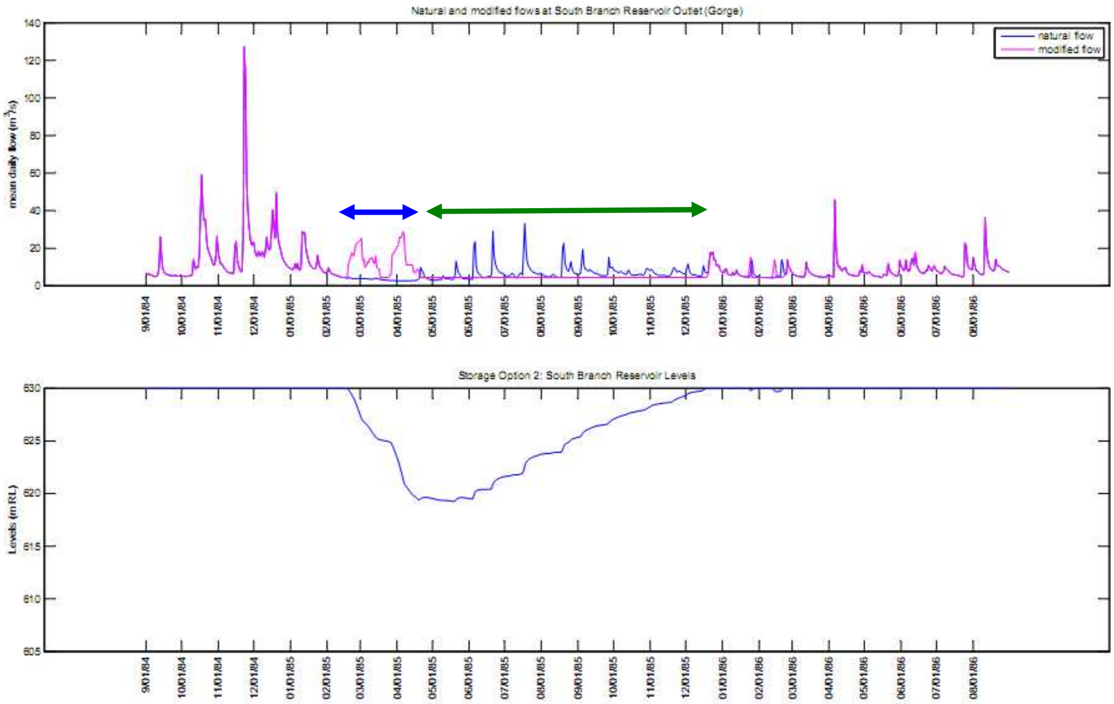


Figure M1: Overlay plot of natural and modified flows from Lake Sumner and lake levels



Irrigation release

Harvested for storage

Figure M2: Overlay plot of natural and modified flows from South Branch Reservoir and levels

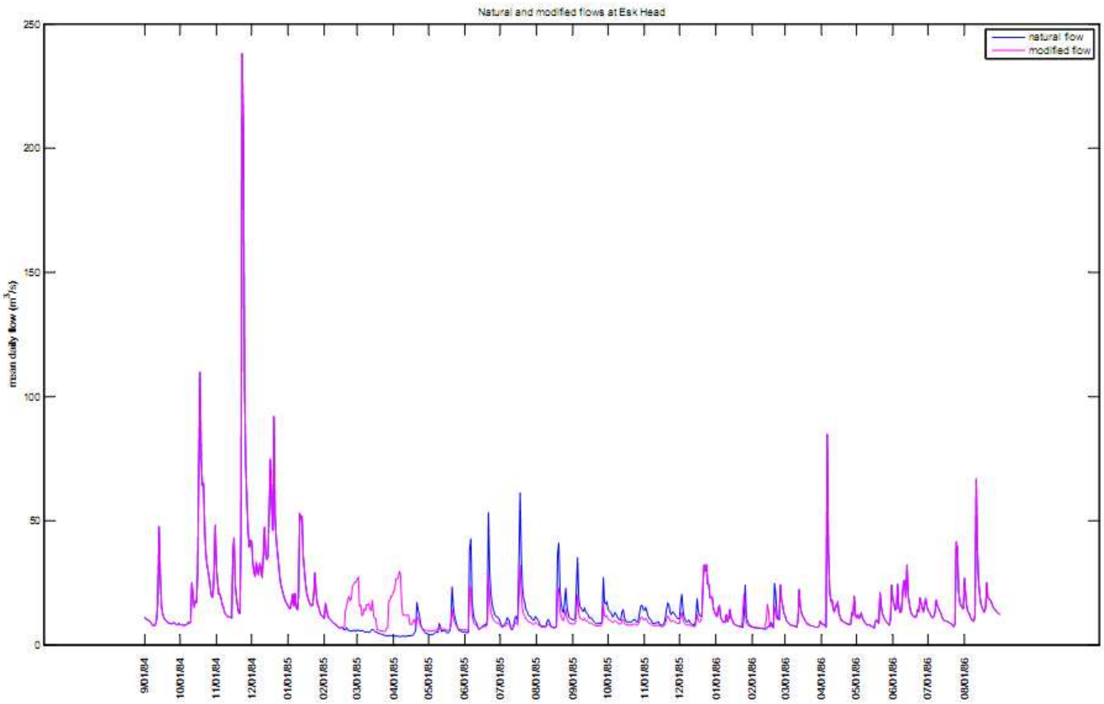


Figure M3: Overlay plot of natural and modified flows from South Branch at Esk Head

