Hydraulic Modelling Analysis for the Lower Goulburn River

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1. INTRODUCTION

The Goulburn Broken Catchment Management Authority (Goulburn Broken CMA) commissioned Water Technology to undertake further analysis of results from the Goulburn River Environmental Flow Hydraulics Study (Water Technology 2010). This report outlines the methods and the results of this analysis and discusses all findings.

Six individual tasks were scoped and refined through discussions with Goulburn Broken CMA and are described below:

Task 1 – For flows of 20,000, 30,000, 40,000, 50,000 and 60,000 ML/d identify all crown land and private land inundated between Lake Eildon and the Murray River.

Task 2 – For the lower Goulburn River downstream of Shepparton map the location of all formal levees and plot longsections of levee crest, ground level and flood levels of the 20,000, 30,000, 40,000, 50,000 and 60,000 ML/d flow scenarios.

Task 3 – Identify all effluents downstream of Goulburn Weir and review how they are modelled and how the dynamic flow behaviour could be better understood.

Task 4 – Recompute all statistics for the reach downstream of Shepparton, breaking it down to areas within and outside of the levee banks.

Task 5 – Map environmental assets not inundated at 60,000 ML/d for the reach from Lake Eildon to the Murray River.

Task 6 – Identify the time required for the floodplain downstream of Goulburn Weir to reach equilibrium for 20,000, 40,000 and 60,000 ML/d flows.

The report is structured in such a way that it presents the analysis of each task independently through Sections 2 to 7, then concludes with a summary of all findings in Section 8.

1.1 Previous Study

The Goulburn River Environmental Flow Hydraulic Study (Water Technology 2010) consisted of the following tasks:

1. Data collation and review – Collate and review of the available topographic and streamflow data information.
2. Topographic data gap identification – Identify the gaps in the available topographic data, and suggest potential mediation options.
3. Asset mapping – Locate and map known public and private assets along the Goulburn River and adjacent surrounds.
4. Hydrologic analysis – Investigate relative contribution from downstream tributaries, and assess design flood hydrographs for the Goulburn River catchment.
5. Hydraulic analysis and flow behaviour – Assess flow behaviour of the Goulburn River over a range of potential environmental flows, and large flood events for floodplain management purposes (discussed in a separate report).
6. Socioeconomic assessment – Evaluate the social and economic costs of potential Goulburn River environmental flows.
7. Real time flow management – Review and scope real time flow management framework.
8. Management option assessment – Scope feasibility of management options for environmental flow releases.

The fifth task listed above consisted of the development, calibration and scenario modelling of eight separate model areas as shown in Figure 1-1. Note that model area E was split into two separate models. Each model was run for flows of 20,000, 30,000, 40,000, 50,000 and 60,000 ML/d with a basic trapezoidal inflow hydrograph. A vast array of post processing and analysis was undertaken using the model results.

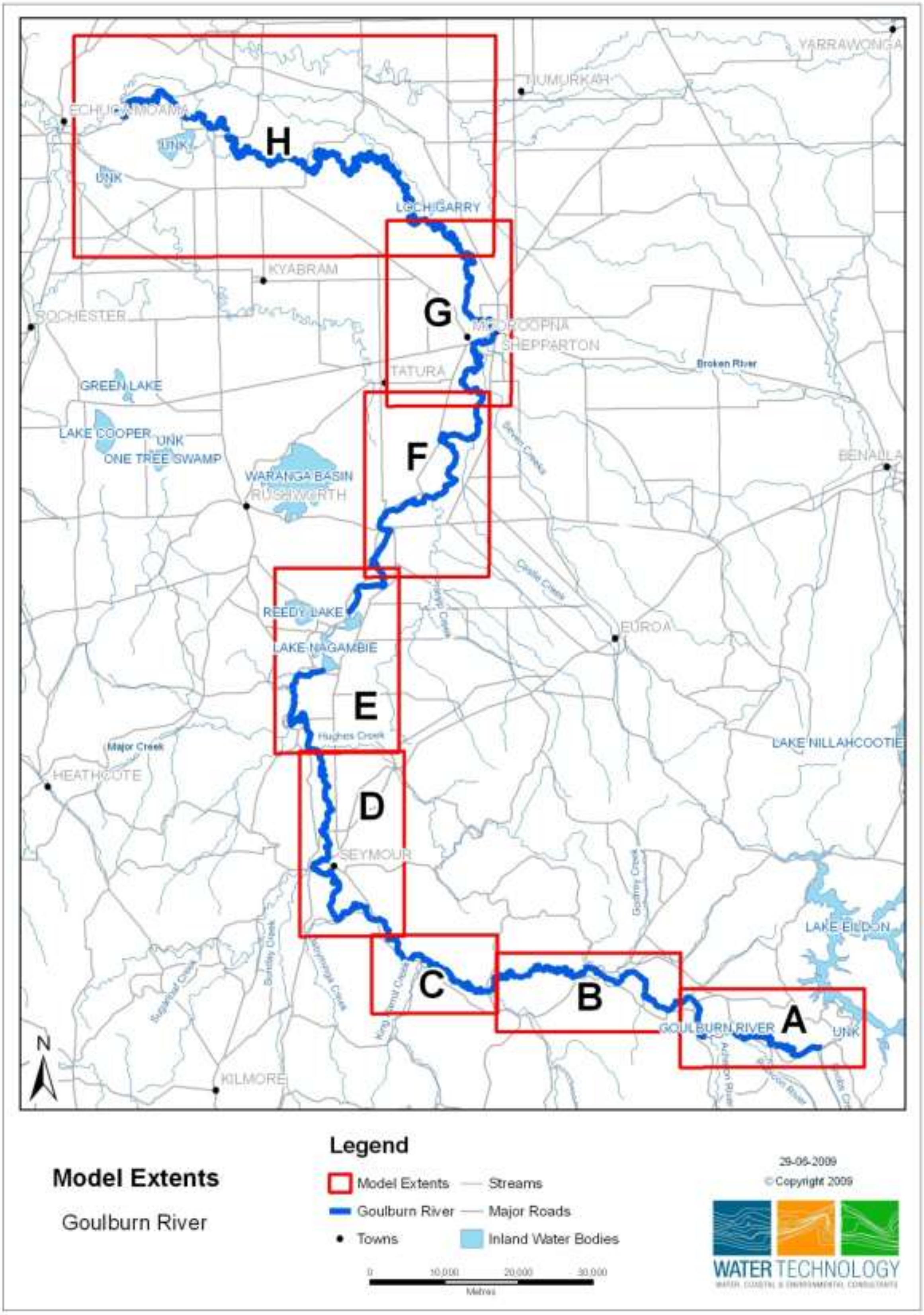

Figure 1-1 Hydraulic Model Reaches

2. TASK 1 – INUNDATED LAND TENURE

2.1 Task Description

For the 20,000, 30,000, 40,000, 50,000 and 60,000 ML/d scenarios determine the extent of private and crown land inundated for the reach between Lake Eildon and the Murray River.

2.2 Task Methodology

The 'Public_Land_Mgmt_s100' shapefile was provided by Goulburn Broken CMA. It was assumed that all objects that were not 'Freehold' in the 'MMTGENERAL' field were crown land. The inundation extents for the five flow scenarios for all model reaches were intersected with the crown land layer and the area of crown land calculated. Mapping layers of crown land and private land inundated were created and maps produced.

2.3 Task Results and Discussion

The summary tables of the crown land and private land inundated are displayed below, with maps and shapefiles provided electronically.

This shows that the larger the flow the higher the percentage of private land inundated, with a flow of 20,000 ML/d having 22% of private land inundated, increasing to 47% at 60,000 ML/d. In terms of actual area this is a large increase in private land inundated, an increase of approximately 18,221 ha, most of which coming from the lower Goulburn River floodplain in Model Reach H.

Table 2-1 Inundated Land Tenure - 20,000 ML/d *

Model Reach	Total Area Inundated (ha)	Crown Land Inundated (ha)	Private Land Inundated (ha)
A	822	394	429
B	901	467	434
C	384	277	107
D	726	501	225
E1	1542	1358	184
E2	49	49	0
F	320	309	11
G	2032	1834	198
H	2905	2363	542
TOTAL	9682	7553	2129

* The information in this table supersedes Table 3.2, pg 17 of Water Technology (March 2010) Goulburn River Environmental Flows Hydraulics Study: Hydraulic model application and affected asset assessment - Environmental flow scenarios.

Table 2-2 Inundated Land Tenure - 30,000 ML/d *

Model Reach	Total Area Inundated (ha)	Crown Land Inundated (ha)	Private Land Inundated (ha)
A	1241	549	693
B	2064	791	1274
C	847	399	448
D	1393	755	638
E1	1932	1526	406
E2	63	56	7
F	1991	1268	723
G	4473	3815	658
H	10430	7311	3119
TOTAL	24435	16470	7965

* The information in this table supersedes Table 3.2, pg 17 of Water Technology (March 2010) Goulburn River Environmental Flows Hydraulics Study: Hydraulic model application and affected asset assessment - Environmental flow scenarios.

Table 2-3 Inundated Land Tenure - 40,000 ML/d *

Model Reach	Total Area Inundated (ha)	Crown Land Inundated (ha)	Private Land Inundated (ha)
A	1761	696	1064
B	3437	1010	2428
C	1383	485	898
D	1847	880	968
E1	2194	1601	593
E2	122	67	55
F	3301	1945	1356
G	5236	4256	981
H	14519	10086	4433
TOTAL	33801	21025	12776

* The information in this table supersedes Table 3.2, pg 17 of Water Technology (March 2010) Goulburn River Environmental Flows Hydraulics Study: Hydraulic model application and affected asset assessment - Environmental flow scenarios.

Table 2-4 Inundated Land Tenure - 50,000 ML/d*

Model Reach	Total Area Inundated (ha)	Crown Land Inundated (ha)	Private Land Inundated (ha)
A	2234	812	1422
B	3466	1010	2456
C	1783	549	1234
D	2377	988	1389
E1	2350	1653	697
E2	216	98	118
F	3964	2154	1810
G	5401	4316	1085
H	17023	10854	6170
TOTAL	38815	22435	16380

* The information in this table supersedes Table 3.2, pg 17 of Water Technology (March 2010) Goulburn River Environmental Flows Hydraulics Study: Hydraulic model application and affected asset assessment - Environmental flow scenarios.

