9. Hydrology

This chapter addresses the Director-General's requirements relating to hydrology which state that Environmental Assessment must:

- Assess how the proposed works would affect the natural physical, chemical and biological processes of the Koondrook-Perricoota Forest Wetland;
- Include a comparison between the hydrograph of natural floods that reach RL 78.5 on the floodplain and the hydrograph of the inundation to be generated by the proposed works in terms of frequency and duration, so as to provide a clear description of the flooding regimes that would be introduced by the project; and
- Assess impact of changed flooding regime on surrounding land use.

This chapter summarises the main findings of the hydrology report provided in Appendix D.

9.1 Existing environment

9.1.1 Murray-Darling Basin

The Murray-Darling Basin comprises the catchment of the Murray and Darling Rivers and their many tributaries, extending from north of Roma in Queensland to Goolwa in South Australia. The Murray-Darling Basin covers more than 1 million km^2 of mainland Australia, including parts of Queensland, New South Wales, South Australia, Victoria and all of the Australian Capital Territory. The Murray-Darling Basin is bounded by the Great Dividing Range in the south and east. The Darling River (and its tributaries) drains southern Queensland and northern New South Wales, crosses the Darling Plain and joins the Murray River upstream of Wentworth.

The MDBA manages the Murray River system in close cooperation with state authorities to ensure reliable water supplies for all users. To regulate the River system, the MDBA has responsibility for the operation of a number of major structures, including Dartmouth and Hume reservoirs, Lake Victoria, Lake Mulwala, and Menindee Lakes, 13 locks and weirs, and five barrages.

9.1.2 Murray River system

The Murray River rises in the Australian Alps, between Mt. Pilot and Forest Hill on the New South Wales/Victorian border and flows 2,530 km to enter the Southern Ocean through Lake Alexandrina in South Australia. The southern bank of the Murray River forms the border between New South Wales and Victoria for 1,880 km of its length. Near its headwaters, the Murray River is augmented by waters diverted by the Snowy Mountains Scheme and is joined on the Victorian side by the Mitta Mitta River above the Hume Reservoir.

While the Snowy Scheme was designed to produce electrical energy, one of the objectives of the scheme was to mitigate the effects of drought on irrigated agriculture in NSW and Victoria. The Snowy Scheme collects and stores water, diverting it through trans-mountain tunnels and power stations and then releasing it west of the Snowy Mountains into the catchments of the

Murray River (the southern Snowy-Murray Development) and the Murrumbidgee River (Snowy-Tumut Development), where it can be used for water supply, irrigation and environmental uses.

The Hume storage is the primary regulating storage operated by MDBA and is typically drawn down in the summer and autumn of every year (MDBC, 1998). Dartmouth Dam, located on the Mitta Mitta River, is the largest regulating storage in the Murray River system with a capacity of approximately 3,900 GL. The Dartmouth Dam storage is primarily used as a reserve storage to supplement the Hume storage in dry years or sequences of years (MDBC, 1998).

Between Lake Hume and Yarrawonga, the major tributaries joining the Murray River are the Kiewa River near Albury and the Ovens River upstream of Yarrawonga Weir, which are both unregulated streams.

Yarrawonga Weir is the point of greatest diversion of water from the Murray River. The two main irrigation channels are the Mulwala Canal and Yarrawonga Main Channel. The Mulwala Canal, on the New South Wales side, has a discharge capacity of about 10,000 ML/day. The Yarrawonga Main Channel, on the Victorian side, has a discharge capacity of 3,200 ML/day. These two channels serve a total area of over 8,000 km^2 in New South Wales and Victoria (MDBA, 2009a).

The next major tributary joining the Murray River downstream of Yarrawonga Weir is the Goulburn River, upstream of Echuca. In the low lying areas of the Barmah-Millewa Forest to the east of Echuca, the river has developed a number of anabranches and distributaries, with those in the south returning to the river in a comparatively short distance, while those to the north flowing into the Edward River system and returning to the main system via the Edward and Wakool Rivers. Under high flows, between a quarter and a fifth of flows would flow north at the Barmah-Millewa Forest into the Edward–Wakool system, with the remainder flowing south along the Murray River (personal communication, D Green, MDBA, November 2009).

The Barmah Choke in the Murray River upstream of the Goulburn River confluence limits how much water can pass via the Murray River channel and is a major operational constraint for water deliveries during peak supply periods.

The next major reach of River is between Echuca and Swan Hill. In this reach, the Murray River is joined by the Campaspe River below Echuca and further downstream by the Loddon River at Benjeroop and Avoca River at Swan Hill. The Koondrook-Perricoota Forest is located within the reach of the Murray River between the Campaspe and Loddon River confluences.

Torrumbarry Weir is located approximately 74 km downstream of Echuca and 133 km upstream of Swan Hill. The purpose of Torrumbarry Weir is to allow the diversion of flows for irrigation, particularly into the Cohuna, Kerang and Swan Hill areas of Victoria. The National Channel, which diverts into Victoria, carries water from the Torrumbarry Weir pool to farms in the adjacent areas (MDBA, 2009c).

Two major streams enter the Murray River between Swan Hill and Mildura, these being the return of the Wakool-Edward River anabranch and entry of the Murrumbidgee River. The Murrumbidgee River catchment is a major sub-catchment of the Murray-Darling Basin and covers an area of 73,400 km^2. The Murrumbidgee catchment is bounded on the east by the Great Dividing Range, and lies between the Lachlan Catchment to the north and the Murray Catchment to the south. The Murrumbidgee River flows for 1,600 km and includes 14 major dams and 8 large weirs. The Snowy Mountains Hydro Electric Scheme assists with regulating water flow and supplying the 10,000 km of irrigation channels (CRC, 2009).

Euston Weir is located downstream of Swan Hill near the townships of Euston (NSW) and Robinvale (Victoria). The Weir can maintain adequately high water levels in the river for navigation and operation of the weir pool can be varied to regulate flows between Hume Dam and the South Australian Border.

The last significant reach of the river extends from Mildura to Goolwa in South Australia. There are eleven weirs/locks located in this reach of the River. The purpose of these weirs (and the associated locks) is to provide permanent navigation between the Murray Mouth and Mildura and provide a relatively constant pool level to facilitate pumping for irrigation and water supply. At Weir 9, water levels are raised to allow gravity diversion to Lake Victoria which is operated as part of South Australia's water supply and plays a key role in managing the flows in the entire Murray River. During periods of peak demand, water can be released from the Lake to continue to supply flows to South Australia. Without Lake Victoria, it would be necessary to restrict demands upstream to ensure South Australia receives its entitlement.

The Darling River, which includes the Menindee Lakes system, is the last major tributary of the Murray River system. The Menindee Lakes storages consist of four large natural lakes (Wetherell, Pamamaroo, Menindee and Cawndilla) and several smaller interconnecting lakes. The purpose of the storages was to secure water for the townships of Broken Hill, Menindee and Pooncarie, provide water for irrigation and farm supplies in the Lower Darling River downstream to Wentworth, meet stock and domestic requirements along the Great Darling Anabranch as well as supplementing resources of the Murray River system, including the supply of water to South Australia (State Water, 2009). The Menindee storage holds approximately 2,000 GL.

The Lower Lakes, Coorong and Murray Mouth extend over approximately 140,000 ha, covering 23 different wetlands types, from very fresh to saltier than the sea. The Coorong is 140 km long and ranked among the top six waterbird sites in Australia, based on the diversity and number of species found there.

9.1.3 Murray River hydrology

The Gunbower-Koondrook-Perricoota Forest is flooded by waters that leave and return to reaches of the Murray River generally between Womboota/Torrumbarry and Barham/Koondrook.

Upstream of Torrumbarry, floodwaters are mostly contained within the banks of the Murray River. Smaller floods first leave the river channel over the right bank just downstream of Torrumbarry Weir at a location known as Swan Lagoon and over the left bank at nearby locations. The frequency of overflows and the volume of water leaving the river in this reach are related closely to the combined flow of the Murray, Goulburn and Campaspe Rivers downstream of the confluence of these rivers.

