GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

Mokoan Return to Wetland
Lake Mokoan Decommissioning Project

Technical Summary on Flooding Impacts

December 2008

Contents

Glossary

Annual Exceedance Probability (AEP)	is the likelihood of occurrence of a flood of given size or larger occurring in any one year. AEP is expressed as a percentage (%) and may be expressed as the reciprocal of ARI (Average Recurrence Interval).
Average Recurrence Interval (ARI)	is the likelihood of occurrence, expressed in terms of the long-term average number of years, between flood events as large as or larger than the design flood event. For example, floods with a discharge as large as or larger than the 100-year ARI flood will occur on average once every 100-years.
Australian Height Datum (AHD)	is the adopted national height datum that generally relates to height above mean sea level. Elevation is in metres
Catchment	the area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	a flood of known magnitude or probability of exceedance used for engineering design and planning purposes.
Discharge (flow)	the rate of flow of water measured in terms of volume (measured in ML or m^3) over time (measured in days or seconds), *i.e.*, ML/d or m^3/s. It is to be distinguished from the speed or velocity of flow which is a measure of how fast the water is moving rather than how much is moving. (Note 1 m^3/s = 86.4 ML/d).
Hydraulics	the study of water flow; in particular flow parameters such as water surface height, water depth, duration and velocity across a floodplain and/or river or stream.
Hydrology	the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.

1. Introduction

Within the Goulburn and Broken river valleys community concerns have been expressed over increased flooding characteristics following completion of Lake Mokoan decommissioning. There are three general areas where concerns have been expressed, downstream of Mokoan inlet channel to Benalla, Benalla township itself, and Mokoan outlet channel to Casey Weir and beyond to Shepparton. Also, there are some community concerns about flooding impacts due to the change in operating rules for Lake Nillahcootie.

The purpose of this technical summary is to aggregate the findings from numerous flood studies and flood investigations into a single document to inform the general community about flooding impacts. The references that have been utilised in preparing this technical summary are presented in **Section 9**. This technical summary replaces the earlier Flood Regime Information Bulletin of July 2005.

The structure of this technical summary is set out as follows:

Catchment and Irrigation Overview (Section 2)

Decommissioning Lake Mokoan – Return to Wetland (Section 3)

Mokoan Inlet Channel Impacts during a Flood (Section 4) at:

- Holland Creek to Benalla;
- Broken River to Benalla;
- Benalla township and Ackerly Avenue (Stock Bridge); and
- Benalla to Shepparton and Casey Weir.

Mokoan Outlet Channel Impacts during a Flood (Section 5) at:

- Along the Mokoan Outlet Channel
- Casey Weir

Lake Nillahcootie Flood Impacts (Section 6)

- The effect of Lake Nillahcootie on Different Design Floods and Operating Rules
- The Influence of Lake Nillahcootie on Flood Timing
- The Influence of Lake Nillahcootie at Benalla Township

Benalla Water Management (Flood Mitigation) Scheme (Section 7)

Conclusions (Section 8).

2. Catchment and Irrigation Overview

Figure 1 illustrates features in the upper areas of the Broken River catchment. The catchment varies from mountainous, undeveloped areas with deeply dissected valleys in the upper reaches to mildly sloping areas between Benalla, Swanpool and Tatong. Holland Creek drains into the Broken River, with a combined catchment area of some 1,460 km^2 immediately upstream of Benalla, a major regional centre located some 200 km north of Melbourne. The catchment from Benalla continues to drain a further 10 km to Casey Weir before turning west towards Shepparton where it joins the Goulburn River.