Table 2-5 Inundated Land Tenure - 60,000 ML/d*

Model Reach	Total Area Inundated (ha)	Crown Land Inundated (ha)	Private Land Inundated (ha)
A	2724	928	1796
B	3948	1042	2906
C	2047	578	1469
D	2851	1069	1782
E1	2464	1695	769
E2	322	135	187
F	4241	2195	2046
G	5624	4344	1280
H	19448	11333	8115
TOTAL	43669	23319	20350

* The information in this table supersedes Table 3.2, pg 17 of Water Technology (March 2010) Goulburn River Environmental Flows Hydraulics Study: Hydraulic model application and affected asset assessment - Environmental flow scenarios.

3. TASK 2 – LEVEE BANK INUNDATION

3.1 Task Description

For the Goulburn Weir to Murray River reach map the locations of the known major formal levees and plot a longsection of all levees showing levee crest, ground level and flood levels of the 5 modelled scenarios. Undertake statistical analysis on length of levee with water against it.

3.2 Task Methodology

3.2.1 Levee Alignment

LICS carried out an extensive survey of levee crests in 2003. This survey provided the alignment of the majority of the levees downstream of Shepparton. Through discussions with Goulburn Broken CMA it was felt that no extensive levees exist upstream of Shepparton. Additional major levees that were not surveyed by LICS in 2003 were digitised using LiDAR.

3.2.2 Levee Crest

The surveyed crest level from LICS was used for the majority of the identified levees, with LiDAR used to extract the levee crest elevation for all other levees.

3.2.3 Natural Surface

The natural surface level at the toe of the levee was estimated by offsetting the levee alignment approximately 10 m on the river side of the levee crest and using the LiDAR to extract the natural surface elevation.

3.2.4 Water Surface Elevation

The modelled water surface elevation for flows of 20,000, 30,000, 40,000, 50,000 and 60,000 ML/d were imported into ArcGIS as grids. The polyline of the levee alignment was converted into points every 100m. These points were then buffered to have a diameter of 100m. The buffered points were then used to sample the water surface elevation grids, returning the maximum water surface elevation within the circle for each water surface elevation grid. This approach was necessary, as the modelled water surface elevation grid was quite coarse due to the size of the modelled grid cell, and often the modelled water surface elevation did not extend out to the levee. The natural surface and the water surface elevations were then compared, with all points where the water surface elevation was less than the natural surface deemed not impacted by flood waters.

3.3 Task Results and Discussion

Longsections were plotted showing the water surface profiles along with levee crest and natural surface elevation, these are supplied electronically. The length of levee with water between 0-0.25, 0.25-0.5, 0.5-1.0, and >1.0 m deep was calculated, along with the length of levee overtopped. This is provided in Table 3-1 to Table 3-3, and electronically in a spreadsheet.

This analysis shows that approximately 8 km, or 4% of the total levee length is overtopped at 60,000 ML/d. This is generally at the downstream end of the floodplain around Yambuna. At 20,000 ML/d there is not much levee with water impacting on it, only around 18km. At 30,000 ML/d this dramatically increases to 116 km, and further increasing to 170 km at 60,000 ML/d. If floodplain reinstatement was desirable, then perhaps these areas of levee impacted at the lower flows would be worth investigating further, as removal would allow wider inundation at low flows.

Table 3-1 Levee Length Inundated - 20,000 & 30,000 ML/d

Levee	Total Levee Length (m)	20,000 ML/d					30,000 ML/d				
		0-0.25	0.25-0.5	0.5-1	>1	over topped	0-0.25	0.25-0.5	0.5-1	>1	over topped
		(m)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*
n1	**1162**	0	0	0	0	0	0	0	0	0	0
n2	**1705**	0	0	0	0	0	36	0	0	0	0
n3	**253**	63	1	0	0	0	46	61	10	0	0
n4	**159**	0	0	0	0	0	0	0	0	0	0
n5	**1872**	9	18	5	1	0	25	10	19	22	0
n6	**13016**	1484	994	1157	436	0	2555	2119	2438	1552	0
n7	**5671**	0	0	0	0	0	0	0	0	0	0
n8	**1854**	73	49	55	78	0	453	230	311	328	0
n9	**13312**	369	183	193	349	0	2436	2461	1867	1437	0
n10	**1697**	0	0	0	0	0	541	237	53	0	0
n11	**20900**	149	81	73	32	0	4062	3725	3212	1736	0
n12	**10764**	319	184	67	37	0	1138	1366	1288	751	0
n13	**1874**	0	0	0	0	0	449	864	159	0	0
n14	**5667**	72	2	0	0	0	607	1379	1673	1358	670
s1	**41701**	306	1219	5331	20836	0	2298	2508	6485	9639	0
s2	**1709**	174	811	691	107	0	0	0	0	0	0
s3	**9693**	146	0	0	0	0	0	0	0	0	0
s4	**2245**	0	0	0	0	0	0	0	0	0	0
s5	**1088**	0	0	0	0	0	0	0	0	0	0
s6	**977**	0	0	0	0	0	0	0	0	0	0
s7	**423**	0	0	0	0	0	0	0	0	0	0
s8	**1873**	0	0	0	0	0	0	0	0	0	0
s9	**2180**	0	0	0	0	0	0	0	0	0	0
s10	**22270**	446	17683	16429	11802	83	12319	10090	7274	2326	56
s11	**840**	14	823	805	764	808	802	779	730	81	562
s12	**1965**	28	1852	1733	1419	810	1701	1574	1344	657	418
s13	**1195**	14	396	363	171	0	378	299	195	59	0
s14	**412**	87	322	115	0	0	237	60	25	0	0
s15	**13095**	1624	3694	2490	823	0	2812	1958	1334	403	0
s16	**6856**	951	3194	2338	405	109	317	103	2	0	0
s17	**7861**	20	33	27	20	52	0	0	0	0	0
s18	**8331**	1074	2138	1825	685	70	1374	1373	1129	546	33

Table 3-2 Levee Length Inundated - 40,000 & 50,000 ML/d

Levee	Total Levee Length (m)	40,000 ML/d					50,000 ML/d				
		0-0.25 (m)	0.25-0.5 (m)	0.5-1 (m)	>1 (m)	over topped (m)	0-0.25 (m)	0.25-0.5 (m)	0.5-1 (m)	>1 (m)	over topped (m)
n1	**1162**	0	0	0	0	0	0	0	0	0	0
n2	**1705**	124	117	48	1	0	104	129	83	5	0
n3	**253**	24	34	87	0	0	19	31	106	0	0
n4	**159**	0	0	0	0	0	2	0	0	0	0
n5	**1872**	161	23	22	28	0	414	215	42	40	0
n6	**13016**	1517	2575	3767	2794	0	1036	1513	4965	4240	0
n7	**5671**	0	0	0	0	0	0	0	0	0	0
n8	**1854**	114	461	448	474	0	64	119	722	655	0
n9	**13312**	1598	2525	3518	1977	0	1434	1751	4768	2744	0
n10	**1697**	274	470	404	15	0	276	244	742	155	0
n11	**20900**	1463	3456	8141	4490	0	744	1573	7468	8739	91
n12	**10764**	992	1736	2597	1409	0	920	1510	3591	2057	941
n13	**1874**	235	513	1093	29	0	29	363	1380	102	734
n14	**5667**	287	997	2091	1961	953	250	684	2215	2250	1534
s1	**41701**	2202	2824	6454	14319	0	1077	2227	6318	17790	0
s2	**1709**	0	0	0	0	0	0	0	0	0	0
s3	**9693**	0	0	0	0	0	0	0	0	0	0
s4	**2245**	0	0	0	0	0	0	0	0	0	0
s5	**1088**	0	0	0	0	0	0	0	0	0	0
s6	**977**	0	0	0	0	0	0	0	0	0	0
s7	**423**	0	0	0	0	0	0	0	0	0	0
s8	**1873**	0	0	0	0	0	0	0	0	0	0
s9	**2180**	0	0	0	0	0	0	0	0	0	0
s10	**22270**	17332	15235	12501	6052	69	17983	17159	15405	9202	78
s11	**840**	821	804	779	507	747	831	816	799	724	799
s12	**1965**	1847	1726	1587	952	650	1863	1823	1686	1299	772
s13	**1195**	396	374	295	105	0	407	395	336	150	0
s14	**412**	377	205	52	0	0	408	273	76	0	0
s15	**13095**	3394	2459	1668	556	0	4416	3127	2190	708	0
s16	**6856**	2677	2088	994	0	3	3572	2766	2089	115	55
s17	**7861**	0	0	0	0	0	34	29	26	14	34
s18	**8331**	2551	1638	1545	585	39	3712	3247	2113	1257	225

Table 3-3 Levee Length Inundated - 60,000 ML/d

Levee	Total Levee Length (m)	60,000 ML/d									
		0-0.25	0.25-0.5	0.5-1	>1	over topped					
		(m)	*(m)*	*(m)*	*(m)*	*(m)*					
n1	**1162**	0	0	0	0	0					
n2	**1705**	90	128	145	18	0					
n3	**253**	24	21	87	42	0					
n4	**159**	27	0	0	0	0					
n5	**1872**	230	420	194	49	0					
n6	**13016**	592	1065	4168	6457	0					
n7	**5671**	0	0	0	0	0					
n8	**1854**	101	62	601	888	68					
n9	**13312**	1232	1457	4797	4003	3					
n10	**1697**	153	250	737	372	0					
n11	**20900**	631	930	4443	13011	572					
n12	**10764**	1314	1331	4194	2593	2572					
n13	**1874**	3	235	1418	217	1110					
n14	**5667**	257	586	2241	2361	1851					
s1	**41701**	306	1219	5331	20836	0					
s2	**1709**	174	811	691	107	0					
s3	**9693**	146	0	0	0	0					
s4	**2245**	0	0	0	0	0					
s5	**1088**	0	0	0	0	0					
s6	**977**	0	0	0	0	0					
s7	**423**	0	0	0	0	0					
s8	**1873**	0	0	0	0	0					
s9	**2180**	0	0	0	0	0					
s10	**22270**	446	17683	16429	11802	83					
s11	**840**	14	823	805	764	808					
s12	**1965**	28	1852	1733	1419	810					
s13	**1195**	14	396	363	171	0					
s14	**412**	87	322	115	0	0					
s15	**13095**	1624	3694	2490	823	0					
s16	**6856**	951	3194	2338	405	109					
s17	**7861**	20	33	27	20	52					
s18	**8331**	1074	2138	1825	685	70					

4. TASK 3 – EFFLUENT REVIEW

4.1 Task Description

Identify all effluents in the reach downstream of Goulburn Weir and review how they are modelled and consider how the dynamic flow rates and behaviour of the effluents could be better understood. This is a preliminary step aimed at identifying all effluents but also aimed at clarifying what we need and want to know to improve our understanding of the behaviour of these effluents.