Figure 9-1 illustrates the major systems that operate during large floods such as the 1975 flood (1 in 15 to 1 in 20 year events) including those upstream of the Forest. This indicates that there are two mechanisms for flooding of the Forest, these being a flooding pathway upstream of the Torrumbarry Weir and a flooding pathway downstream of Torrumbarry Weir. The proportion of flood waters that leave and re-enter the river is likely to vary in a complex way depending on the peak flow rate, duration and volume of Murray River floods.

Figure 9-1 Relationship between the tributaries of the Murray River during the 1975 flood (Source: MDBC, 2002).

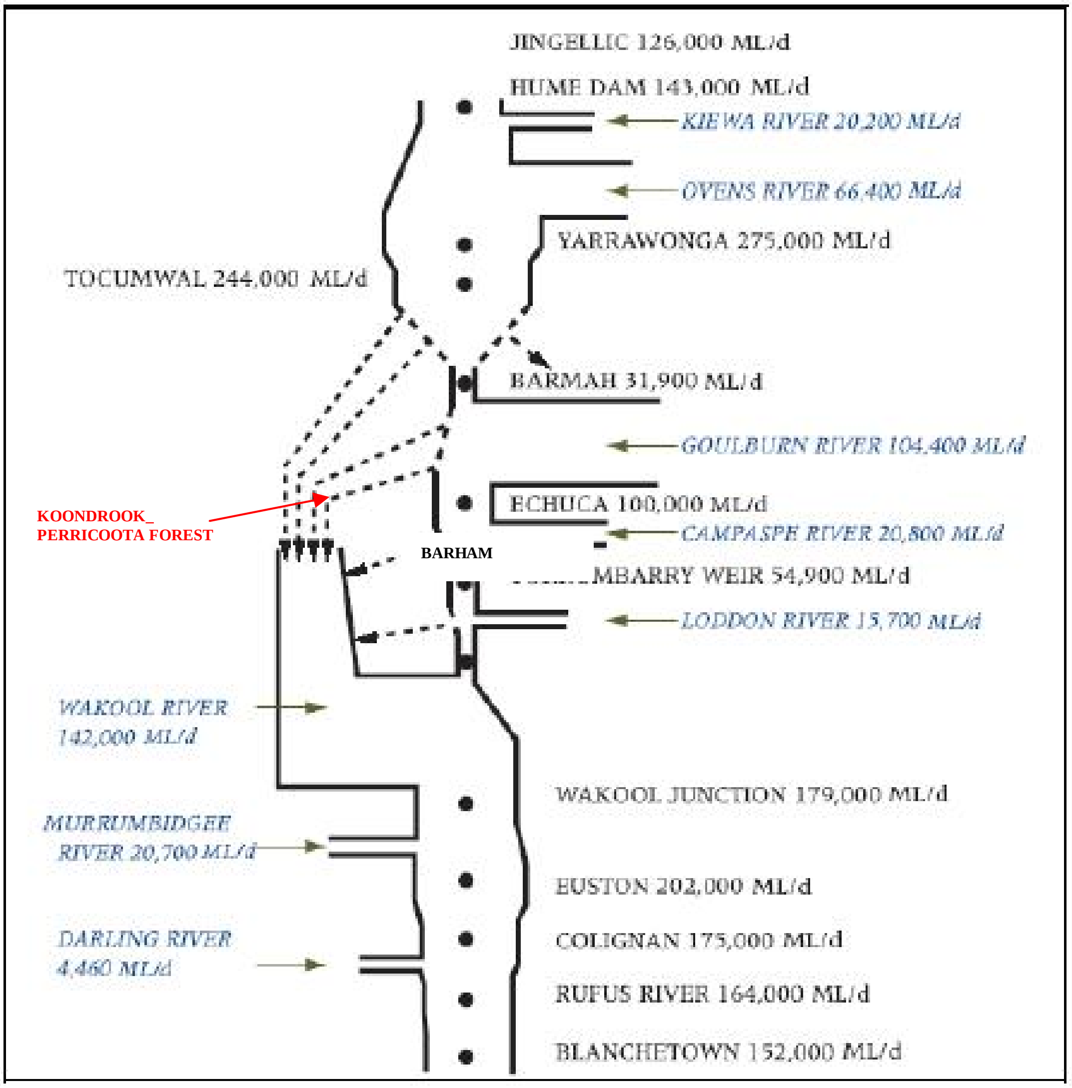


Table 9-1 details the peak flood flows of historic floods at Echuca, Torrumbarry and Barham. It is evident from these peak flows that during moderate flood flows, a large proportion of the inflow into the Forest is derived from spilling downstream of Torrumbarry Weir.

Table 9-1 Historic flood peaks in Murray River at Echuca, Torrumbarry and Barham

Year	River Murray at Echuca, u/s of Campaspe River Confluence[1]	River Murray at Torrumbarry[2]	River Murray at Barham[2]
1956	125 000	66 000	34 820
1974	91 500	59 300	32 200
1975	99 000	60 000	34 220
1981	109 500	57 500	33 700
1991			27 500
1993	121 000	60 000	33 100

Notes 1. Derived from modelled flow data from MSM-BIDMOD. 2 Based on gauged flow data.

Table 9-2 details the flows for various recurrence intervals at the Echuca, Torrumbarry and Barham flow gauging sites.

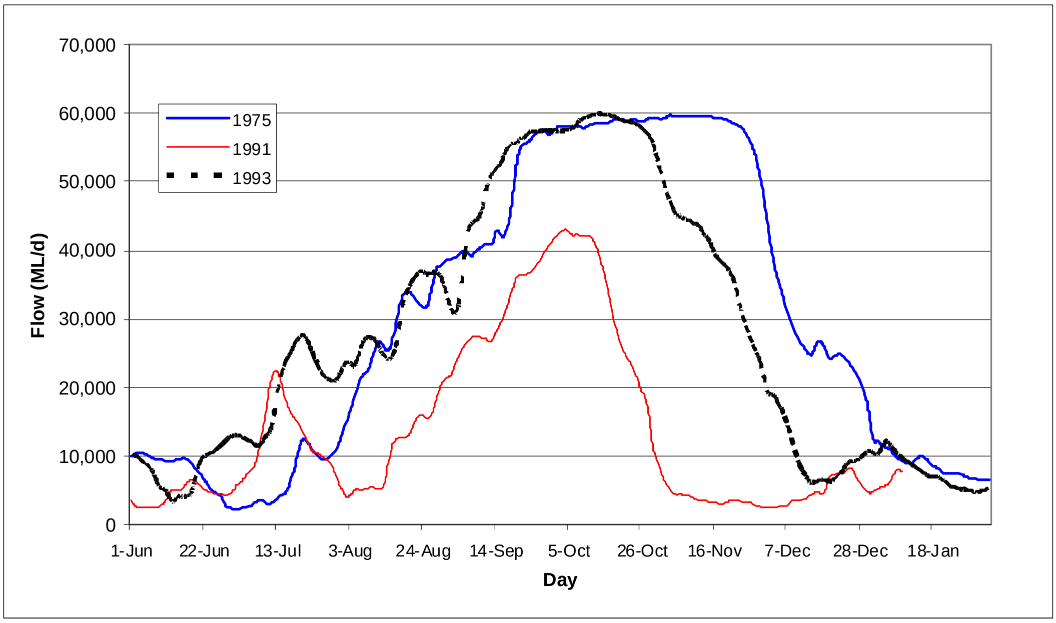
Table 9-2 Average recurrence interval of flood flows in Murray River at Echuca, Torrumbarry and Barham

Annual Exceedence Probability	Average Recurrence Interval	River Murray at Echuca, u/s of Campaspe River Confluence[1]	River Murray at Torrumbarry[2]	River Murray at Barham[2]
AEP %	ARI	Flow (ML/day)	Flow (ML/day)	
50	1 in 2 years	33,000	45,000	25,000
20	1 in 5 years	58,000	55,000	32,000
10	1 in 10 years	79,000	60,000	35,000
5	1 in 20 years	102,000	61,000	37,000
2	1 in 50 years	135,000	63,000	38,000
1	1 in 100 years	163,000	65,000	39,000

Notes 1. Based on modelled flow data from MSM-BIDMOD. 2 Based on gauged flow data.

Flooding extents of the Forest are significantly impacted by flood volume. Figure 9-2 illustrates the flood hydrographs of three events on the Murray River that inundated the Forest.