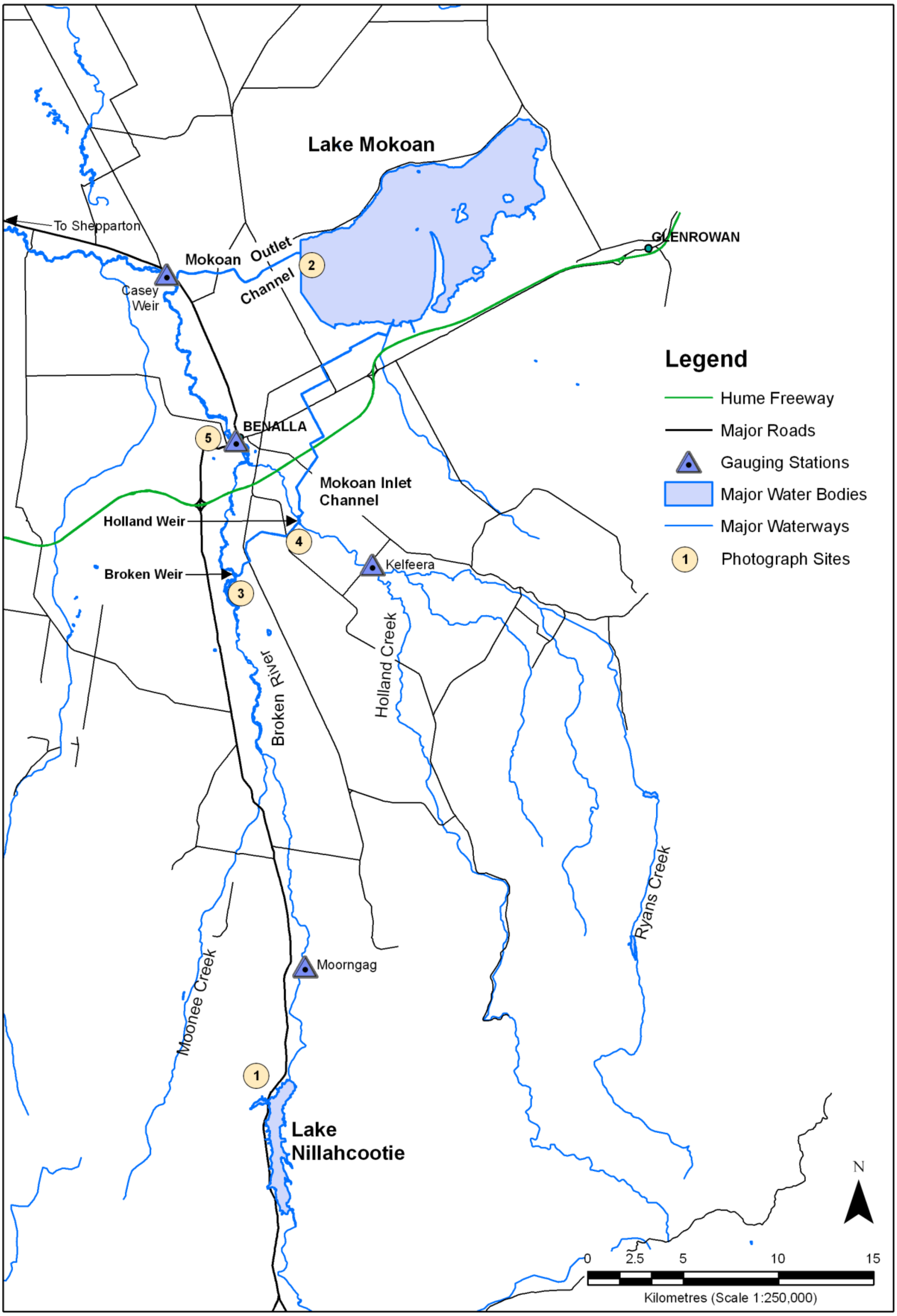

Figure 1: Locality Plan

A relatively small storage of 40,400 ML, known as Lake Nillahcootie (**Photo 1A**), exists on the Broken River located some 36 km upstream (south) of Benalla, and commands a catchment area of 439 km^2.

Goulburn-Murray Water operates the storage, primarily for irrigation, domestic and stock and urban water supply purposes. Lake Nillahcootie dam has a fixed concrete crest spillway (**Photo 1B**), and a secondary spillway on the opposite side. The release capacity is limited when the storage is below full supply level.

Photo 1A: Lake Nillahcootie looking upstream

Photo 1B: Nillahcootie dam wall showing spillway

Lake Mokoan is a large off-line storage of 365,000 ML (**Photo 2**) and is located about seven kilometres north east of Benalla. Subject to water quality, the storage has been used to provide water for irrigation and domestic and stock purposes within the Broken River valley, and at times, augment supply to the lower Goulburn River and River Murray. It also provides amenities and recreational values.

Photo 2: Lake Mokoan and dam wall

The natural catchment of Lake Mokoan at the old Winton Swamp is some 338 km^2. While having its own catchment, Lake Mokoan is primarily filled by a diversion channel known as the Mokoan inlet channel. Water may be diverted from the Broken River (which can be supplied by Lake Nillahcootie) and Holland Creek to Lake Mokoan via Mokoan inlet channel. The Broken and Holland weirs (refer to **Figure 1**) make it possible to elevate water heights to enable flow diversions into Mokoan inlet channel. **Photo 3** and **Photo 4** provides further description.

Photo 3: Mokoan inlet (diversion) channel from Broken River

Photo 3 left is the start of the Mokoan inlet channel which carries flows from the Broken River to Holland Creek, which is made possible by a weir structure across the river. The Broken River and the Broken Weir structure lie within the treed area in this photograph.

The capacity of the Mokoan inlet channel from the Broken River to Holland Creek is 1,800 ML/d.