4.2 Task Methodology

The existing model results were mapped and major effluents downstream of Goulburn Weir were identified. The model was reviewed at these locations to determine how the model represents these effluents.

4.3 Task Results and Discussion

Three major effluents were identified downstream of Goulburn Weir, these are shown in Figure 4-1 and are described below. A digital map of Figure 4-1 is also provided at a larger scale.

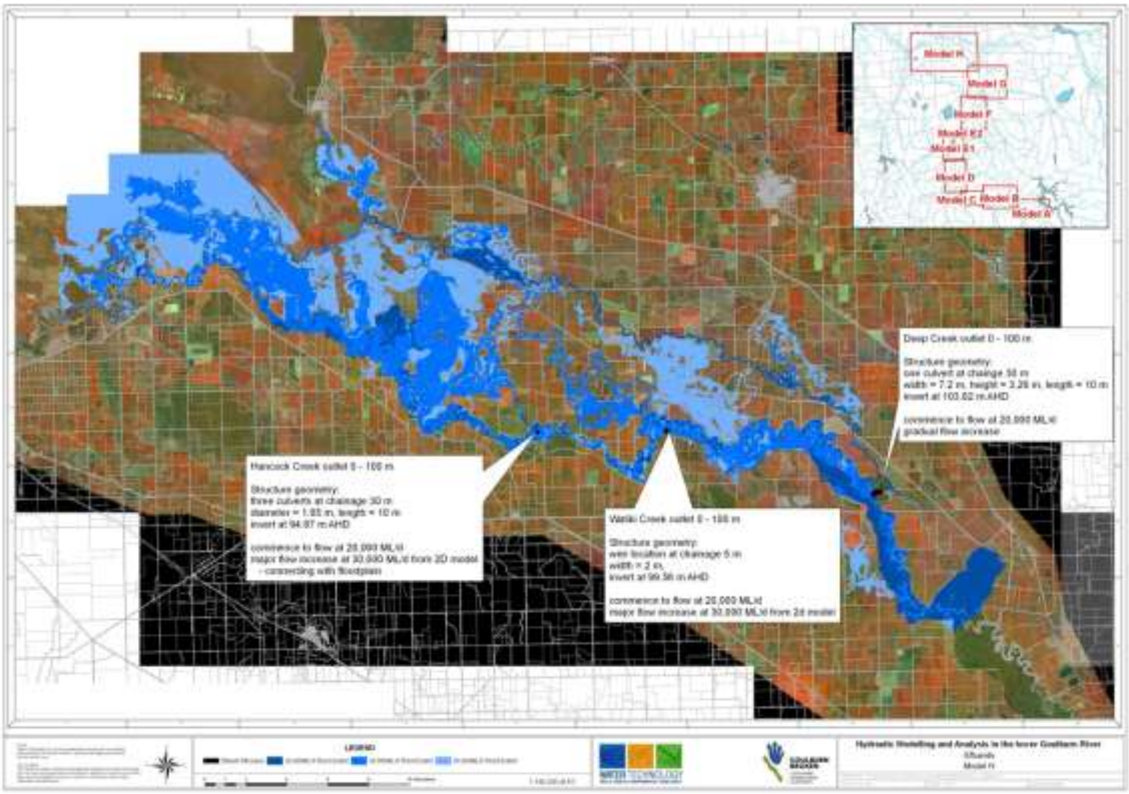

Figure 4-1 Review of Modelled Effluents

4.3.1 Deep Creek

Deep Creek is modelled as a small 1D standard link channel, linked to the 60 m 2D grid at chainage 100 m. A 10 m long rectangular culvert is modelled at chainage 30 m, with an invert of 103.82 m AHD, 7.2 m wide and 3.26 m high. This structure has a stoplog mechanism that can raise and lower the outlet invert, this was constructed by local landholders post 1993 flood to reduce flows through Deep Creek.

At 20,000 ML/d this structure passes a relatively low flow around 200-300 ML/d, at 40,000 ML/d this increases to above 2,000 ML/d, and at 60,000 ML/d the flow through the outlet is approximately 3,000 ML/d.

4.3.2 Wakiti Creek

Wakiti Creek is modelled as a small 1D standard link channel, linked to the 60 m 2D grid at chainage 100 m. At chainage 5 m a broad crested weir is modelled with an invert of 99.56 m AHD, 2 m wide.

At 20,000 ML/d this structure does not flow, at 40,000 and 60,000 ML/d this structure passes approximately 1,000 ML/d and 1,400 ML/d respectively.

4.3.3 Hancock Creek

Hancock Creek is modelled as a small 1D standard link channel, linked to the 60 m 2D grid at chainage 100 m. At chainage 30 m three 10 m long circular culverts are modelled with an invert of 94.87 m AHD, 1.65 m diameter.

At 20,000 ML/d this structure does not flow, at 40,000 and 60,000 ML/d this structure passes approximately 4,500 ML/d.

The flows through the effluents described above were extracted from model calibration runs of dynamic historic events carried out during the Lower Goulburn Floodplain Rehabilitation Scheme study (Water Technology 2005). The flows for each tributary were extracted during the rising limb of the Goulburn River hydrograph when the flow in the Goulburn River was 20,000, 40,000 and 60,000 ML/d. These flow rates are indicative and will be dependent on not only the flow in the Goulburn River, but also the condition of the structures (i.e. open/closed, partial blockage, etc), as well as the tail water conditions in the creeks (i.e. when the creeks begins to spill the flow rate will be higher than when the entire floodplain is full and the tail water condition in the creeks rise).

Downstream of Hancock Creek broad overbank flooding occurs from the Goulburn River through Madowla Lagoon. This is a complex area with the Bama Sand Hills providing a major constriction in floodplain flow, with 4 localised points where water can pass. Wakiti Creek and Hancock Creek both flow into this system, and it is likely that flows through these outlets are dynamically linked and impacted on by the downstream water level in Madowla Lagoon. During larger floods around 60,000 ML/d this system flows out into the Deep Creek system to the north and into the Murray River. When the Goulburn River begins to fall, flow from the floodplain is likely to return to the river at a slow rate through this system.

If rating curves of these effluents are required then it is suggested that some historic hydrographs be modelled and rating curves developed from these. This will ensure the dynamics of the system is captured, rather than developing relationships based on an artificial rising limb or steady state flows. As a starting point the calibration runs modelled as part of the original Lower Goulburn Floodplain Rehabilitation Project (Water Technology, 2005) could be analysed.

The structures linking Deep Creek, Wakiti Creek and Hancock Creek to the Lower Goulburn River have been modelled explicitly in the hydraulic models developed in previous studies. Therefore, for each timestep in the model run, the upstream and downstream water level, flow, velocity and flow through the structure can be extracted. Also, the regulating structures can be modelled dynamically to simulate opening and closing gates, either by specifying a gate level or a target flow/level at a downstream point.

5. TASK 4 – INUNDATION STATISTICS IN AND OUT OF LEVEE

5.1 Task Description

Recompute all statistics for the reach downstream of Shepparton to the Murray River, breaking it down to the areas within the levee banks and outside the levee banks.

5.2 Task Methodology

Following on from Task 2 the levee alignment was used to draw a polygon around the floodplain area considered to be within the levees and outside the levees. All the statistics previous calculated during the Goulburn River Environmental Flow Hydraulics Study (Water Technology 2010) were recomputed for inside and outside of the levee system. The existing modelled results and the various roads, properties, buildings, vegetation layers from the previous study were used to maintain consistency across studies.

5.3 Task Results and Discussion

The previous study (Water Technology 2010), analysed a series of statistics for each model reach as summarised below.

1. Area inundated (maximum and drained)
2. Volume stored on floodplain (maximum and drained)
3. Building inundated (total number, percentage of residential buildings with depths greater than 0.3 and 0.6 m)
4. Length of road inundated and number of bridges inundated
5. Landuse area inundated
6. Wetland area inundated
7. Native terrestrial vegetation inundated
8. Caravan park/holiday cabins inundated

These eight statistics have been recomputed for the area downstream of Shepparton and broken into within and outside of the levees, as defined by the Levee polygon shown in Figure 5-1. A number of plots and tables follow, presenting the results, with digital GIS files also supplied.

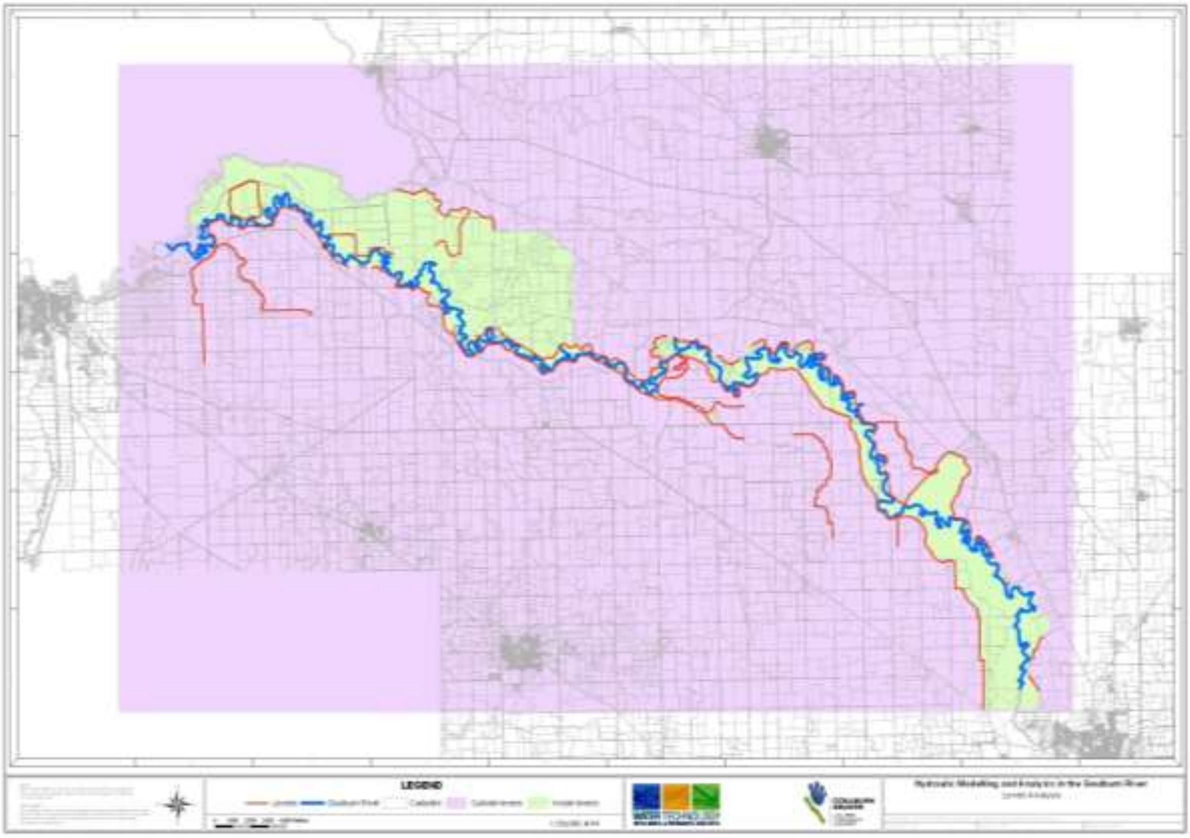

Figure 5-1 Levee polygon for statistical analysis

5.3.1 Area Inundated

The maximum area inundated has been analysed below within and outside of the levee system. This shows that as the flow increases from 20,000 ML/d to 60,000 ML/d there is a steady increase in the area inundated outside of the levee system, increasing from approximately 15% to 40% of the total inundated area. The area inundated inside the levee system, and indeed the total area inundated, is dramatically increased between 20,000 to 30,000 ML/d, after which incremental increases in area inundated are still significant but not as great.