Figure 9-2 Recorded flood hydrographs – Murray River at Torrumbarry Weir



In 1975, the flood hydrograph was characterised by the duration of the peak, which resulted in flows being sustained above 50,000 ML/day for a period of almost three months. For this event, flooding of the Forest occurred via inflow points both upstream and downstream of Torrumbarry Weir for extended periods.

In 1991, the peak flow at Torrumbarry was about 43,000 ML/day; therefore no flooding occurred via the inflow point upstream of the Weir. The flow at Torrumbarry exceeded 18,000 ML/day which is the threshold for inflows via Swan Lagoon for a period of about two months.

As detailed in Section 6.4, the project would broadly be between the 1991 and 1993 flood events.

9.1.4 Changes in Murray River hydrology

There are a number of gauging stations along the Murray River in the general vicinity of the Koondrook-Perricoota Forest. These include the Murray River at Echuca (upstream of the Campaspe River confluence), Torrumbarry Weir (located at the south-eastern end of the Forest) and a flow gauge at Barham (located near the downstream end of the Forest). Modelled streamflow sequences for these locations were obtained from the MDBA which were extracted from the MSM-BIGMOD model and form the basis for this assessment.

The changes in the Murray River flow regime near Torrumbarry have significantly reduced water availability and hence the frequency, duration and magnitude of flooding of flood dependent communities including those within the Forest.

Table 9-3 to Table 9-5 illustrate the significant reduction in the frequency of flood events exceeding a range of threshold flows leading into the Forest. For a flow of 20,000 ML/day, the frequency has reduced from 87% for modelled natural flows to 44% for modelled current day flows, a reduction of approximately 49%. A 61% reduction in flood frequency is estimated to occur under the 2030 median climate change scenario.

Table 9-3 Frequency of floods under different flow scenarios at Torrumbarry Weir

River Flow (ML/day)	Flood count (% of years flow peaks above daily flow rate)		
	Natural	Current	Median climate change
18 000	95	66	61
20 000	90	51	45
25 000	87	44	34
30 000	76	35	28
35 000	65	28	18
40 000	55	23	12
50 000	45	16	9
57 000	23	5	3

Note flows at this location are affected by upstream effluents over the right and left banks of the Murray River

Table 9-4 Maximum period (years) between Murray River flows exceeding threshold flows d/s Torrumbarry Weir

River Flow (ML/day)	Years between floods above daily flow rate		
	Natural	Current	Median climate change
18 000	4	4	6
20 000	4	4	9
25 000	4	9	9
30 000	4	9	10
35 000	4	10	10
40 000	4	10	13
50 000	4	13	13
57 000	13	38	38

Table 9-5 Average annual duration (days) of Murray River flows exceeding threshold flows d/s Torrumbarry Weir

River Flow (ML/day)	Average annual duration (days) flows exceeding daily flow rate		
	Natural	Current	Median climate change
18 000	70	27	24
20 000	63	28	19
25 000	47	21	14
30 000	38	17	10
35 000	29	11	7
40 000	23	8	6
50 000	14	5	3
57 000	4	1	0

From the information provided in Table 9-3 to Table 9-5, it is evident that under current conditions, there has been a significant change in the frequency and duration of flooding compared to natural conditions, and that further negative impacts can be expected under forecast climate change scenarios.

9.1.5 Torrumbarry Weir

Torrumbarry Weir is located at the south-eastern most end of the Koondrook-Perricoota Forest and is a key structure in the design of the project. Torrumbarry Weir has significant potential to assist in Forest inundation due to its ability to raise River operating levels and its location at the highest point of the Forest.

9.1.6 Koondrook-Perricoota Forest hydrology

Figure 9-3 shows the main hydrologic features of the Forest. The flow of floodwater through Koondrook-Perricoota Forest is dominated by the Burrumbury-Barbers Creek system, sourced naturally from the Swan Lagoon on the Murray River just downstream of the Torrumbarry Weir. For the first 15 km, the Forest system comprises well defined channels, which then break down into a myriad of smaller, interlinked runners. These runners cover an area of about 4,500 ha, before eventually joining together into several defined streams, the largest of which is the Myloc Creek. Myloc Creek, together with subsidiary runners, become the Barbers Creek.

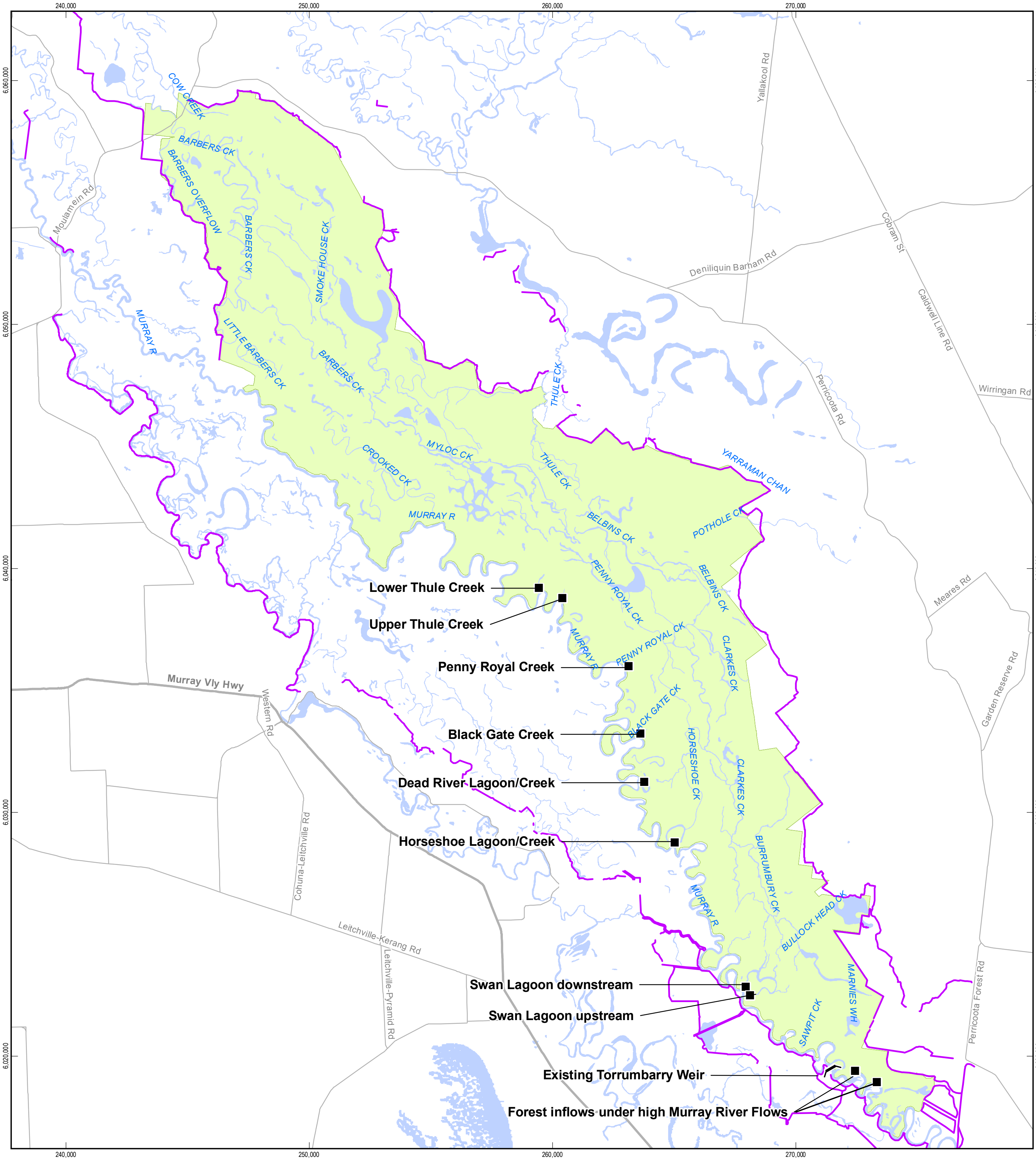
There are eight inlet locations were water can enter the Forest from the Murray River between Torrumbarry Weir and Barham and there are five inlet locations on the left bank of the Murray River that allow floodwater to enter the Gunbower Forest.