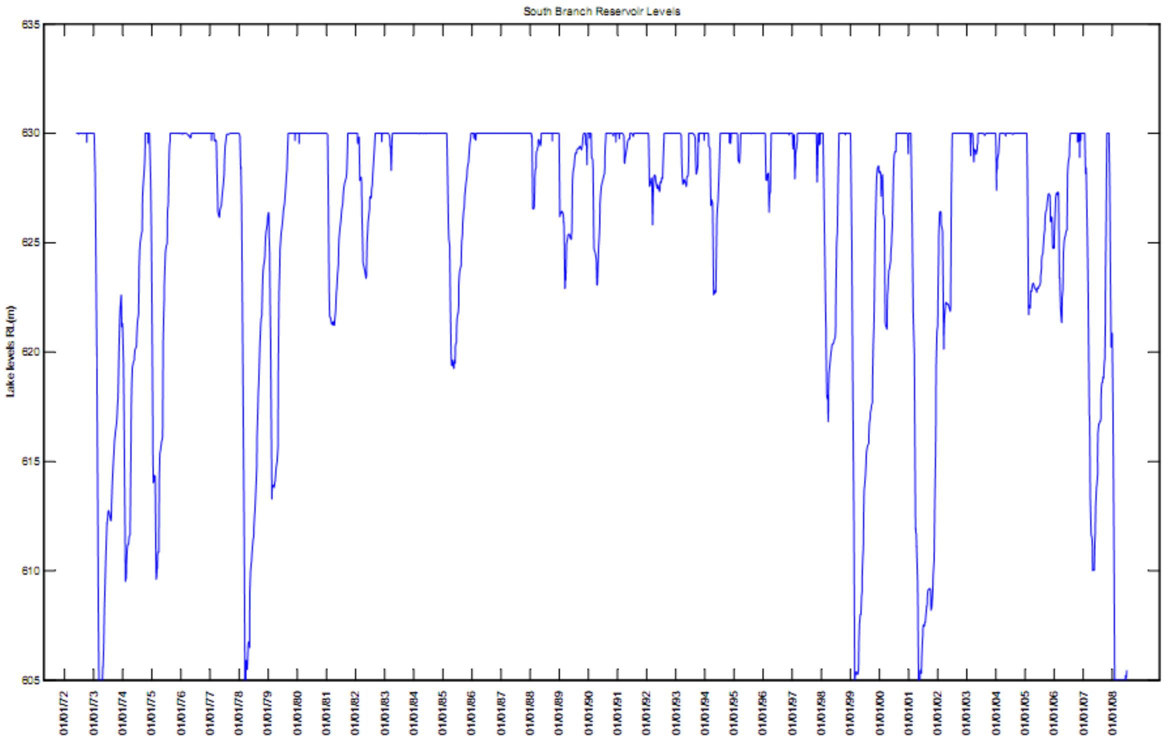


Figure G3: Reservoir levels in South Branch Reservoir during 36 year simulation period