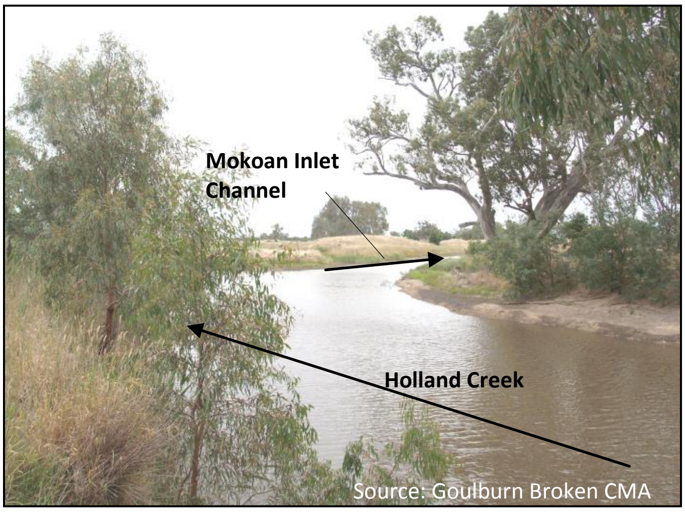

Photo 4: Mokoan inlet (diversion) channel leaving Holland Ck

The design capacity of Mokoan Inlet Channel between Holland Creek and Lake Mokoan is 2,400 ML/d. Diversions are made possible by a diversion weir on Holland Creek located immediately downstream of the Mokoan inlet channel as indicated in **Photo 4**.

Experience has shown that the Mokoan inlet channel can be operating at maximum capacity due to natural flows from Holland Creek alone.

Upstream of Broken Weir local flooding occurs when river flows exceed 800 ML/d. Releases from Lake Nillahcootie are therefore constrained to 800 ML/d. Accordingly, the full diversion capacity of the Mokoan Inlet Channel cannot be utilised unless upstream flooding along the Broken River is accepted. After commissioning of the Lake Mokoan project in 1969, it became apparent that flooding just upstream of Broken Weir occurred when flows in the Broken River at that location were around 600 ML/d. As a consequence of this flooding, containing banks were constructed to allow flows up to 800 ML/d before flooding occurs to adjacent land.

Until 1992, flow diversions were governed by operating rules (further described in **Section 6**) that provided monthly target curves for filling Lake Nillahcootie. Once the target storage levels were achieved excess flows were transferred to Lake Mokoan, at a maximum rate of 800 ML/d. Downstream tributary inflows frequently result in releases from Lake Nillahcootie being curtailed well below 800 ML/d so as to avoid or minimise localise flooding in the vicinity of Broken Weir.

In 1992, the operating rules were modified to take into account water quality issues associated with blue green algae in Lake Mokoan. The intention then (and now) was to keep water in Lake Nillahcootie in preference to diverting it to Lake Mokoan.

The modification of the operating rules has led to community concerns over possible increases in flood risk, in terms of frequency and flood height.

3. Decommissioning of Lake Mokoan – Return to Wetland

As part of the Victorian Government water reform, Lake Mokoan will be decommissioned, resulting in an average of 44,000 ML being returned to the Broken, Goulburn, Snowy and Murray Rivers each year. The re-adjustment to the flow regime towards natural conditions will generate waterway health benefits with minimal change to flood risks.

Decommissioning involves removal of a small section of the Lake Mokoan dam embankment, and modifying the outlet structure to allow the future wetland to overflow more naturally into the outlet channel (formerly Stockyard Creek).

Under the new arrangements, there will be no transfer of water from Lake Nillahcootie or from Holland Creek into Lake Mokoan as described in **Section 2**. Lake Mokoan will revert to its original feature as a wetland, and fed by inflows from its natural catchment, and possibly from local drainage inflows.

4. Mokoan Inlet Channel Impacts during a Flood

4.1 General

Diversions into Lake Mokoan have occurred when conditions were right. The maximum capacity of the Mokoan inlet channel varies between 1,800 ML/d and 2,400 ML/d, but it is not possible to pass this amount of water down the Broken River without flooding downstream properties (refer **Section 2**).

Past flow transfers were governed by the ability of Lake Mokoan to take the water (*e.g.*, the lake was not full and there were no water quality issues), and also the ability to divert water from (in order of preference) local drainage, Holland Creek and Broken River downstream of Lake Nillahcootie without aggravating flooding.

The concern, by some community members, is that flow transfers via the Mokoan inlet channel will no longer be possible following decommissioning, creating additional flooding to downstream areas including Benalla.

Inspection of flow records, since 1987 at Kelfeera and Mokoan inlet channel gauging stations, reveal that the Holland Creek bank full flow capacity of 4,300 ML/d (**Ref 1**) would have been exceeded on 22 occasions if the inlet channel did not operate. Records show during these occasions the Mokoan inlet channel operated 14 times of which 10 events still exceeded bank full. This indicates that the flow diversion has never been relied upon to provide any level of flood protection. The average duration of flow, greater than bank full flow capacity, is some 10 and 14 hours with and without Mokoan inlet channel diversion.