During high Murray River flows (in excess of 50,000 ML/day upstream of Torrumbarry Weir) inflow into the Forest also occurs from the south-east boundary of the Forest, upstream of Torrumbarry Weir (Tuteja et al, 2008).

The primary flow points from the Murray River downstream of Torrumbarry Weir are located at Swan Lagoon. Swan Lagoon starts to flow when the flow in the Murray River is about 18,000 ML/day whilst the Borrumbury Creek system starts to flow when the flow in the Murray River is about 20,000 ML/day.

Analysis of historic flow records shows that for flows up to 46% of the peak flow at Torrumbarry Weir (about 60,000 ML/day) spills into the combined Gunbower-Koondrook-Perricoota Forest. Hydraulic Modelling (DECC, 2008) showed that for flows up to 40,000 ML/day, the flow split between the Gunbower and Koondrook-Perricoota Forests was approximately 50:50.

Flood extents for the 1991 and 1993 flood events are provided in Figure 9-4 and Figure 9-5. The peak flows at Torrumbarry Weir for these events were 43,000 ML/day and 60,000 ML/day, respectively. It is clear from the 1991 flood extent that there was no inflow to the Forest from the Murray River in the Forest upstream of Burrumbury Creek (i.e. inflows from the Murray River upstream of Torrumbarry Weir). However, the 1993 flood extent shows significant inundation in the Forest upstream of the Torrumbarry Weir.



Legend

- Regulator
- Inflow locations
- Existing levees
- Waterway
- Koondrook Perricoota Forest Site

1:150,000 (at A3)

0 1 2 4

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

N

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NSW Office of Water

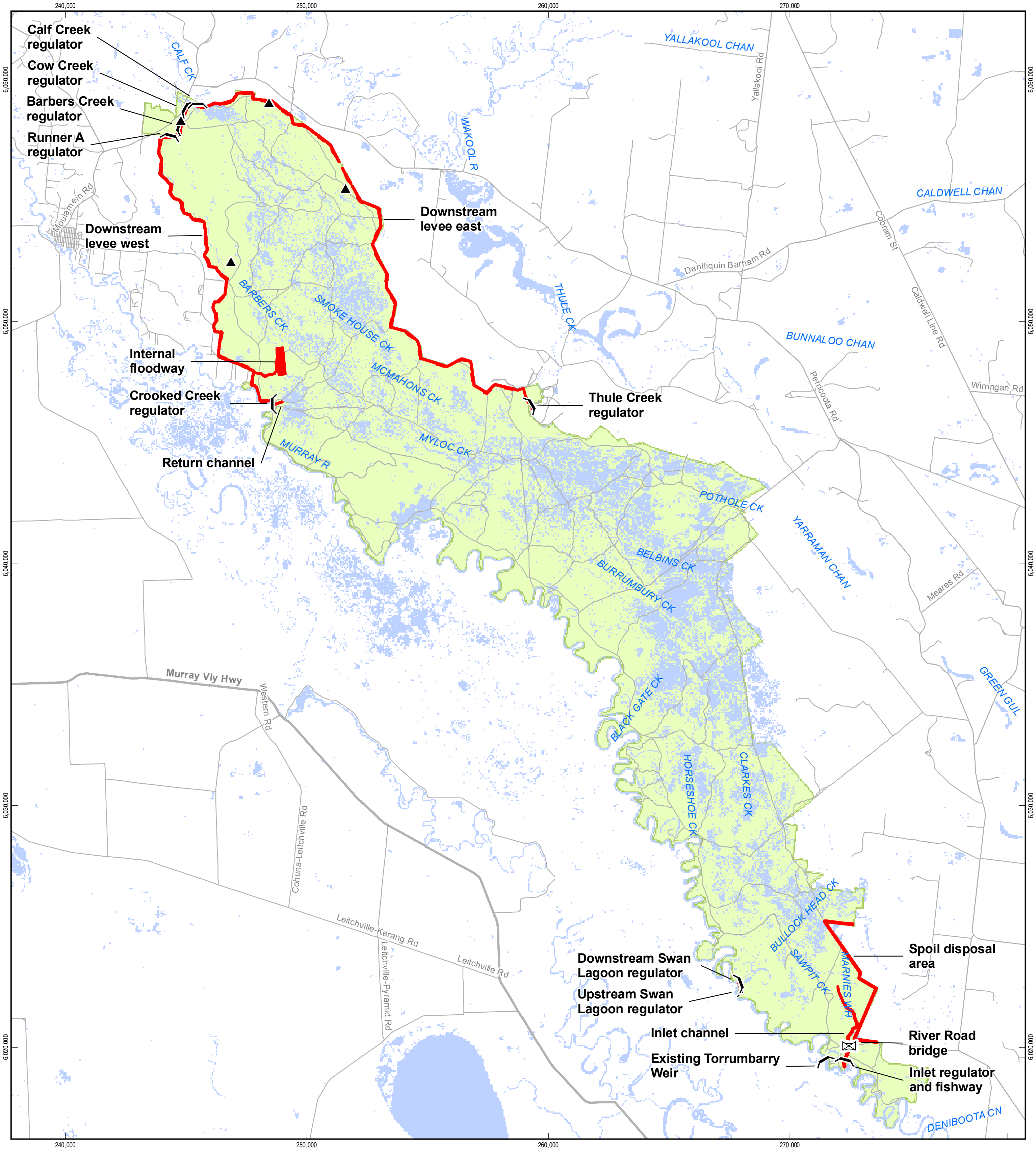
Koondrook-Perricoota Flood Enhancement Works

Job Number	21-18573
Revision	A
Date	10 DEC 2009

Figure 9.3 Main hydrology features in the forest

Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Dept of Commerce, Street Map- Navtec, Drawn: Cwilson



Legend

- 1991 flood extent
- Turkey's nest dam
- River Road bridge
- Regulator
- Construction features
- Roads
- Koondrook Perricoota Forest Site

0 1 2 4
Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

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Koondrook-Perricoota Flood Enhancement Works

Job Number	21-18573
Revision	A
Date	10 FEB 2010

Figure 9.4 1991 flood extent

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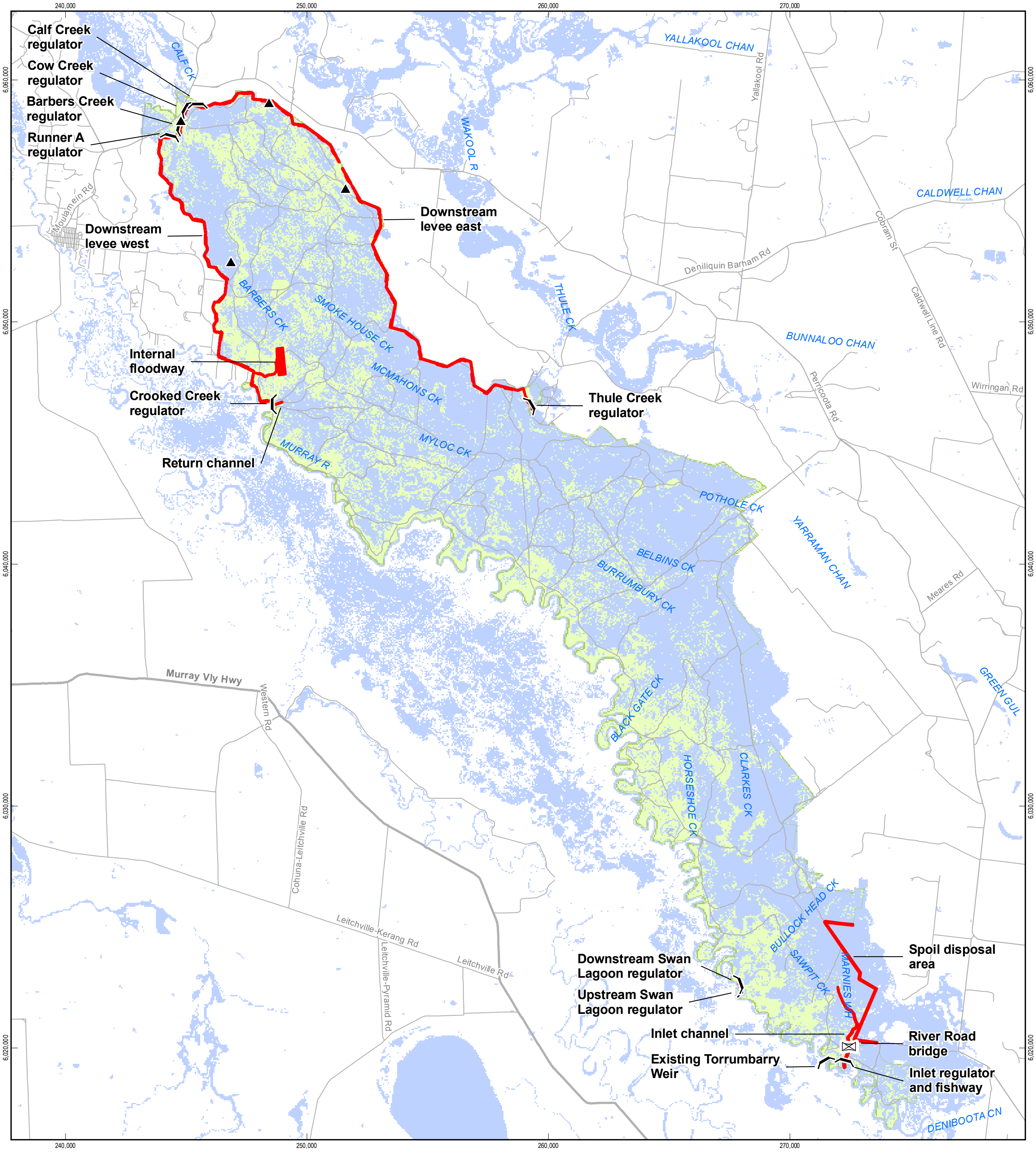
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Dept of Commerce, Street Map- Navtec, Drawn: Cwilson, cwilson