Model Reach H was not run through to draining as were the upstream models A to G due to model size and long run times. Therefore the area drained analysis has not been performed.

Table 5-1 Area inundated (ha) summary table

	20,000 ML/d	30,000 ML/d	40,000 ML/d	50,000 ML/d	60,000 ML/d
Inside Levee System	3,740	10,235	12,129	12,897	13,538
Outside Levee System	659	2,336	4,767	6,561	8,499
Total	4,399	12,572	16,895	19,458	22,037

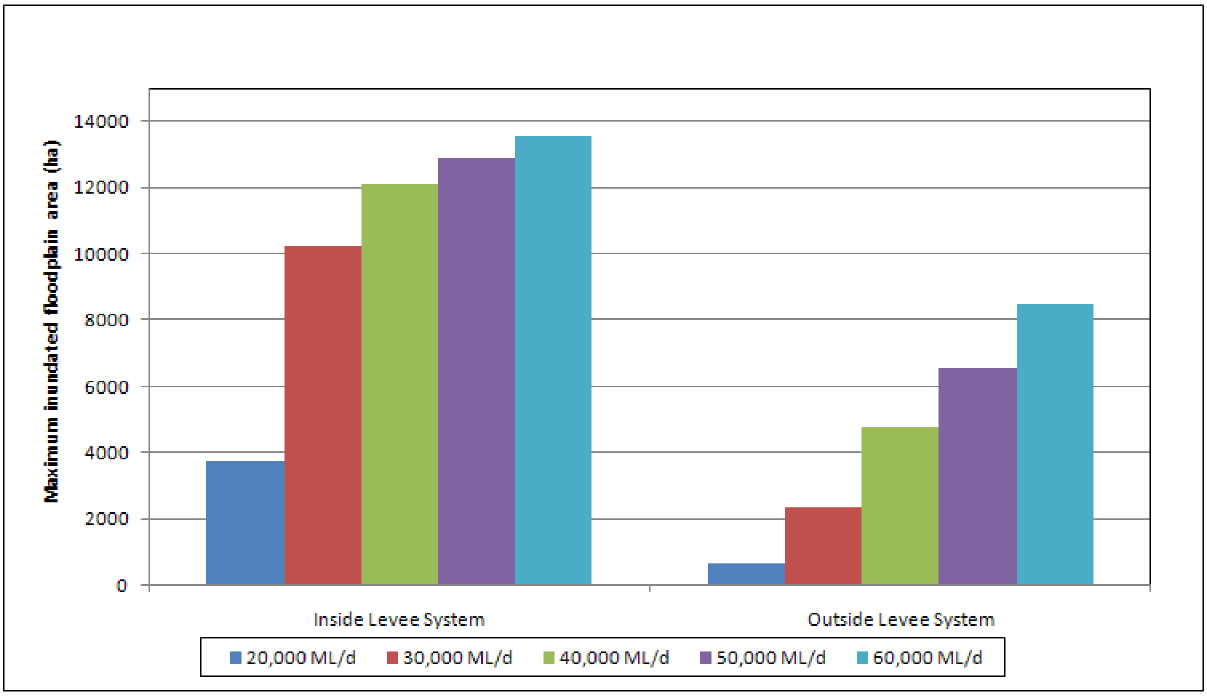

Figure 5-2 Area inundated summary plot

5.3.2 Volume Stored on Floodplain

The maximum volume stored on the floodplain has been analysed below within and outside of the levee system. This shows that as the flow increases from 20,000 ML/d to 60,000 ML/d there is a steady increase in the volume stored on the floodplain outside of the levee system, following the same trend as maximum area inundated presented previously. As the volume stored and area inundated are closely related, again the maximum volume stored on the floodplain is dramatically increased between 20,000 to 30,000 ML/d, after which incremental increases in volume stored are still significant but not as great.

Model Reach H was not run through to draining as were the upstream models A to G due to model size and long run times. Therefore the volume drained analysis has not been performed.

Table 5-2 Volume stored on floodplain (ML) summary table

	20,000 ML/d	30,000 ML/d	40,000 ML/d	50,000 ML/d	60,000 ML/d
Inside Levee System	39,119	107,971	140,564	164,063	183,578
Outside Levee System	8,895	30,656	52,973	68,244	79,229
Total	48,014	138,627	193,537	232,307	262,807

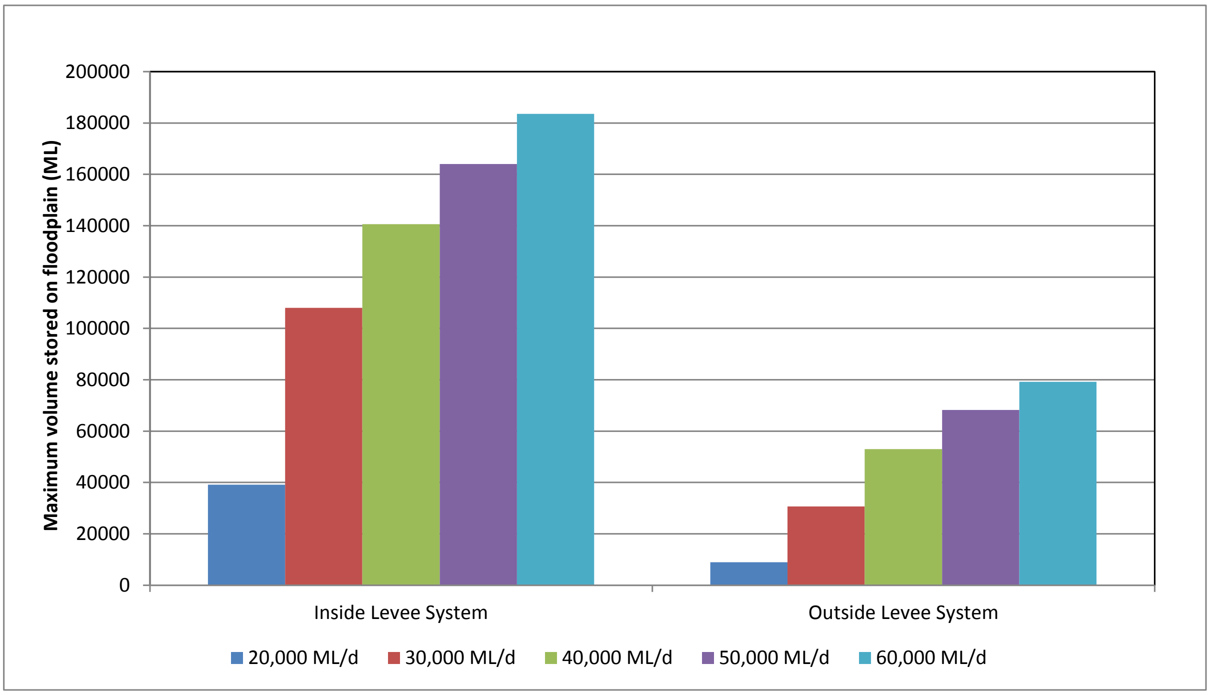

Figure 5-3 Volume stored on floodplain summary plot

5.3.3 Buildings Inundated

The buildings inundated analysis was not carried out for model reach H in the previous study (Water Technology 2010). However, for this study, all buildings in the study area were digitised from aerial imagery and categorised as house or other. This was a subjective categorisation from interpreting the aerial images, so some houses may be abandoned or may be sheds, but generally the categorisation is likely to be reasonable. The digitised buildings were intersected with the model depth grids, with the depths above 0.3 and 0.6 m analysed.

The number of houses inundated at 60,000 ML/d is quite small, and it is likely that these houses either have elevated floor levels or local flood protection such as small levees to reduce the frequency and likelihood of flooding. The other buildings inundated increase dramatically between 20,000 and 30,000 ML/d with an additional 37 building inundated, then incrementally increasing by between 15 to 25 buildings up to 60,000 ML/d.