4.2 Holland Creek to Benalla

This section summarises work carried out by Earth Tech (**Ref 1**) to determine changes to flooding characteristics. Earth Tech utilised surveyed cross sections of Holland Creek including associated floodplain areas, between the Holland Weir to Benalla, to create a hydraulic model. The model allows the computation of water heights for any particular flow rate at the cross section locations. This in turn, is a useful way of determining any change in flood heights if flow can be reduced by flow diversions to Lake Mokoan away from Holland Creek.

As described earlier (**Section 4.1**) Mokoan inlet channel however, can never be relied upon during floods to divert flows. Therefore, flows in areas downstream of the inlet channel will return to natural conditions.

Table 1 below quantifies the height differences which represent the 'worst' case scenario as it assumes that the Mokoan inlet channel can operate at full capacity of 2,400 ML/d, even where small flows are present in the Creek. Furthermore, the results are over estimating the height differences due to the ground surveys not spanning the entire floodplain *i.e.,* the wider the floodplain the depth of flooding is reduced.

Table 1: Flood height differences along Holland Creek

Holland Creek Average Recurrence Interval (years)	Flow With / Without Inlet Channel (ML/d)	Holland Creek Average Flow Height Difference between Inlet Channel and Benalla (mm)
2	6,220 / 8,640	265
5	14,860 / 17,280	110
20	33,005 / 35,424	7
100	54,605 / 57,024	6

Source: Earth Tech (**Ref 1**)

Changes in flood depths across floodplain areas for floods above the 1 in 5 year flood would be 100 millimetres or less, assuming water can be transferred to Lake Mokoan via the inlet channel.

4.3 Broken River to Benalla

Broken River flows upstream of the Mokoan inlet channel will remain lower than naturally occurring frequent flows due to the influence of Nillahcootie storage.

Earth Tech (**Ref 1**) carried out hydraulic modelling between the Broken Weir to Benalla in the same manner as described in **Section 4.2**.

Downstream of the inlet channel, the 1 in 100 year flood heights will not change, however the frequency and height of minor events will, but to a lessor degree than shown in **Table 1** assuming Mokoan inlet channel can operate at the Broken River diversion weir. The smaller changes are due to the larger carrying capacity of the river channel compared with Holland Creek, and the lower carrying capacity of the Mokoan inlet channel between Broken River and Holland Creek of only 1,800 ML/d.

4.4 Benalla Township and Ackerly Avenue (Stock Bridge)

4.4.1 General

The Benalla gauging station, located near the Benalla art gallery, has an established rating curve (**Ref 2**), which provides stage-discharge relationship, *i.e.*, for a particular gauge height a flow rate can be determined. **Table 2** and **Figure 2** provide insight into a range of historic and design floods with peak flood frequency at Benalla gauge.

Table 2: Historic and design flows and flood heights at Benalla

Design and Historical Floods Average recurrence Interval (years)	Benalla Gauge Flow (ML/d)	Benalla Gauge Height (m)
1.11*	2,190	1.943
2*	11,000	2.543
~ 2 (2005 Flood)	11,000	2.540
5	28,425	3.454
~ 7 (Sept 1975 Flood)	36,288	3.781
~10 (July 1981 Flood)	41,385	3.941
10	42,940	3.985
~14 (May 1974 Flood)	50,110	4.281
20	59,530	4.464
50	86,445	5.066
100 (Oct 1993 Flood)	111,508	5.50*

*(**Ref 11**)

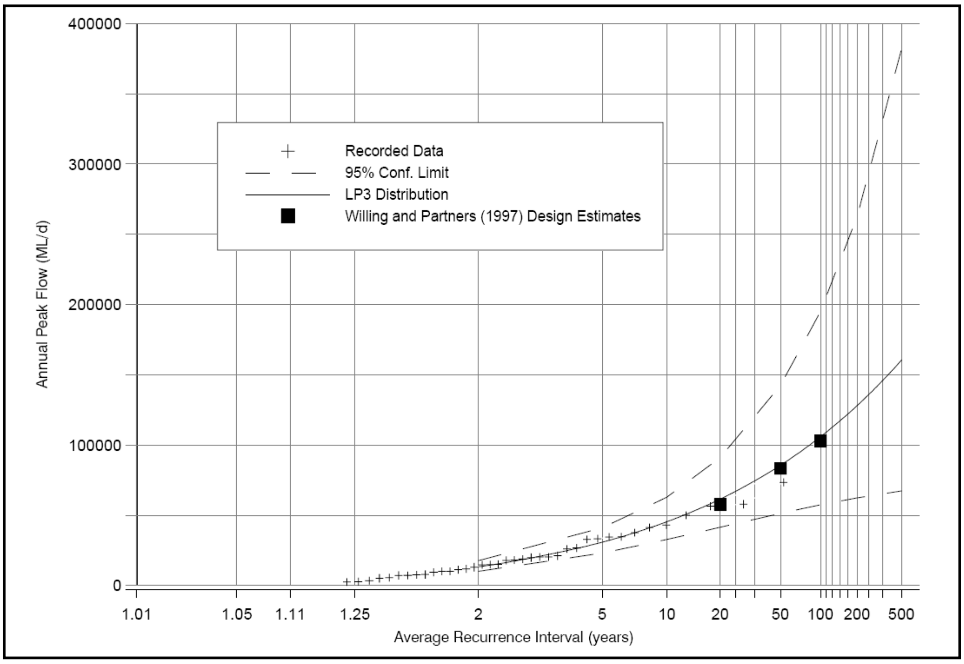

Figure 2: Peak flood frequency Analysis - Broken River at Benalla (**Ref 3**)