Legend

- 1993 flood extent
- Turkey's nest dam
- River Road bridge
- Regulator
- Construction features
- Roads
- Koondrook Perricoota Forest Site

0 1 2 4
Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

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Koondrook-Perricoota Flood Enhancement Works

Figure 9.5 1993 flood extent

Job Number	21-18573
Revision	A
Date	10 FEB 2010

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Dept of Commerce, Street Map- Navtec, Drawn: Cwilson, cwilson

9.1.7 Existing levees around the Koondrook-Perricoota Forest

The existing levee systems of relevance to this project can be described in three geographic areas as:

- Upstream of Torrumbarry Weir and the Forest;
- From the middle to upper Forest north side; and
- Downstream end of the Forest.

Upstream of Torrumbarry Weir

The upstream levees appear to be located on private land and are therefore private banks. These banks are located in a floodplain zone that provide a pathway for floodwaters into the upper reaches of the Forest in moderate to large floods, for example the 1993 flood.

The imagery of the 1993 flood does not indicate any influence of these banks and it might be concluded that they are minor or have been built since 1993. Anecdotal evidence suggests that these banks were constructed post 1993.

Although a quantitative study of the effect of these banks on flooding has not been conducted, these banks have the potential to reduce the flow rate and volume of floodwaters entering the forest in moderate to large floods (1 in 10 years and larger).

Middle to upper Forest - North Side

The known levees in this location are shown on Figure 9-3. They are mostly on private land and are therefore private works and their purpose is to prevent the escape of flood waters from the forest onto private farmlands. These banks have heights varying from 0.2 to 0.8 m high (pers. com. NOW, Mike Erny). As the Forest boundary does not follow high ground along the entire alignment, there are locations where private lands drain into the forest. The occurrence of cross drainage works for the banks is minimised by on-farm drainage runoff collection and reuse systems.

Flood mapping indicates that moderate to large floods may outflank or breach these banks causing inundation of private farm lands adjacent to the forest. Satellite imagery indicates that the banks were effective for the 1993 flood (1 in 20 years). This imagery also shows that flows into Thule Lagoon may have been restricted by these banks when otherwise a significant flow would have been expected under natural floodplain conditions.

Downstream end of the Forest

An existing bank is located to the north of the Barham township. In conjunction with other smaller banks, this has protected the township from moderate to large historic floods such as the 1975 and 1993 floods (1 in 20 years).

9.2 Impact assessment

Potential impacts from the project related to changes to the hydrology are discussed in the following section and include:

- Impacts on the Murray River water allocation and supply security conditions in context of the Project's water requirements from the system;

- Impacts on the Murray River flows and levels downstream of the Forest due to the diversion of water into forest and return of water directly to the Murray River;
- Impacts on the Forest itself and surrounding land use due to the proposed flooding regime and the extent of inundation; and
- Impacts on the Barbers Creek system and the hydrological regime outside the forest due to the operation of the downstream regulators;

9.2.1 Murray River water allocation and supply security

Water availability

Due to the complexity of the Murray System both in terms of water accounting and system operation (water delivery), the regulated delivery of water to the Forest cannot be undertaken in isolation and needs to based on a whole of system approach. To this extent, the delivery of water to all Icon Sites has been considered concurrently by the MDBA.

System wide hydrological modelling has been undertaken by MDBA (2008) to quantify the degree to which the water demand at all Icon Sites can be met with the water available as environmental entitlements under historic climate and potential climate change conditions. This assessed the competing actions in regards to system operation and the tradeoffs that need to be considered between the Icon Sites in meeting their respective ecological and hydrological targets.

The water available for environmental purposes would be obtained from a range of different entitlements including Commonwealth water accounts, and NSW environmental water accounts. A large proportion of the water would be accessed from the 500 GL entitlements available for the environment under the Living Murray Initiative. This water would be obtained from water savings generated throughout the Murray River system as well as a range of other water recovery measures such as buy back of entitlements. The delivery of this water therefore does not represent a net increase in outflows or diversions from the system, and can largely be considered a substitution of demands.

MDBA (2008) modelling shows that water requirements of all Icon Sites can be fully met by the 500 GL of recovered water, with the exception of the Lower Murray Lakes. A practical water rostering method has been developed by the MDBA and demonstrates that system operation can be structured to negate impacts on other system users in terms of reliability of supply and maximise water availability at each of the Icon Sites.

The modelling has shown that there is a need for some refinement of the allocation protocol developed to maximise the efficiency of the managed events delivered to the Forest. A Preliminary Operating Plan (NSW Public Works, 2009) for the Forest has been developed and would be finalised prior to commencement of operation.

Water accounting

A key objective of the National Water Initiative is to ensure that adequate measurement, monitoring and reporting systems are in place to support public and investor confidence in the amount of water being traded, extracted for consumptive use, and recovered and managed for environmental and other public benefit outcomes (National Water Initiative, 2009). A national water accounting system is currently being established and includes the development of national standards for environmental water accounting as well as standards for water accounting information systems.

The location of structures which form part of the project enables accurate measurement of regulated flows which enter and exit the Forest for water accounting purposes. It also allows for the progressive monitoring of flow regimes and volumes and the ecological responses to flood events. The project would accurately account for water diversions and therefore comply with the proposed National Metering Standards.

9.2.2 Impacts on Murray River flow regimes

Impacts from diversions

The project has been designed to minimise impacts on flow conditions in the Murray River downstream of the Forest boundary and to minimise impacts during large flood events.

During managed flow events, water would be diverted from the Murray River via the inlet channel and regulator, up to a design flow of 6,000 ML/day. Water would be ponded in the lower Forest area to a design level of 78.5 mAHD for a duration of about 100 days.

Water would be released to Barbers Creek via the lower regulator structures which discharge into the Wakool River. This water is eventually returned to the Murray River at its junction with the Wakool River some 360 km downstream of the Forest. Under managed flow events, up to 10% of the water diverted from the Murray would be returned (via the Wakool River), after allowing for transmission losses.

To improve system efficiency and provide greater flexibility to control the inundation level and duration without having to pass large flows into Barbers Creek, water would also be returned directly to the Murray River via the Return Channel from Crooked Creek. The return channel and regulator structures have been designed to discharge up to 1,850 ML/day. Approximately 38% of the volume diverted from the Murray River would be returned at this location (upstream of Barham).