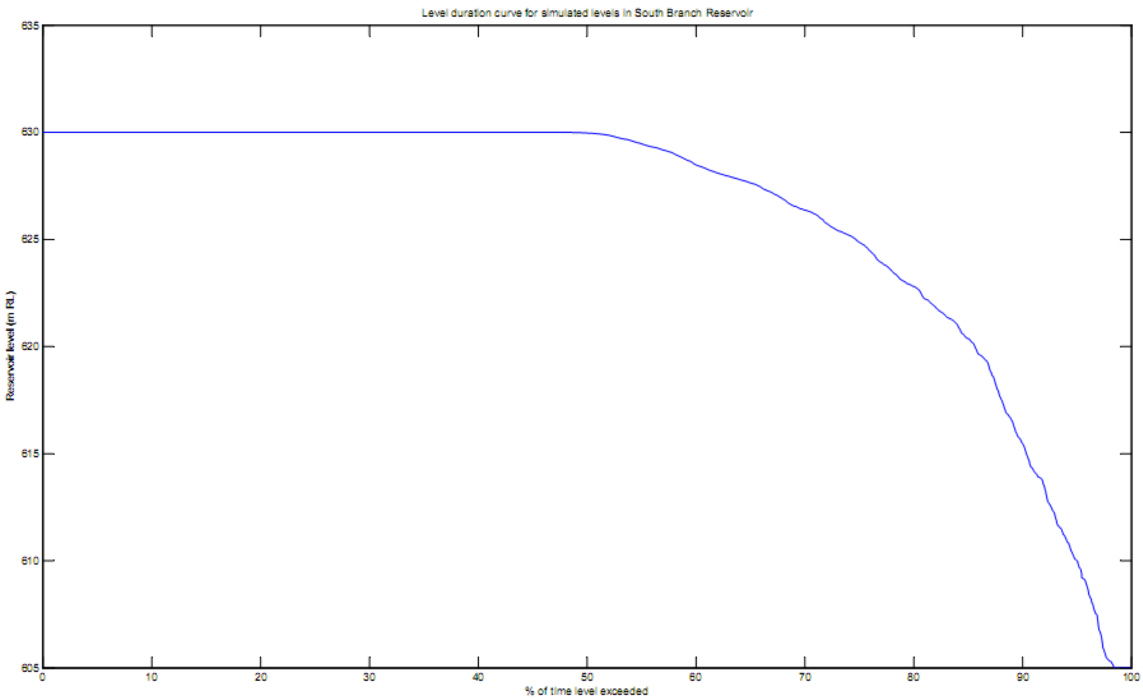


Figure G7: Level duration curve for South Branch Reservoir

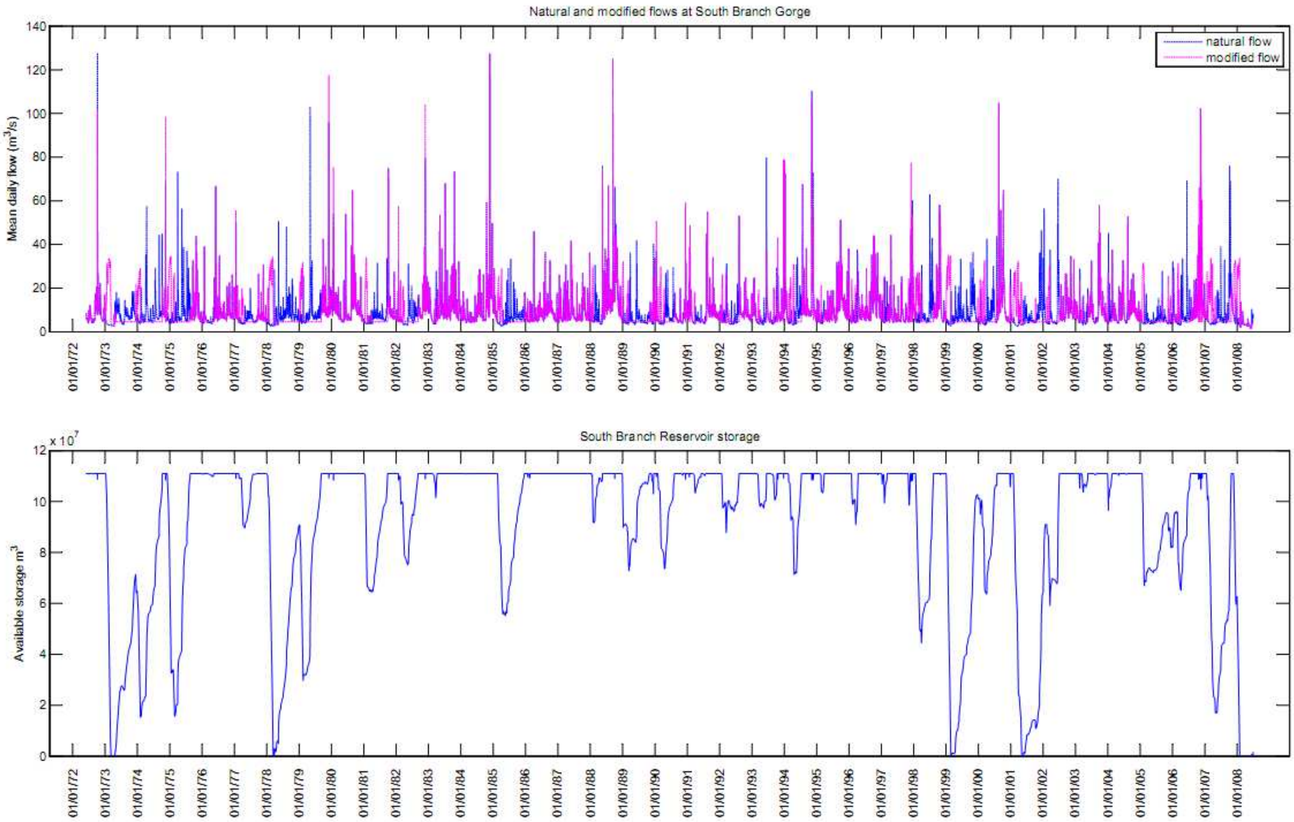


Figure I1: Overlay plot of natural and modified flows from South Branch Reservoir and available storage.