4.4.2 Ackerly Avenue (Stock Bridge) at Benalla

The 'Stock Bridge' is located immediately downstream of the railway viaduct as shown in **Photo 5** below.

Photo 5: Stock Bridge (Ackerly Avenue) across the Broken River floodplain. Railway viaduct shown in the left

Some community members have expressed concerns about additional flooding over Ackerly Avenue because of the lost opportunity to transfer flow to Lake Mokoan post decommissioning, *i.e.*, water transfers by-pass Benalla via Mokoan inlet channel. This concern has been raised as the road provides an alternative heavy transport link through Benalla.

When 2.2 metres on the Benalla gauge is reached, Ackerly Avenue will begin to flood. This gauge height represents a flow of 6,000 ML/d, which equates to a 1 in 1½ year flood (**Ref 11** and **Figure 2**). As described earlier, the worst case scenario is if the flow diversion of 2,400 ML/d can always be relied upon (but never has) to Lake Mokoan. It will make no practical difference whether flows are diverted out of Broken River or Holland Creek as the confluence of the two systems is upstream of the Benalla gauge. The results are conservative since they make no allowance for attenuation or for operational constraints (discussed in **Section 5**) that reduce or prevent flow diversions during floods.

Under this assumption, flow would increase from 6,000 ML/d to a maximum 8,400 ML/d, which equates to 1 in 1¾ year flood (**Ref 11** and **Figure 2**).

By deduction, if the Mokoan inlet channel can be relied upon to provide flood mitigation then the frequency of flooding would be reduced by three months. However, analysis of flow records on the Holland Creek and Mokoan Inlet channel (detailed **Section 4** earlier) indicates that the changes will be less than three months as diversions to Lake Mokoan only occur during a fraction of time during those occasions when the Broken River channel capacity is exceeded.

4.4.3 Benalla Township

There will be no changes to the 1 in 100 year flood heights as a result of the Lake Mokoan decommissioning. This conclusion is drawn as the Mokoan inlet channel can never be relied upon during floods to transfer water (maximum of 2,400 ML/d) to Lake Mokoan as described in **Section 4.1**.

Assuming water transfers are possible during times of floods, the stage-discharge relationship (**Ref 2**) at the Benalla gauge provides a way to quantitatively measure flood impacts at Benalla (refer **Section 4**).

The maximum change in flood heights have been estimated and shown in **Table 3**.

The results show that, not unexpectedly, there are significant reductions in levels at the Benalla gauge for the smaller frequent floods, but these do not cause additional houses to be flooded above floor level at Benalla (**Ref 4**).

Table 3: Estimated change in flood heights and houses flooded at Benalla

Peak Flow* Flow With / Without Mokoan Inlet Channel Diverting Max Flow Capacity 2,420 ML/d	Height Difference at Benalla Gauge (mm)	Change in No. of Houses Flooded at Benalla (Ref 4) (Number)
2,190 / 4,610	152	0
11,000 / 13,420	156	0
28,425 / 30,845	102	0
42,940 / 45,360	76	0
59,530 / 61,950	62	1
86,445/ 88,865	47	42
111,508 / 113,928	22	53

For comparison purposes on flood height and frequency see **Table 2 and **Figure 2***

For less frequent floods, approaching the 1 in 100 year (or the 1993 flood), there are some 50 additional houses estimated to be subject to over the floor flooding. This shows that the number of dwellings affected is sensitive to minor changes to flood heights. This can be explained as many dwellings built before the 1993 flood were set to flood heights established in 1984. Since 1993 floor heights have been are set between 300 and 400 millimetres higher.

4.5 Benalla to Shepparton and Casey Weir

The 1 in 100 year flood heights between Benalla and Shepparton will not change significantly. Again the changes in flood heights have been estimated assuming that Mokoan inlet channel can operate and at a maximum 2,400 ML/d (as described in **Section 4.1**). GHD has estimated (**Ref 5**) increases in flood heights between 40 mm and 80 mm for the 1 in 100 year and 1 in 5 year flood respectively at Casey Weir, located on the Broken Rover some 10 km downstream of Benalla. These results are similar for Benalla.

Closer to Shepparton flood height increases will be less due to attenuation of flows provided by the Broken River floodplains and excess flooding captured by the Broken Creek system, to the north, which never returns back to the Broken River.