River flow and level fluctuations

MDBA modelling has shown that during a managed event, flows in the Murray downstream of Torrumbarry Weir could be as low as 5,000 ML/day to 6,000 ML/day (pers com Mike Erny) and as high as 18,000 ML/day to 35,000 ML/day.

Rapid changes in flows in the Murray River upstream and downstream of Torrumbarry Weir, following the commencement and completion of diversions into the Forest via the inlet channel, has the potential to impact on river bank stability. The design inflow hydrograph of the managed event allows for the gradual ramping up and ramping down of diversions to account for a range of operational issues such as supply rate availability, the targeted ecological response in the Forest and to accommodate the migration of fish into and out of the Forest.

The Torrumbarry Weir pool provides substantial operational flexibility to regulate water deliveries and enable rates of rise and fall in Murray River flows to be managed within current

MDBA river operating guidelines. It is not expected that the project would result in rapid changes to flows in the Murray River.

Impacts on the Murray River during large uncontrolled floods

During moderate to large Murray River floods, all Forest watering structures would be de-activated to enable floodwaters to enter and exit the Forest area in an uncontrolled manner, similar to the existing situation. Thus, it is intended that the project would not impact on large flood flows in the Murray River, relative to existing conditions.

9.2.3 Impact of Koondrook-Perricoota Forest flooding

Flooding frequency and extents

Flood inundation areas derived from satellite imagery together with an assessment of the River flow frequency for the 1991 and 1993 flood events are detailed in Table 9-6.

Table 9-6 Summary of flood extent and flood frequency.

Event	Approximate area of forest inundated (ha)	Torrumbarry Flow (ML/day) and approx ARI (years)	Echuca Flow (ML/day) and Approx ARI (years)
1991	7,800	43,000 (< 1 in 2)	49,000 (<1 in 5)
1993	23,600	60,000 (1 in 10)	121,000 (> 1 in 20)

During the 1993 event, floodwaters entered the Forest in locations both upstream and downstream of Torrumbarry Weir. The estimated flood extent resulting from a managed watering event in the Forest as part of the proposed operation is provided in Figure 9-7 and illustrates that the overall extent of inundation would be between the 1991 event and the 1993 flood event. Flood extents for the 1991 and 1993 events are included in Figure 9-4 and Figure 9-5.

The hydrographs for the 1991 and 1993 floods are provided in Figure 9-2. Figure 9-6 compares the hydrograph of the inflows to the Forest during the 1991 event to the managed watering event. Compared to the 1991 flood, the managed event would have a lower peak inflow to the Forest, however the duration of inflows would be greater.

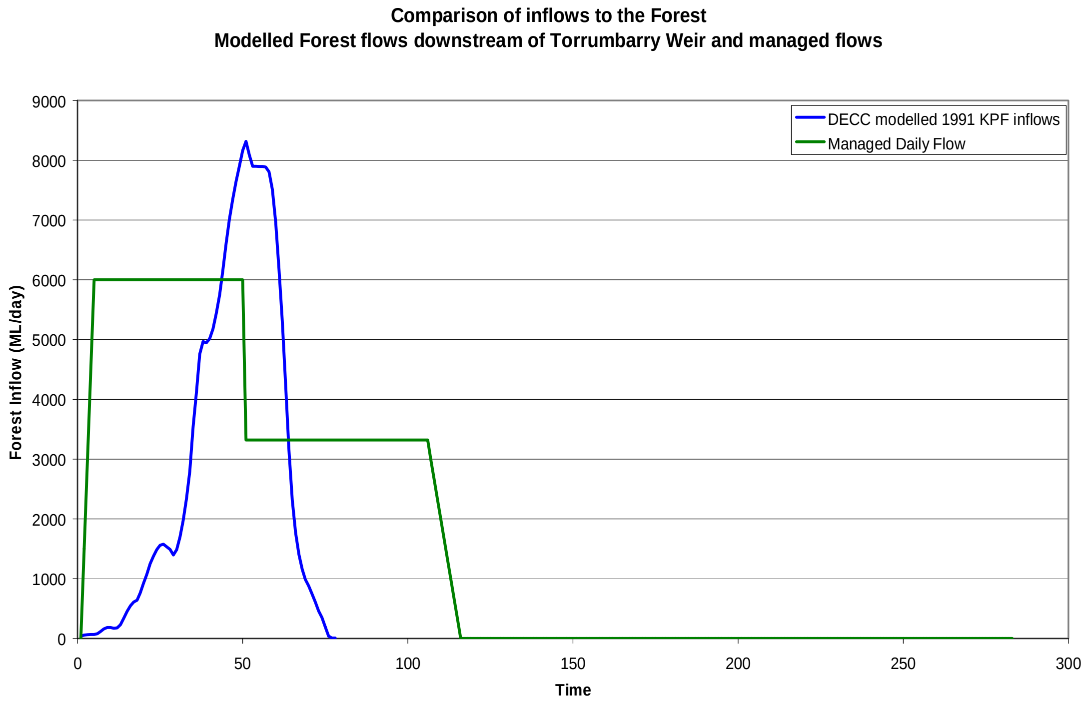


Figure 9-6 Hydrograph of the proposed operational scenario

It is inferred that the managed flow event would result in an inundation extent which is similar to a natural flood with a return interval more frequent than about 1 in 5 years, limited only by the availability of the water. This frequency of flooding is consistent with the project objectives.

Two key criteria of the hydrologic objectives are the frequency of flooding events and the maximum interval between events. Hydrological modelling of the Murray River undertaken by MDBA (2008) has confirmed that these criteria are likely to be satisfied. MDBA modelling results are summarised in Table 9-7.

Table 9-7 MDBA (2008) hydrological modelling results

Flood event	Average flooding frequency (% of years)	Maximum interval between events (years)
Target frequency for large flood events in the Forest with an inundation extent generally equivalent to the event described in Section 6.4.4	33.0	4
Natural benchmark - Frequency for a natural flood event generally equivalent to the event described in Section 6.4.4. This is based on natural conditions, i.e. no river operations, diversions and only natural levels of storage in the system	45.3	7.4
Current benchmark - Frequency of a flood event under the current river operations that is generally equivalent to the event described in Section 6.4.4. This is based on current river operations, diversions and storage capacities and historical flow conditions	15.4	21.9