Table 5-3 Buildings inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	house	***other***	***house***	***other***	***house***	***other***	***house***	***other***	***house***	***other***
Inside Levee System	1	*3*	5	*41*	6	*52*	7	*59*	8	*62*
Outside Levee System	1	*7*	8	*39*	8	*46*	11	*72*	12	*88*
Total	2	10	13	80	14	98	18	131	20	150

Table 5-4 Percentage of residential buildings inundated above 0.3 and 0.6 m

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	>0.3m	***>0.6m***	***>0.3m***	***>0.6m***	***>0.3m***	***>0.6m***	***>0.3m***	***>0.6m***	***>0.3m***	***>0.6m***
Inside Levee System	*50%*	*30%*	*38%*	*51%*	*43%*	*53%*	*39%*	*45%*	*40%*	*41%*
Outside Levee System	*50%*	*70%*	*62%*	*49%*	*57%*	*47%*	*61%*	*55%*	*60%*	*59%*

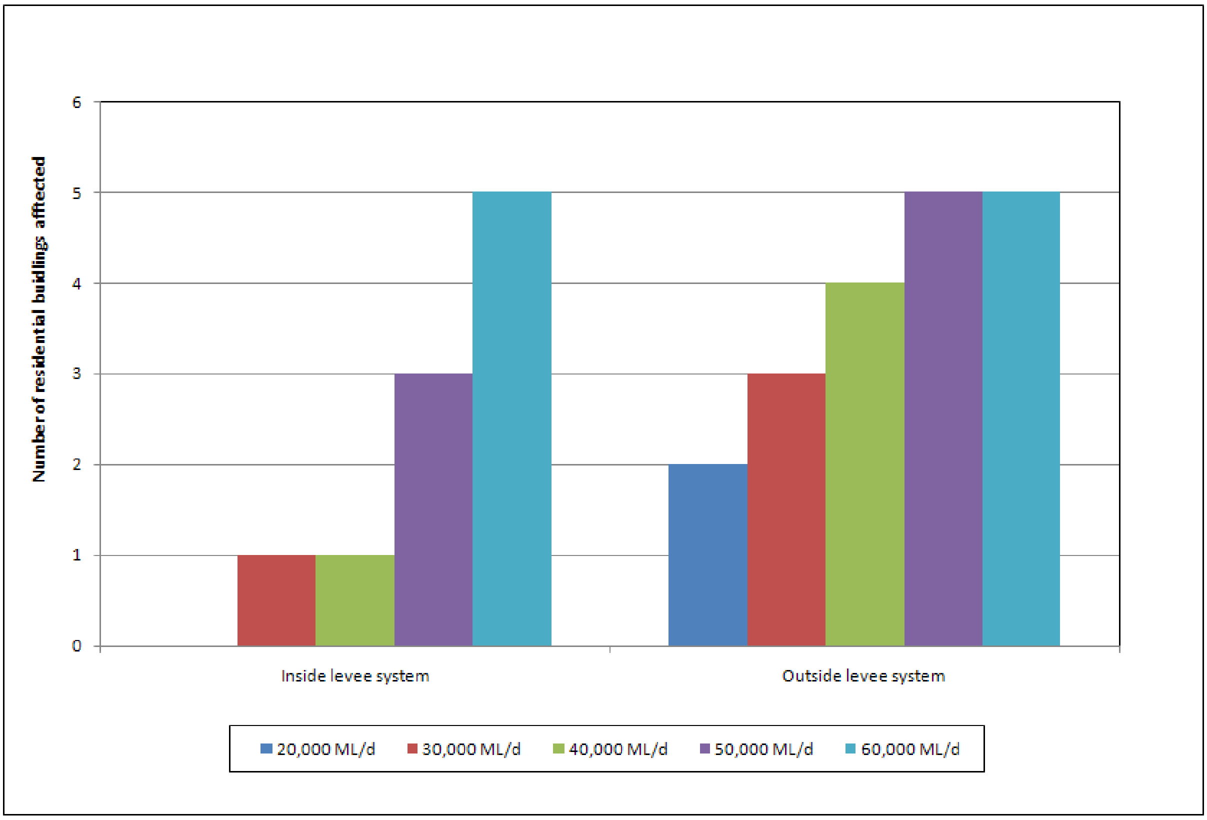

Figure 5-4 Buildings inundated summary plot

5.3.4 Roads and Bridges Inundated

The roads and bridges inundated were analysed the same as previously (Water Technology 2010), with both roads and bridges categorised as sealed or unsealed. Footbridges were also identified and included in the bridges analysis.

The length of sealed road inundated is much smaller than the length of unsealed road inundated in the lower Goulburn River floodplain.

Table 5-5 Length of road (km) inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	sealed	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*
Inside Levee System	0.05	*65.67*	0.42	*187.03*	0.42	*220.42*	0.63	*234.17*	0.75	*242.62*
Outside Levee System	0.85	*5.22*	3.58	*26.56*	4.23	*78.81*	5.93	*105.00*	8.37	*129.90*
Total	0.89	70.89	4.00	213.59	4.66	299.23	6.57	339.17	9.12	372.52

Table 5-6 Length of road bridges (km) inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	sealed	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*
Inside Levee System	0.05	*0.04*	0.31	*0.27*	0.29	*0.38*	0.31	*0.38*	0.32	*0.40*
Outside Levee System	0.02	*0.17*	0.13	*0.17*	0.19	*0.18*	0.20	*0.33*	0.26	*0.32*
Total	0.07	0.20	0.44	0.45	0.49	0.56	0.51	0.71	0.58	0.73

Table 5-7 Length of footbridges (km) inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	sealed	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*	*sealed*	*unsealed*
Inside Levee System	0.00	*0.08*	0.00	*0.15*	0.00	*0.37*	0.00	*0.66*	0.00	*1.14*
Outside Levee System	0.00	*0.00*	0.00	*0.04*	0.00	*0.05*	0.00	*0.07*	0.00	*0.37*
Total	0.00	0.08	0.00	0.19	0.00	0.42	0.00	0.74	0.00	1.51

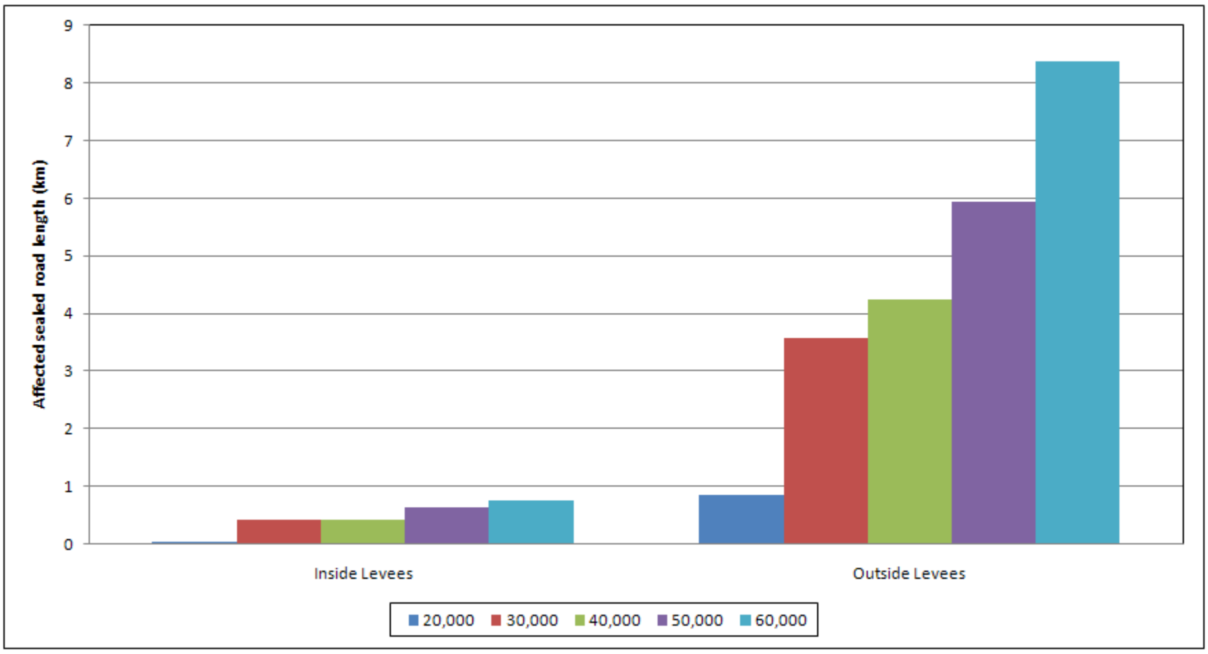

Figure 5-5 Sealed road inundated summary plot

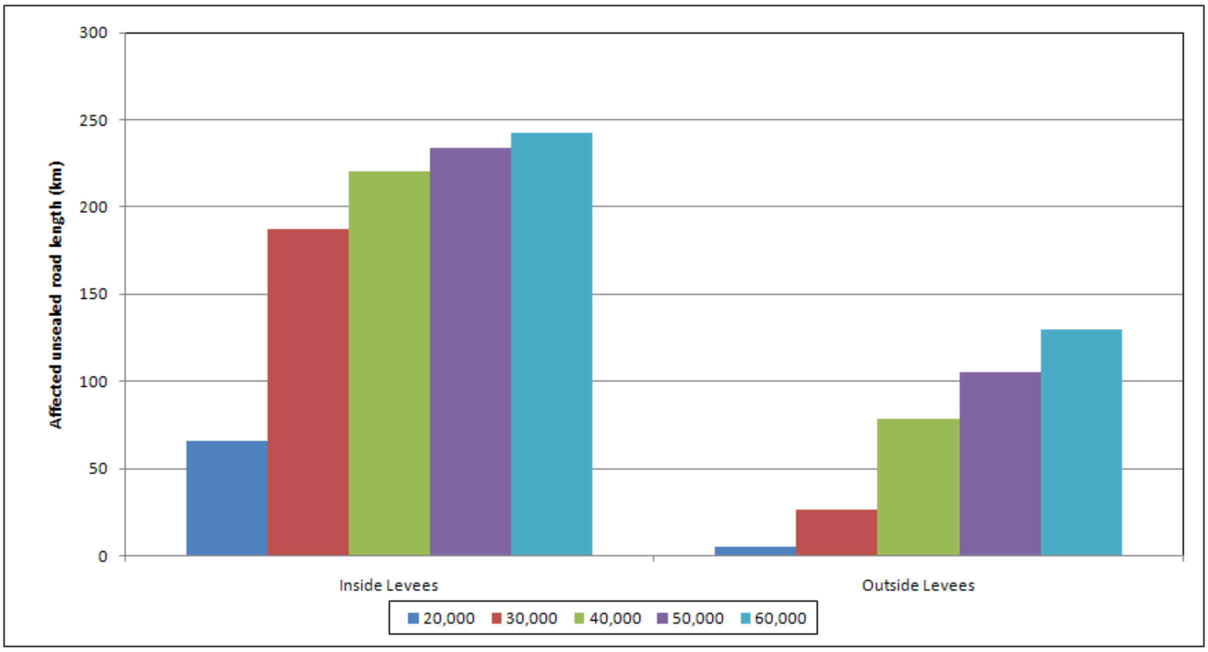

Figure 5-6 Unsealed road inundated summary plot

5.3.5 Land use Inundated

The same eight land use categories were used as in the previous study (Water Technology 2010), with all other land use types lumped into the other category.

This analysis shows that forestry and the other category dominate the area inundated inside the levee system, with dryland broadacre cropping and dryland pasture other significant land uses affected. The other category is dominated by three classes of land use, natural feature protection, other conserved area and residual native cover, this is likely to be associated with crown land. There is a large increase in the forestry and other category inundated inside the levee system between 20,000 and 30,000 ML/d.