Information determined by Sinclair Knight Merz (**Ref 3**), indicates the height differences for the 1 in 100 year flow will be smaller for the Shepparton area compared with Benalla.

5. Flooding with the Modification to the Mokoan Outlet

Decommissioning Lake Mokoan will return land back to the pre-development of Lake Mokoan. The modifications will allow overflow to occur at the same level as that which existed for Winton Swamp. A 2005 GHD report (**Ref 5**) concluded the following four key points:

1. The preferred option for the decommissioned Mokoan embankment and outlet works is for a 10 m breach (*i.e*., the removal of dam wall over a 10 m length) and provision of a modified outlet works[1] to maintain an overflow crest level of 161.14 m AHD for Winton Swamp.
2. With the preferred outlet arrangements (*i.e*. 10 m breach with outlet), a 100-year ARI event over the Mokoan catchment would result in:
   - A peak water level in Winton Swamp of 161.72 m AHD (0.58 m above the overflow level of 161.14 m AHD);
   - An area of land, around and including the future Wetland, liable to flooding of about 5,300 ha;
   - Durations of flooding above the overflow level (161.14 m AHD) would be greater than eight days; and
   - Flood level surcharges of between 0.4 to 1.1 m would be experienced in the seven swamps within the Lake Mokoan area.
3. Increases in peak water levels in the outlet channel for a range of flood events in the Mokoan catchment with the preferred outlet (*i.e*., 10 m breach with outlet) arrangements combined with the 1993 flood level at Casey Weir are in the order of 10 mm *i.e*., future Wetland overflows will only add a maximum of 10 mm to flood levels at Casey Weir in a 1 in 100 year flood.
4. For more frequent floods in the Broken River than the 1993 event, the estimated peak discharges from the Future Wetland will not significantly increase (*i.e.,* by less than 0.01 m) the water levels above the existing compacted banks along the outlet channel.

Additional work in 2008 by GHD (**Ref 6**) has analysed the impacts of an October 1993 flood into the future Winton Wetland on water levels downstream of Lake Mokoan with a 10 m wide embankment breach in the Mokoan embankment. The results show that outflows from the proposed 10 m breach will only increase levels in the outlet channel immediately downstream of Lake Mokoan by 20 mm and, at the downstream end of the outlet channel near Casey Weir the increase will be only 10 mm. Given the large volume of water coming down the Broken River from Benalla, these flows would be entirely dissipated below Casey Weir with no increased flood levels.

The small catchment of the future Winton Wetlands combined with the large capacity of the wetlands to absorb flood inflows and the narrow breach which effectively chokes outflows means that decommissioning of the Mokoan storage will effectively have no impact on flood levels downstream in the Broken River.

[1] Further consideration by GHD (**Ref 6**) of overflow rates, and advice that controlled releases from the Winton Wetlands would not be required has lead to the decision to have a 10 m breach at elevation 161.14 m AHD and no outlet structure.

6. Nillahcootie and Mokoan Storages and Operating Rules

The Mokoan and Nillahcootie storage system was developed to provide storage to meet irrigation demands in the Goulburn Valley and stock, domestic and town requirements throughout the Broken Valley. It was not developed, nor has it been operated with flood mitigation as its primary purpose but as a secondary benefit. This was recognised but not quantified in the 1963 Parliamentary Public Works Committee report (**Ref 7**) that recommended the construction of both Winton Swamp Storage (Lake Mokoan) and Lake Nillahcootie.

Prior to 1992, operating rules were established that took into account Lake Nillahcootie target filling levels which varied from about 30% full in June to 75% full in November. If conditions were right and the volume in Lake Nillahcootie exceeded target levels, the water authority had the opportunity to transfer water to Lake Mokoan.

The target filling curves were only one consideration in transferring flows. Other constraints included the Lake Nillahcootie outlet structure capacity, downstream river channel limitations (described in **Section 2**), the volume in Lake Mokoan, the ability to supply flows to Lake Mokoan from Holland Creek and the prevailing flows in the river from downstream tributaries.

Since 1992, Lake Nillahcootie has been operated to fill as early as possible during the winter/spring period. This change was introduced to manage the risk of Lake Mokoan being taken out of service due to a blue green algae outbreak. The current decommissioning of Lake Mokoan will mean the present operating rules will remain.

Lake Nillahcootie now starts to fill up in May after the end of the irrigation season so that it is more likely to be full at the start of the next irrigation season. Post decommissioning, Lake Nillahcootie will be the only storage in the system and will be called on more frequently than in the past, and therefore will be lower at the end of each irrigation season.

Further details on operational aspects can be found Fact Sheet No. 4 Broken System – Lake Mokoan – Management and Operation on website www.lakemokoan.com.

6.1 Lake Nillahcootie Flood Impacts

Cardno Lawson Treloar (**Ref 8**) recently carried out the Lake Nillahcootie Flood Study to quantify the level of flood mitigation benefit provided in Benalla by Lake Nillahcootie. Computer modelling was used for a range of design flood events to estimate how different starting levels in the lake affected Benalla flood heights.