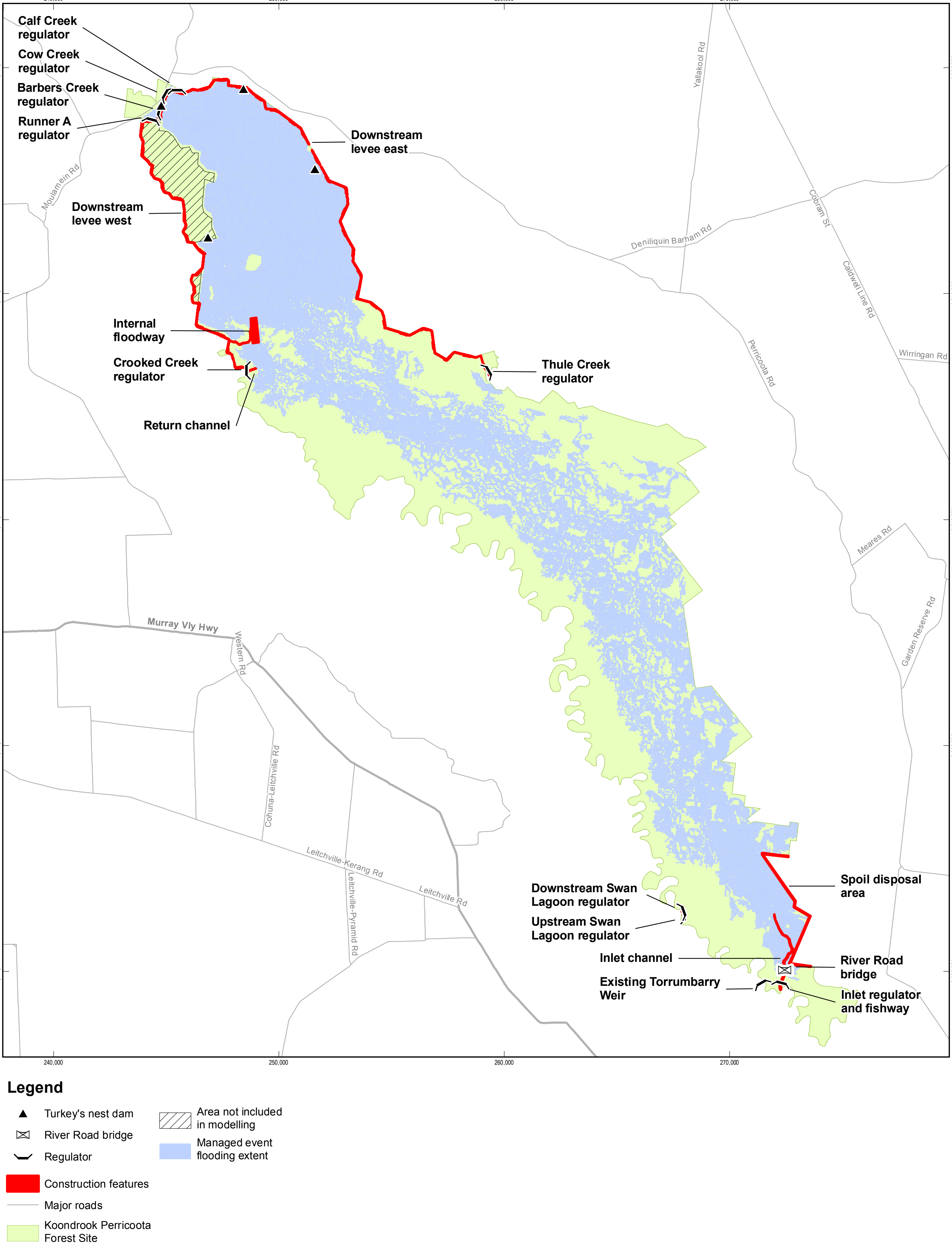
Flood event	Average flooding frequency (% of years)	Maximum interval between events (years)
Without works - Frequency of a flood event under the current river operations that is generally equivalent to the event described in Section 6.4.4. This is based on there being access to water recovered under The Living Murray Initiative however it does not account for operation of the project.	18.8	20.8
With works - Frequency of a flood event under the current river operations that is generally equivalent to the event described in Section 6.4.4. This is based on there being access to water recovered under The Living Murray Initiative and includes operation of the project.	29.1	11.8

The modelling results confirm that the ‘with works’ scenario (29.1 % of years) is approximately equal to the target frequency of inundation (33 % of years) when taking in consideration all other key Murray system operational requirements. As discussed in Chapter 5 and Section 6.4, this frequency of flooding would meet the project objectives of improving the long term ecological health of the Forest.

Whilst the maximum interval between flood events of the maximum design event exceeds the target interval for the Forest, it is expected that further optimisation of water delivery via The Living Murray water account using more sophisticated rostering methods and alternative watering hydrographs (or partial watering events), would enable watering events to be delivered that satisfy the maximum interval criterion.

The downstream levees would be operated to raise pool levels to inundate upstream sections of the Forest. These levees would change the distribution of floodwaters that exceed the level of service of the existing Barham levee system in the lower forest area compared to current conditions. Hydraulic modelling has demonstrated that the re-distribution would be completely contained within the Forest boundary. A major advantage of this redistribution of floodwater is the ability to return flows from managed events directly to the Murray, thereby significantly improving the water use efficiency of the project.

As detailed in Section 6.4.4, modelling for the period 1990 – 2005 was conducted to understand how the project would have operated during this period. The results indicate that the frequency and duration of flood events would have resulted in watering of some River Red Gums in 44% of years during this period, inundation of wetlands in 81% of years, and waterbird breeding events in 31% of years (refer to Table 6-11). Chapter 8 assesses the ecological impacts and concludes that the project would deliver water that would achieve the project objectives by improving the ecological condition of the Forest.



1:150,000 (at A3)

0 1 2 4

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

N

GHD

CLIENTS | PEOPLE | PERFORMANCE

NSW Office of Water

Koondrook-Perricoota Flood Enhancement Works

Job Number 21-18573
Revision B
Date 10 FEB 2010

Figure 9.7 Managed event flooding extent

G:\21\18573\GIS\Arcview\Map_Documents\21.18573.Z041_Managed_event_flooding_extent_hydroreport.mxd

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Dept of Commerce, Street Map- Navtec, Drawn: Cwilson, cwilson

Comparison of peak water levels in the 1993 flood event to the managed flood event

Assumed peak 1993 flood levels within the Forest were surveyed and then compared to levels modelled for a managed 6,000 ML/day inflow at full supply which corresponds to the maximum managed event water level. Figure 9-8 shows the longitudinal profile along the floodplain of the 1993 flood event and the modelled managed event. Chainages used in the longitudinal section correspond to the approximate centreline of the managed flood extent between the inlet channel at the upstream end, and the Barbers Creek regulator at the downstream end of the Forest. A laterally horizontal water gradient was used when comparing some flood marks.

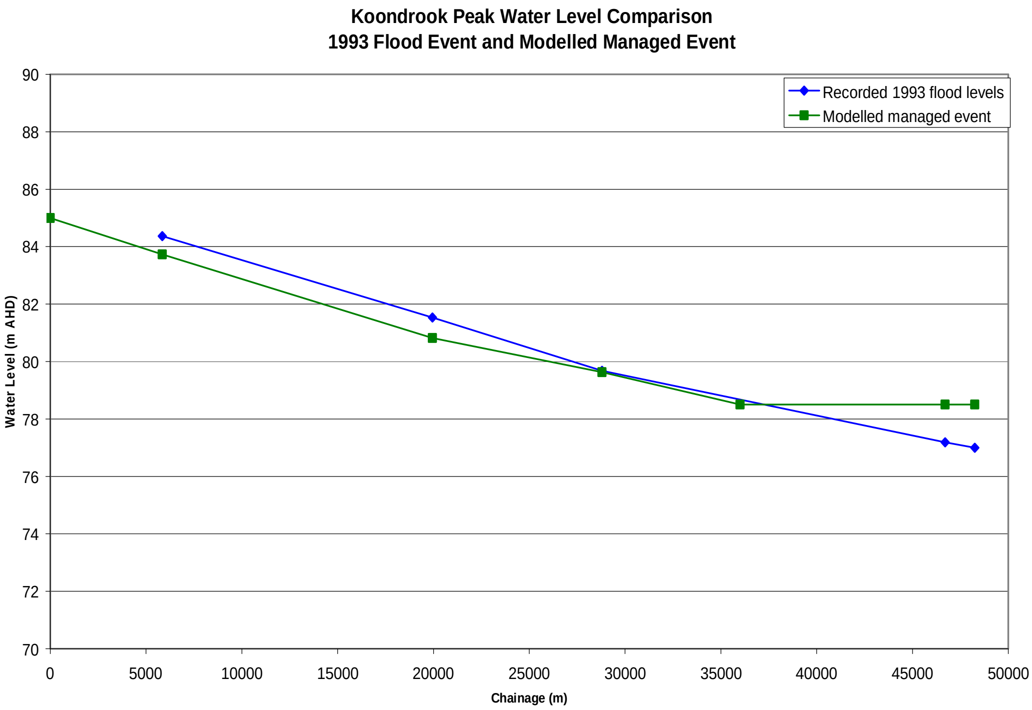


Figure 9-8 Longitudinal profile of peak water levels in the 1993 flood event and the managed flood event

The profile shows that 1993 flood levels are above managed flood event upstream until around 30 kilometres down the floodplain where levels equate. A similar water surface gradient applies to around the 35 kilometre chainage before the managed event profile flattens at the downstream pool. The typical flood gradient extends to around 48 kilometres for the 1993 event where the flood level reaches approximately RL 77 m AHD and the managed event is RL 78.5 m AHD.

Downstream impacts from large flood events

Results from recent modelling by NSW Water Solutions (2009a) shows that the downstream structures when fully open have little impact on the conveyance of large floods through to the Barbers Creek system. A flood flow equivalent to the 1993 event having an assessed ARI of 1 in 10 - 20 years was evaluated and it was demonstrated that the maximum afflux of 0.16m would occur in Runner A, resulting in an upstream water level of 77.12 mAHD. The backwater effects of the afflux extended about 4 km upstream of the regulator structures and therefore the increase in flood level as a result of the proposed structures is unlikely to result in increased discharge to the Murray River upstream of the levees.