Table 5-8 Land use area (ha) inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	Inside levee	*Outside levee*	*Inside levee*	*Outside levee*	*Inside levee*	*Outside levee*	*Inside levee*	*Outside levee*	*Inside levee*	*Outside levee*
Dryland Broadacre Crops	15	171	292	435	548	538	663	865	765	1,271
Dryland Pasture	415	186	1,385	613	2,018	744	2,271	1,539	2,506	2,437
Forestry	1,699	94	4,991	273	5,441	344	5,582	420	5,657	545
Intensive agriculture	0	-	38	7	46	7	52	8	56	33
Irrigated pasture	40	4	286	23	430	46	518	140	651	268
Other Fruit[1]	0	-	1	-	1	0	5	1	15	2
Other[2]	1,571	199	3,214	287	3,615	324	3,777	383	3,858	453

[1] Other fruit includes: Tree fruits, Vine fruits, Oleaginous fruits, Irrigated vine fruits, Irrigated tree fruits and Irrigated vine fruits.
[2] Other includes several small areas of different landuse area types: Manufacturing and industrial, Urban residential, Rural residential, Commercial services, Public services, Recreation and culture, Other minimal use, Natural feature protection, Strict nature reserves, Other conserved area, Managed resource protection, Remnant native cover, Residual native cover, Utilities, Roads, Defence, Railways, Quarries, Vegetables & herbs, Waste treatment and disposal, Irrigated vegetables & herbs, as well as the area taken up by surface water features: Water, Lake, Reservoir/dam, Water storage and treatment, Water storage - intensive use/farm dams, Surface water supply, River, Channel/aqueduct and Marsh/wetland.

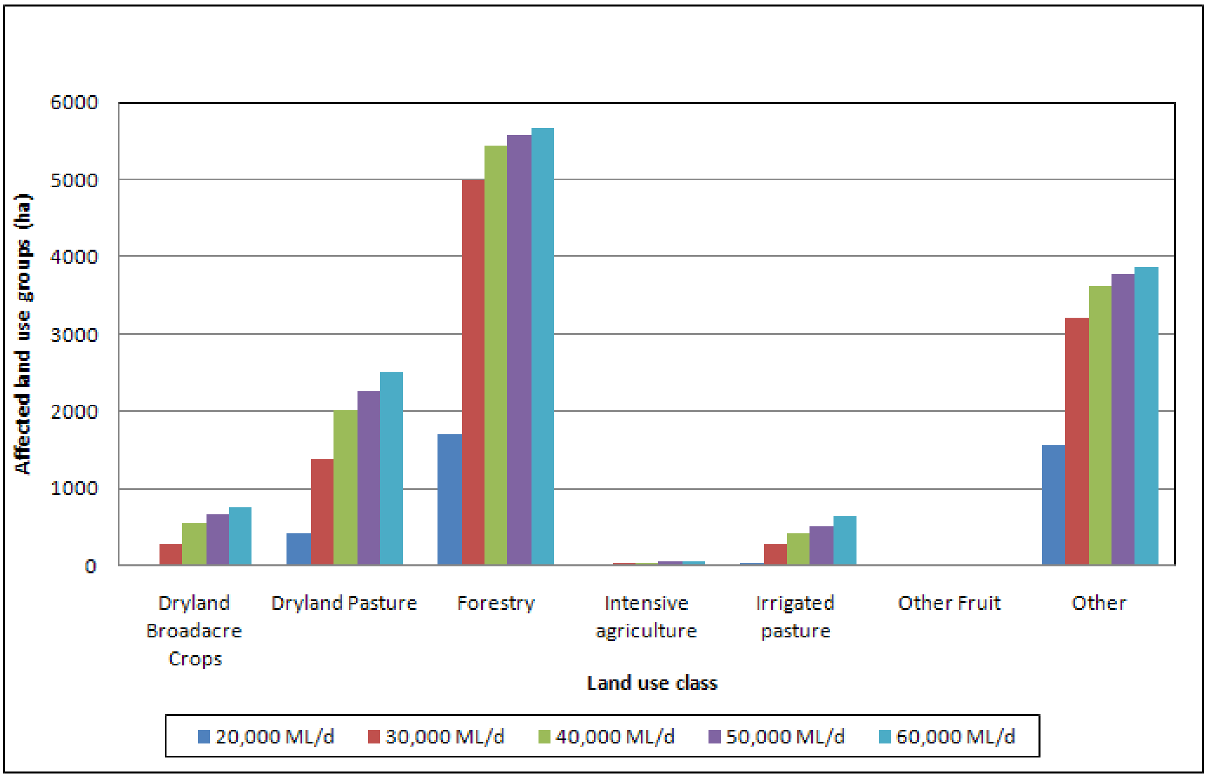

Figure 5-7 Land use area inundated inside levee system summary plot

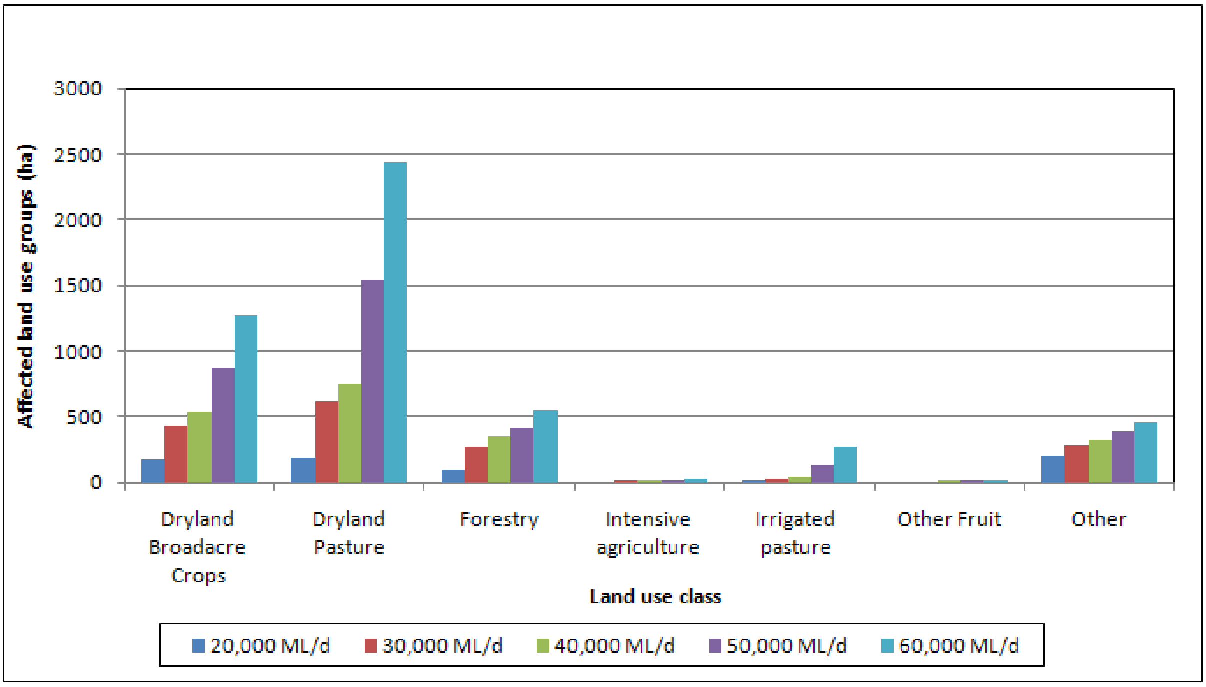

Figure 5-8 Land use area inundated outside levee system summary plot

5.3.6 Wetlands Inundated

In the previous study (Water Technology 2010) the wetlands were defined by the drained inundated area from a 60,000 ML/d flow event. Model reach H was not drained due to model size and run time, so the wetland definition for the lower Goulburn River floodplain for the below statistics uses the DSE wetland layer "*wetland_1994*".

The wetland area inundated has been analysed in Table 5-9 as a percentage of the area inundated at 60,000 ML/d. This shows that at 30,000 ML/d 97% of the wetlands inundated at 60,000 ML/d have been inundated within the levee system. For wetland areas outside the levee system, a flow of 50,000 ML/d is required to inundate a significant proportion of wetlands.

The majority of the wetlands inundated within the levee system are classified as shallow or deep marsh, open water and meadow. Outside of the levee system the majority of the wetlands inundated are classified as meadow.

Table 5-9 Wetland area inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	Area (ha)	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*
Inside Levee System	608	54%	1,086	97%	1,110	99%	1,117	99%	1,125	100%
Outside Levee System	0	0%	13	9%	18	11%	109	70%	155	100%
Total	609		1,099		1,128		1,226		1,280	

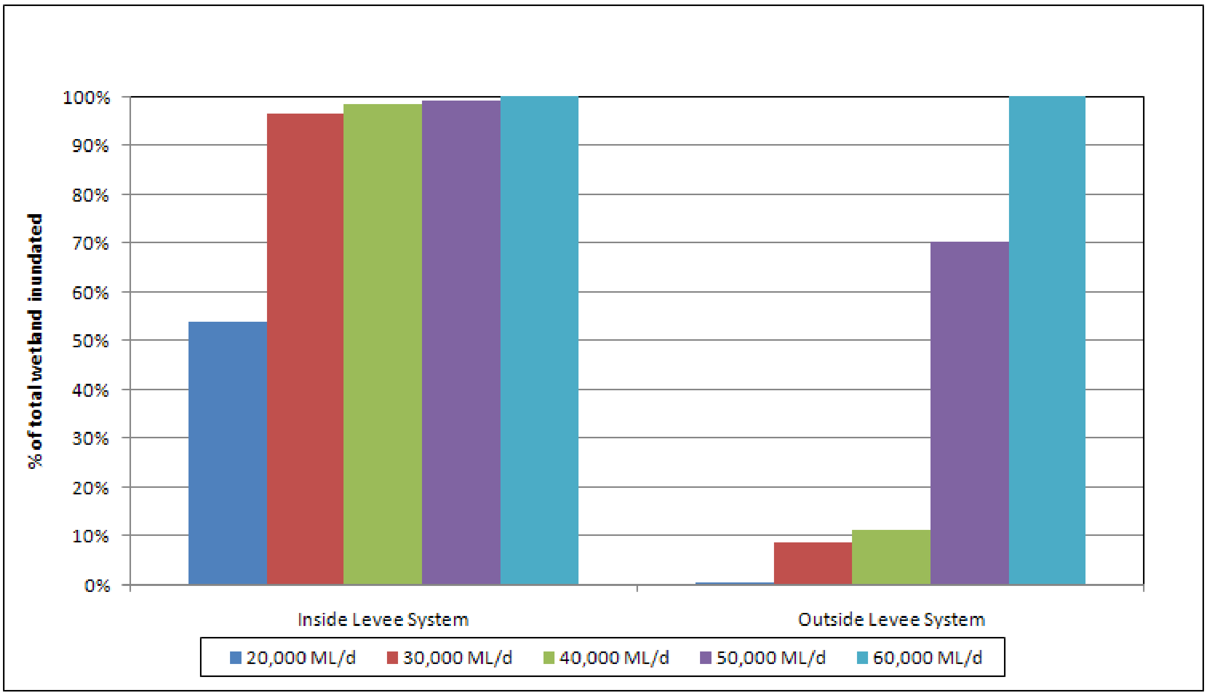

Figure 5-9 Percentage of wetland area inundated at 60,000 ML/d plot

5.3.7 Native Vegetation Inundated

The same definition as used in the previous study (Water Technology 2010), "*Highly likely native vegetation – woody"* from the DSE native vegetation layer was used to describe terrestrial native vegetation. A similar analysis to that of the wetlands was carried out and is presented below.