Lake levels were also analysed for the period leading up to the four largest flood events since Lake Nillahcootie was constructed. This was done for both pre 1992 and post 1992 operating rules for the transfer of water from Lake Nillahcootie to Lake Mokoan. This was undertaken to determine any impacts at Benalla of the changes that occurred to the operating rules in 1992.

6.1.1 The Effect of Lake Nillahcootie on Different Design Floods and Operating Rules

As part of the Lake Nillahcootie Flood Study (**Ref 8**) a hydrologic model was run for a variety of starting storage levels at the lake (empty, 25% full, 50% full, 75% full and 100% full) and for a range of design floods (1 in 10 year, 1 in 20 year, I in 50 year and 1 in 100 year events). Historic rainfall information and flow information from river gauges were used to calibrate the model. The model was also run with the lake removed to see how the presence of Lake Nillahcootie influenced flood heights at Benalla.

The results showed that for all design events and all starting levels there were significant peak flow reductions immediately downstream of Lake Nillahcootie. However, these reductions lessened downstream at Benalla. Flows from the remainder of the catchment downstream of Lake Nillahcootie were found to have a greater influence on the peak flow at Benalla. If Lake Nillahcootie happens to be less than 75% full prior to a flood event, flood heights at Benalla would be reduced by 70 mm to 110 mm for the range of flood events considered.

When the model was run with the storage completely removed, it was found that flood heights in Benalla would have increased by 230 mm for a 1 in 100 year flood, compared to what happened in October 1993, when the reservoir was full. This indicates the benefits at Benalla that the physical presence of the storage has. Smaller flood events were found to have lesser impacts.

As a further check, the four largest historic floods since the construction of Lake Nillahcootie were also assessed with Lake Nillahcootie at 0%, 25%, 50%, 75% and 100% full, and also with no Lake Nillahcootie present. These historic flood events were the 1974, 1975, 1981 and 1993. (refer to **Table 2** showing details on these historic floods). The results supported the earlier analysis of the design floods.

In order to see how feasible it was to keep Lake Nillahcootie less than 75% full, historic records were analysed in detail for the 1974, 1975, 1981 and 1993 flood events.

The three earlier events applied to situations in which the operating rules allowed flow transfer from Lake Nillahcootie to Lake Mokoan when conditions were right. The October 1993 flood event occurred in a period in which there were no flow transfers to Lake Mokoan.

The analysis showed that, for three of these four events, Lake Nillahcootie was full and spilling before the flood events occurred. For the May 1974 event Lake Nillahcootie was 85% full prior to the flood. This occurred outside the period when flow transfers were most likely to take place (between June and November). Hence the flood heights at Benalla would be the same regardless of which operating rules were applied.

During the 1993 flood, the operating policy (then and now) was to maintain Lake Nillahcootie at or near 100% capacity over the winter/spring period. However, as this was the flood event that had the greatest affect on Benalla residents, a detailed analysis of the effect of the two operating rules was undertaken. The results confirmed that, irrespective of which operating rule was applied, Lake Nillahcootie would have filled in the months prior to the October 1993 flood. Had the pre-1992 operating rules applied there would have been no difference to the flooding at Benalla.

The report concluded that some airspace in Lake Nillahcootie can have a limited effect in reducing the impacts of flooding at Benalla. However, the ability to draw down the reservoir before a flood is limited. Analysis of the four largest floods since the construction of the lake shows that application of either the pre or post 1992 operating rules would achieve the same result at Benalla.

6.1.2 The Influence of Lake Nillahcootie on Flood Timing

Rainfall upstream of Lake Nillahcootie was modelled for a 1 in 100 year event with no contributions from the other parts of the catchment. It was found that it took 42 hours after the commencement of the rainfall event for the flood peak to reach Benalla for a full storage (**Ref 8**), and longer if the storage was less than full.

In comparison, it only takes about 30 hours after commencement of rain for the flood peak to reach Benalla if all parts of the catchment are contributing. This means that the effect of the initial level in Lake Nillahcootie is not a major factor in the peak flows at Benalla. Flows from the remainder of the catchment downstream of Lake Nillahcootie reach Benalla much sooner.

Peak flows from the Holland Creek and Broken River catchment downstream of Lake Nillahcootie reach Benalla at approximately the same time under design flood events.

6.1.3 The Influence of Lake Nillahcootie at Benalla Township

In order to better understand the flood impacts that available airspace at Lake Nillahcootie might have within Benalla further analysis was undertaken. Data from recent additional work for Benalla Rural City was used to assess the number of properties flooded (**Ref 4**).

The results indicate that the construction of Lake Nillahcootie has provided flood mitigation benefits to Benalla for the larger floods. Without the lake, flood heights at Benalla would rise by 230 mm, flooding an additional 317 properties above their floor level in a 1 in 100 year event.