These results demonstrate that moderate flood flows would be contained within the levees which would be constructed to a design elevation of 78.8 mAHD. It is concluded that under large floods up to the 100 year ARI, flood levels would not overtop the downstream levee.

Thule Creek

Thule Creek is one of the natural outflow creeks from the Koondrook-Perricoota Forest, located about halfway along the Forest and flowing in a northerly direction towards the Wakool River.

Under natural flooding conditions, the Thule Creek effluent becomes active during small to moderate flooding events within the Forest as evident from flood mapping of the 1991 and 1993 flood.

The Thule Creek Regulator structure is required to prevent the loss of floodwater during the initial filling phases of managed flow events. Under managed flow events, it is not proposed to release water from the Forest area via Thule Creek. Therefore there would be no changes to the downstream hydrology of the Thule Creek system compared to the current flow regime.

During large uncontrolled flood flows, the Thule Creek Regulator would be fully opened (along with the downstream regulator structures) and floodwaters would be allowed to pass through the structure and enter the Wakool River system, as occurs under current conditions. During hybrid events, a proportion of flows would also be passed through the regulator to flow down Thule Creek.

Forest debris blocks

On smaller gated regulator structures such as the Swan Lagoon regulators, blockage through the accumulation of debris imported from the River has the potential to impact on the operability of the structures and the hydraulic capacity. For structures with larger openings, up to 4m wide in some cases, the risk of blockage through debris is likely to be less of an issue.

To mitigate the impacts of debris blockage on small gated structures, debris booms are proposed to be installed reduces the risk of debris impacting on the operation of the gates and blockage of the opening of the structure. Detailed Operating Plans for the structures would describe operational activities leading up to, during and following flooding events to manage the accumulation of debris at the structures.

Comparison of flood hydrographs

DSTA completed a study on the downstream effects of the project using the hydraulic modelling software package MIKE-11 to analyse the impact of downstream structures. The model compared flood levels, distribution and velocities for the current flood plain conditions and the proposed configuration in the scheme (levee and regulators fully opened) using recorded 1993 flood flows. The peak flood level for the 1993 event was around RL 77 m AHD recorded at Moulamein Road (close to the regulator structures), well below the design levee height. There is no evidence of floods reaching the levee height of 78.8 m AHD for flood events under current conditions.

The modelling showed that the scheme had a maximum afflux of 0.16 m at the downstream Runner A regulator which reduced to zero within 4 km upstream. This indicates that there is a very small impact on flood plain inundation due to the scheme. Similarly, changes in flood flows would be small as regulator structures have negligible impact on flows downstream of Moulamein Road. DTSA concluded that during uncontrolled flood events there would not be significant changes to the natural flood regime.

9.2.4 Impacts on surrounding land use

Existing forest levees

The eastern and northern perimeter of the Forest is bounded by private property which comprises mixed land use including dryland and irrigated agriculture. An existing levee system extends from the southern most point of the Forest adjacent to the Murray River and, except for some isolated sections of high ground, along the entire perimeter to Moulamein Road. These levees have been constructed by private landowners to provide flood protection to the adjacent private property (refer to Figure 9-3).

Flood inundation extents from the 1993 flood event, as detailed in Figure 9-5, show that the existing Forest levees contained that flood within the Forest boundary and prevented uncontrolled flooding of private property.

Under a managed flow event, modelling has shown that in the upstream part of the Forest, the depth and overall extent of flooding would be less than the 1993 flood event. It is therefore expected that the project would not impact on the risk of flooding of private property adjacent to the eastern and northern boundary of the Forest.

In the downstream Forest area, existing levees are located on the western perimeter of the Forest which is adjacent to Barbers Creek and the flood runners upstream of Moulamein Road. These levees play an important role for flood protection of the township of Barham.

The project does not involve upgrading any existing levees other than the section of downstream levee that provides Barham with flood protection.

Upgrade of the downstream levee

The project involves construction of a downstream levee to raise the flood pool to achieve a desirable duration of inundation in the middle and upper sections of the Forest. Along a section of the downstream levee, this would involve upgrading a section of the existing levee that provides flood protection to Barham.

There is uncertainty regarding the construction standards applied to the existing levee. The downstream levee would be engineered and maintained to higher standards than the existing levee and this would reduce the risk of the levee being overtopped during uncontrolled flood conditions relative to the current situation. As a result, there is a reduced risk that lands immediately downstream of the levee would be inundated, including the township of Barham.

Under a managed flow event, the downstream levee and regulators would create storage with an embankment height of approximately 4 m relative to the floodplain level. The levee embankment and regulating structures would be designed with consideration of adequate freeboard requirements to mitigate damage from wave action, requirements for bank stability, the levee embankment design with specifications on material selection, compaction requirements and moisture control requirements.

These design processes would refine the design and the potential risks to areas downstream of the levee embankments would be appropriately mitigated.

9.2.5 Hydrology of the Barbers Creek system

The primary drainage system for the downstream end of the Forest comprises Barbers Creek, Runner A, Cow Creek and Calf Creek. About 2 km downstream of Moulamein Road these creeks enter a large floodplain, with only Barbers Creek remaining as a defined carrier. From there, Barbers Creek flows in a north-westerly direction to the confluence with the Wakool River. The total length of Barbers Creek from Moulamein Road to the Wakool River is approximately 58 km.

The cross section of Barbers Creek is relatively uniform over its length, with a bed width of around 20 m and steep tree lined banks. Bank heights range between 3 to 4m, with the left bank generally higher than the right bank.

There are four block bank structures and one severe blockage due to the natural accumulation of debris in Barbers Creek. These are located between 27 km and 52 km downstream of Moulamein Road.

There are a number of landholders along the Barbers Creek downstream of the Koondrook-Perricoota Forest. For several landholders, the blockbank structures are used to pond water and act as pumping pools for irrigation and stock and domestic water use. Seven landholders have irrigation water licenses with agricultural land use adjacent to the Barbers Creek comprising a mixture of permanent crops (e.g. Avocado orchards) and annual crops (eg. cereals).

NSW Water Solutions (2008) undertook an investigation into the hydraulic capacity of Barbers Creek downstream of the Forest and demonstrated that the natural in-bank capacity of Barbers Creek ranged from 1,270 ML/day to 2,300 ML/day and the capacity of the Creek is reduced by approximately 10% as a result of the existing block bank structures, including overtopping of the block banks. Assuming no overtopping of the block bank structures, the capacity at the block banks ranged between 0 - 160 ML/day for the block bank structures and 490 ML/day at the location of the debris block.

NSW Water Solutions (2008) noted that all of the block bank structures have steep downstream face slopes and no erosion protection works. Accordingly, they are considered incapable of sustaining overtopping flow with significant erosion and wash out. To avoid erosion of the existing block banks, flows would need to be maintained so that no overtopping occurs.

During managed watering events, outflows via the four downstream Creeks would be limited to total of 250 ML/day. It is also proposed that “bywashes” or small floodways would be installed on the block banks to control overbank flows and prevent damage to the banks during controlled releases. Concept designs have been developed for these structures and are included in Appendix G (NSW Water Solutions, 2009b).

During larger flood events, flood flows would be un-obstructed through the Forest and allowed to pass along the Creek system at the frequency and at flow rates that are similar to current conditions. Therefore, during large uncontrolled flood events, the project is unlikely to impact the risk of flooding along Barbers Creek compared to current conditions.

9.3 Mitigation and management measures

The project has been designed to incorporate reasonable and feasible measures to maximise beneficial impacts on hydrology and minimise adverse impacts. Potential impacts would be managed by implementing the Operating Plan outlined in Section 6.4. The purpose of the Operating Plan is to provide a framework for the operation of the structures to meet key ecological objectives within the broader context of The Living Murray Initiative and Scheme's governance. Specifically, the Operating Plan would define:

- The process to be implemented to determine the volume of water that is able to be used for environmental watering purposes;
- The governance system that would apply to operate the project within the context of the overall The Living Murray Initiative;
- Watering principles that would be used to initiate and manage a watering event. These principles would be linked to the ecological objectives for the individual event such that water is supplied at the timing, duration and frequency required to achieve the environmental objectives.