This shows that at 30,000 ML/d 85% of the native vegetation inundated at 60,000 ML/d is already inundated within the levee system. Outside of the levee system it takes flows of approximately 50,000 ML/d to inundate a similar percentage, however the actual area of native vegetation outside the levee is much lower than inside the levee.

Table 5-10 Native vegetation area inundated summary table

	20,000 ML/d		30,000 ML/d		40,000 ML/d		50,000 ML/d		60,000 ML/d	
	Area (ha)	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*	*Area (ha)*	*% of 60,000 ML/d*
Inside Levee System	3,609	33%	9,147	85%	10,227	95%	10,601	98%	10,811	100%
Outside Levee System	429	15%	1,267	44%	1,912	66%	2,413	83%	2,907	100%
Total	4,037		10,414		12,138		13,015		13,718	

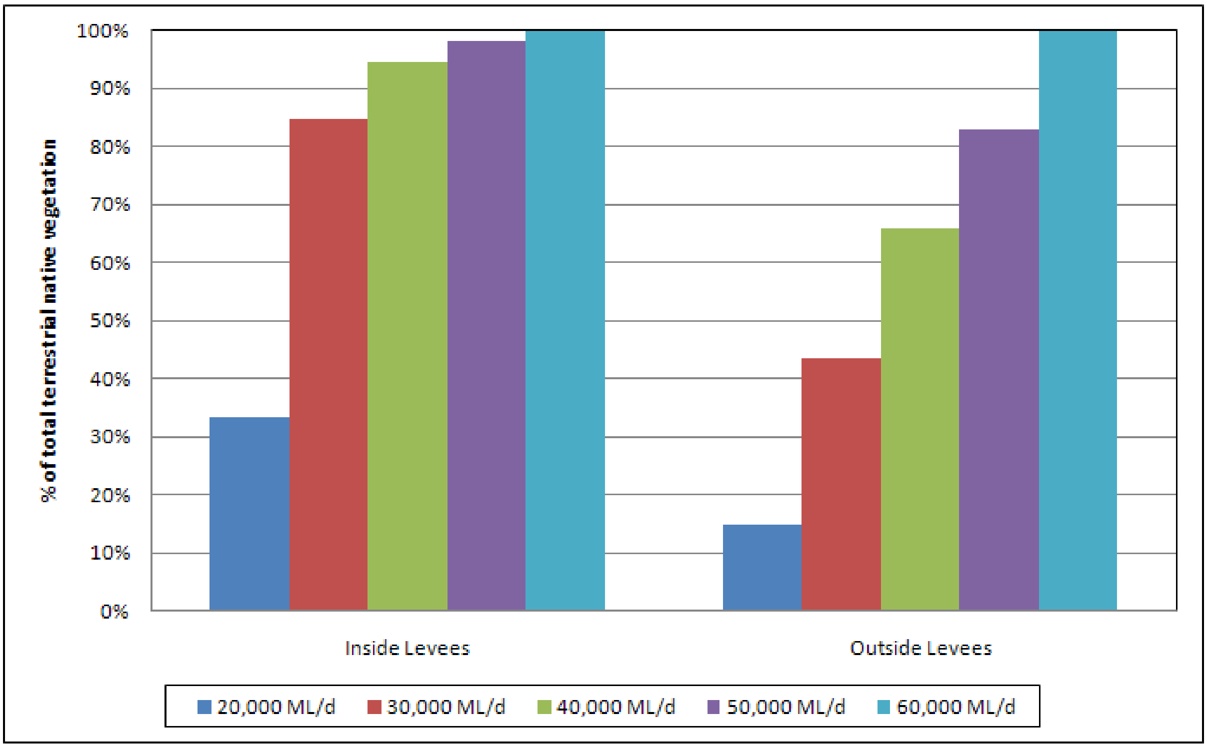

Figure 5-10 Percentage of native vegetation area inundated at 60,000 ML/d plot

5.3.8 Caravan Parks/Holiday Cabins Inundated

Only one caravan park was identified to be within the lower Goulburn River floodplain 60,000 ML/d inundated area from inspection of aerial images and internet searches. This caravan park is located at Stewarts Bridge Road, Kanyapella and is called River Bend Caravan Park. The River Bend Caravan Park is also located within the levee area. It seems there are approximately 30 buildings/caravans plus an office and shop, with potential for fluctuating numbers dependent on the peak periods.

The area impacted by inundation has been assessed below:

- 20,000 ML/d – no inundation
- 30,000 ML/d – 36% of area inundated
- 40,000 ML/d – 67% of area inundated
- 50,000 ML/d – 74% of area inundated
- 60,000 ML/d – 74% of area inundated

There is potential for other small caravan parks and holiday resorts to be located in the floodplain, however these were not identified through aerial image and internet searches.

6. TASK 5 – ENVIRONMENTAL ASSETS NOT INUNDATED

6.1 Task Description

Map environmental assets not inundated at 60,000 ML/d for the reach from Eildon to the Murray River.

6.2 Task Methodology

The inundation extent from the existing 60,000 ML/d modelled scenario was plotted over aerial imagery and the existing GIS layer of native trees (NV2005_EXTENT, with the description of "*highly likely native vegetation – woody*"). The existing trees layer was clipped outside of the 60,000 ML/d flood extent and inside the 100 year ARI flood extent from the Victorian Flood Database, providing polygons of significant areas of trees outside the 60,000 ML/d flood extent. Other significant areas of trees not mapped but shown on aerial imagery were identified and digitised manually. Small insignificant areas of trees were not included, such as those along roadsides.

6.3 Task Results and Discussion

Digital maps are provided for each model reach showing the locations of identified areas of trees not inundated at 60,000 ML/d. The area of trees not inundated in the lower Goulburn River Model Reach H is significantly higher than in other reaches due to the floodplain being much larger, and the floodplain being protected by a levee system. If this levee system was altered or flows reinstated through Loch Garry then there would be significant potential for inundation of large areas of native trees that are not currently experiencing frequent inundation. Further analysis of the maps and the LiDAR may provide some indication of areas of trees not inundated that could be reinstated with localised environmental watering works.

Table 6-1 Area of Trees Not Inundated at 60,000 ML/d

Model Reach	Area of Trees Not Inundated (ha)
Model Reach A	118
Model Reach B	321
Model Reach C	284
Model Reach D	356
Model Reach E1	600
Model Reach E2	80
Model Reach F	795
Model Reach G	99
Model Reach H	8,055
TOTAL	**10,708**

7. TASK 6 – ATTENUATION OF FLOWS

7.1 Task Description

Identify the time required for the floodplain downstream of Goulburn Weir to reach equilibrium for 20,000, 40,000 and 60,000 ML/d flows. This is required to understand how long a flow must be maintained for the maximum inundation extent to be reached.

7.2 Task Methodology

There are some limitations in the current model runs that prevent an accurate assessment of the attenuation longitudinally down the river. The existing model runs have assumed independent inflow hydrographs for all of the separate model areas, and have not routed the attenuated hydrograph through each model. At this stage the previous work has been summarised, looking at attenuation within each individual model area for the 20,000, 40,000 and 60,000 ML/d flow scenarios, providing a discussion around the total travel time and the likely upper bound from this analysis. For each model area the horizontal attenuation from the river to the edge of the floodplain was also assessed by comparing level hydrographs at the river and at the floodplain edge. For each model reach the hydrographs were generally compared at three locations longitudinally down the river (upstream, mid reach and downstream), at the river and at the extremities of both sides of the floodplain. These locations were identified and submitted for approval prior to the analysis. Model H was not run all the way through to draining due to the very large model size and long run times experienced. This analysis used 1D and 2D results from the previous study, which in some instances was difficult to retrieve from archive. For some models where more than one model result file existed due to model instabilities and 'hotstarts' (restarting a model part way through the run), not all result files were archived correctly, so some data is missing. For all scenarios only the current results were utilised, with no additional model runs performed.

It is important to note that the runs that have been used to obtain this information were carried out for a different purpose and therefore results should only be considered indicative. Model runs used "trapezoidal" hydrographs, created to ramp up to the desired flows of 20,000 ML/d, 30,000 ML/d, 40,000 ML/d, 50,000 ML/d and 60,000 ML/d for several hours (around 100 hours) and then ramp down again. In reality a natural hydrograph in the Goulburn River may look very different to this.

7.3 Task Results and Discussion

The Goulburn River Environmental Flow Hydraulics Study (Water Technology 2010) summarised the attenuation time along the river as follows.

- Reach A Eildon to Alexandra: 40-48 hours
- Reach B Alexandra to Ghin Ghin: 60-72 hours
- Reach C Ghin Ghin to Kerrisdale : 24-32 hours
- Reach D Kerrisdale to Mitchellstown: 48 to 56 hours
- Reach E Mitchellstown to Wahring: 96 to 122 hours
- Reach F Wahring to Kialla: 144to 172 hours
- Reach G Kialla to Bunbartha:126 to 192 hours

Goulburn Broken CMA further analysed the attenuation time along the reach for each model for the 20,000, 40,000 and 60,000 ML/d flow scenarios and summarised the attenuation as shown below in Table 7-1. Water Technology independently checked and verified the attenuation times.