The results also show significant potential reductions in the number of properties flooded above floor level if the lake is at 75% capacity or less prior to a 1 in 100 or a 1 in 50 year flood. There is a reduction of 273 houses and 27 houses respectively. For lesser floods the impact is relatively small.

However, there are severe physical limitations in lowering Lake Nillahcootie ahead of a flood. For example, to lower the storage to 75%, a volume release of 10,000 ML would be required prior to a flood, which would take two weeks due to the limitations. Flood events generally occur over a 30 hour period, which practically provides no opportunity to lower the storage. Observations of the four largest historic floods since the construction of Lake Nillahcootie reveals that only one event, the May 1974 flood, occurred when the lake was less than 100% full. For the other three events the storage was full.

7. Water Management (Flood Mitigation) Scheme for Benalla

The Water Management Scheme for Benalla was approved by the Minister for Water in 2002, and is unrelated to the decommissioning of Lake Mokoan.

The Approved Scheme for Benalla includes environmentally sensitive vegetation management adjacent to the urban environs, improvement to the railway culverts near the East Main Drain, and the acquisition of the Market Street Floodway. Reduction of flood heights between 50 and 200 mm are expected for large floods along the Broken River and up to 750 mm near the East Main Drain and North-eastern Railway.

Benalla Floodplain Management Study (**Ref 9**) and earlier Benalla Flood Study (**Ref 10)** formed the basis of the Approved Water Management Scheme. The Nillahcootie Storage and Mokoan Inlet channel were both assessed as non effective flood mitigations measure for Benalla.

The Approved Scheme for Benalla does not rely on any diversions to Lake Mokoan during floods, and in practice diversions to Mokoan do not take place during large floods.

8. Conclusions

Lake Nillahcootie, even when full prior to a flood event, provides some benefit at Benalla in reducing flood heights. The operational arrangements of the Mokoan and Nillahcootie storage system were established for water harvesting purposes and on occasions may provide some additional incidental minor reductions in flow height and duration for Benalla and its surrounding environs. This is true only if the Mokoan inlet channel operates, which cannot be guaranteed. During wet periods when the probability of flooding is highest, it is most likely that Lake Nillahcootie will be full prior to a flood event. Further downstream to Shepparton any changes to flow heights will be further reduced due to attenuation of flows provided by the Broken River and Broken Creek floodplains.

The minor changes in flow regime, particularly for frequent floods are environmentally favourable for waterway and riverine health. Flows above bank full provide a number of important functions including the wetting of riparian areas delivering important organic matter (food) to waterway species, and providing access for some native fish species to nearby wetlands. Minor increases in flood heights for frequent floods are important as a way forward to restore waterway and riverine health back towards natural conditions. This is particularly important as climate change predictions suggest inland areas of Australia will, in the long-term, become drier with less catchment runoff entering waterway and wetland systems.

9. References

Ref 1: Earth Tech (2005) for Goulburn Broken Catchment Management Authority, *Mokoan Inlet Channel Closure – Impacts on Broken River and Holland Creek hydraulics*

Ref 2: Thiess (2002), Stage-Discharge Rating Curve at Benalla Gauge (No. 21.02)

Ref 3: Sinclair Knight Merz (2002) for City of Greater Shepparton, *Shepparton Mooroopna Floodplain Management Study*

Ref 4: Cardno Willing (2008) for Rural City of Benalla, *Flood Mapping (Post Flood Management Works)*

Ref 5: GHD (2005) for Goulburn-Murray Water, *Works Decommissioning Concept Study – Report on Hydrology and Downstream Hydraulics*

Ref 6: GHD (Draft 2008) for Goulburn-Murray Water, *Lake Mokoan Hydrology – Response to Community Concerns*

Ref 7: Cardno Lawson Treloar (2008) for Rural City of Benalla, *Lake Nillahcootie Flood Study*

Ref 8: The Parliamentary Public Works Committee (1963), *Progress Report No. 3 - Water Resources of Victoria Inquiry Subject:-The Broken River Basin*

Ref 9: Cardno Willing (2002) for Delatite Shire Council City of Benalla, *Benalla Floodplain Management Study*

Ref 10: Willing & Partners (1995) for City of Benalla, Benalla Flood Study

Ref 11: Thiess Environmental Services (1999) for Department of Natural resources and Environment, *Flood Warning Station Information Manual – Goulburn Broken CMA Drainage Division 4 River Basins 3-6 & 9*

For More Information:

- www.lakemokoan.com
- Fact Sheet No. 4 Broken System – Lake Mokoan – Management and Operation
- Fact Sheet No. 8 Mokoan – Return to Wetlands – Wetland Ecology and Management
- Responses to Benalla District Flood Awareness Group, 36 Questions plus Fact Sheet around
- GHD (Working Progress 2008) for Goulburn-Murray Water, *Lake Mokoan Inlet Channel Investigation*