Table 7-1 Lateral attenuation of model reaches

Model Reach	Model Attenuation Time (hours)		
	20,000 ML/d	**40,000 ML/d**	**60,000 ML/d**
Reach A Eildon to Alexandra	56	40	36
Reach B Alexandra to Ghin Ghin	112	96	48
Reach C Ghin Ghin to Kerrisdale	20	54	30
Reach D Kerrisdale to Mitchellstown	56	52	56
Reach E1	48	96	84
Reach E2	8	56	96
Reach F Wahring to Kialla	112	132	70
Reach G Kialla to Bunbartha	132	120	72

The previous study did not comment on the attenuation time through Model Reach H - Bunbartha to Murray River. Personal communication with Guy Tierney of the Goulburn Broken CMA suggested that travel times between Shepparton and McCoys Bridge (on the Murray Valley Highway) are in the order of 2 to 3 days, with another 8 days to the Murray River. These are obviously largely dependent on the magnitude of the flood, and are a rough estimate. Guy Tierney also mentioned that Roel von't Steen carried out an investigation into the travel times of the Goulburn River years ago, where he compared travel times for a range of flood magnitudes. This work would provide a more definitive description of travel times through the lower Goulburn River floodplain.

The lateral attenuation of flow as it leaves the river, reaches the floodplain boundaries and in some cases equilibrates with the Goulburn River water level, was also assessed. This can be observed visually in the many hydrographs provided below and is described in text here.

The lateral attenuation investigations showed a range of results dependent on the location along the Goulburn River:

- Between Nagambie and Shepparton flow does not inundate the floodplain at 20,000 ML/d.
- Downstream of Shepparton significant floodplain inundation is observed at flows of 20,000 ML/d.
- The water level in much of the floodplain lags behind the level in the main river, eventually catching up and rising with the river. This generally occurs due to the presence of a sill between the river and the edge of the floodplain, which once overtopped then takes a little time to fill the floodplain. This is often accompanied by water levels in the wetland remaining perched after the level in the river has fallen (i.e. water is retained behind the sill).
- In areas where the edge of the floodplain is relatively close to the river such as the right bank of model E2 at the downstream cross-section, the floodplain responds very quickly, with no lag between the river and floodplain.
- In contrast, on the left bank of the same cross-section as above, the floodplain shows a lag of over 2 days for the 40,000 ML/d scenario, this is because the floodplain breaks out from further downstream and backs up in a low lying area. For the 60,000 ML/d flow the time lag is much shorter between river and floodplain because the larger magnitude flow fills the limited floodplain volume quicker.

- In some areas where the floodplain breaks away and forms an anabranch the water level in the floodplain does not reach the water level in the main river as there is a hydraulic grade on the water surface (i.e. it is flowing not ponding), this is the case on the far left bank of the downstream cross-section in model F.
- In some areas there is quite a long delay (up to a week) between the peak water level in the Goulburn River and the floodplain. This is often related to a sill between the main river and the floodplain and then the long time to fill a large floodplain volume, such as the lower Goulburn River floodplain in model H. The lower Goulburn River floodplain also has numerous anabranches that drain water away from the floodplain leading to longer lag times to fill the floodplain.

7.3.1 Model Reach E2

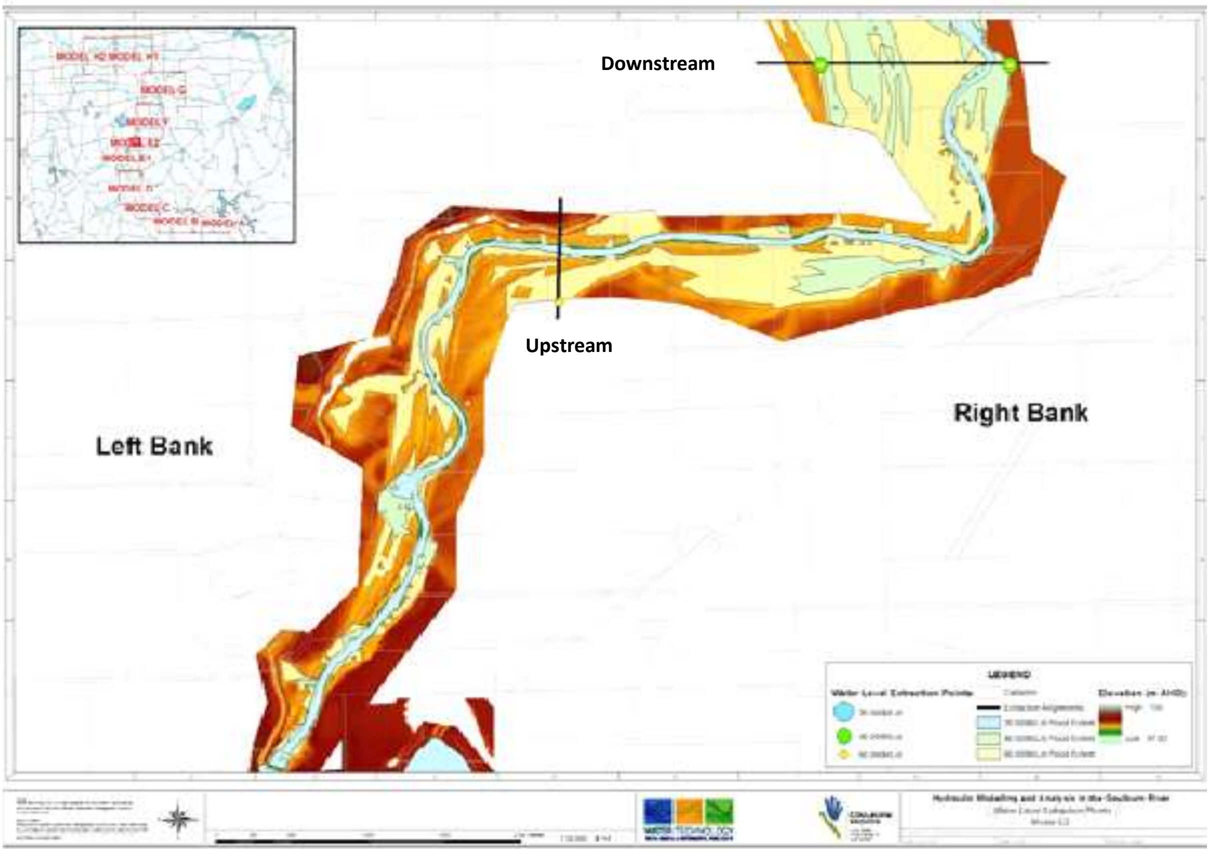

Figure 7-1 Overview of model reach E2 with hydrograph extraction points

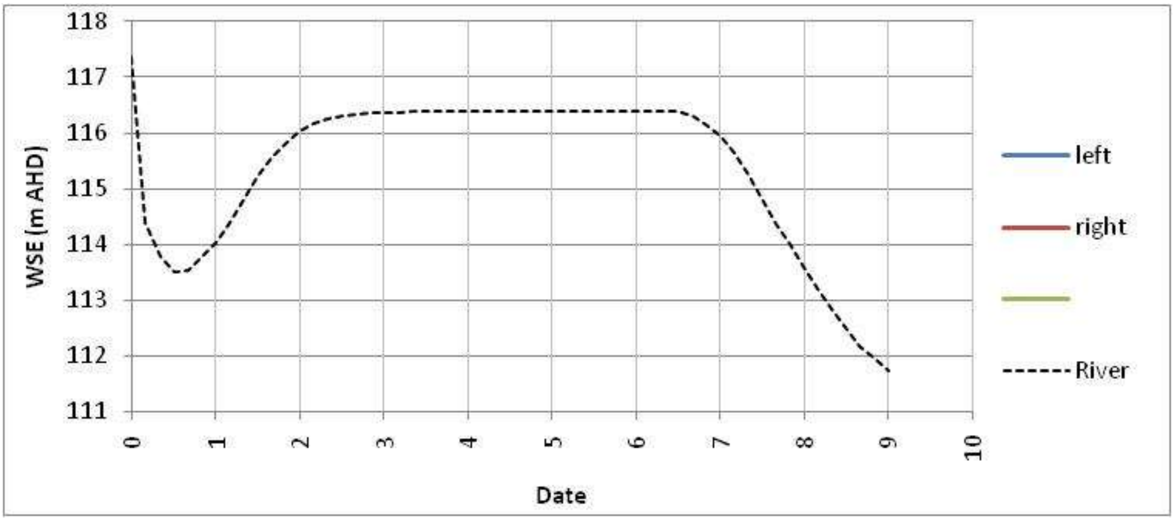

Figure 7-2 Model E2 upstream extraction line 20,000 ML/d

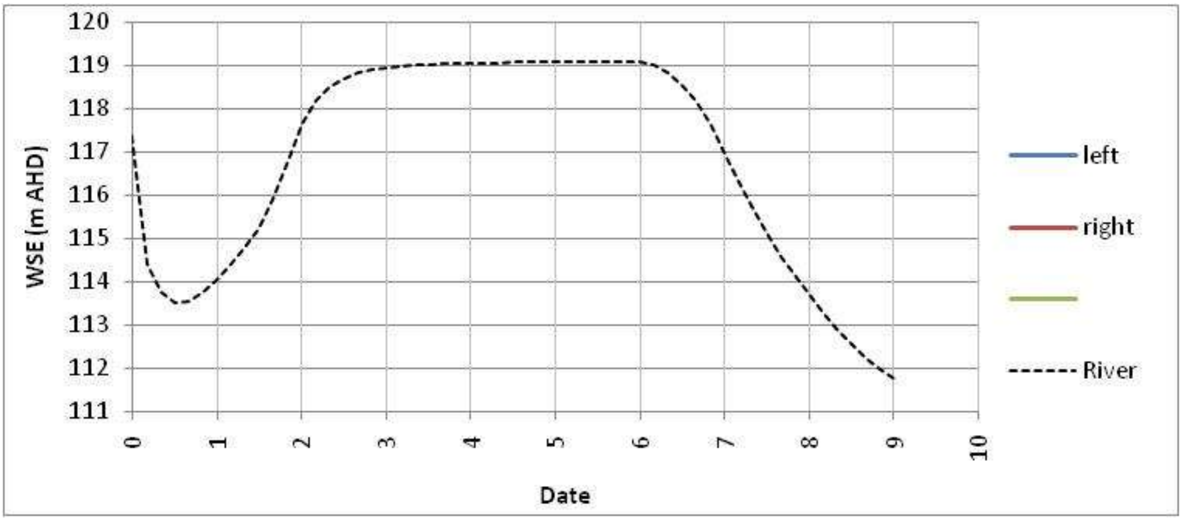

Figure 7-3 Model E2 upstream extraction line 40,000 ML/d

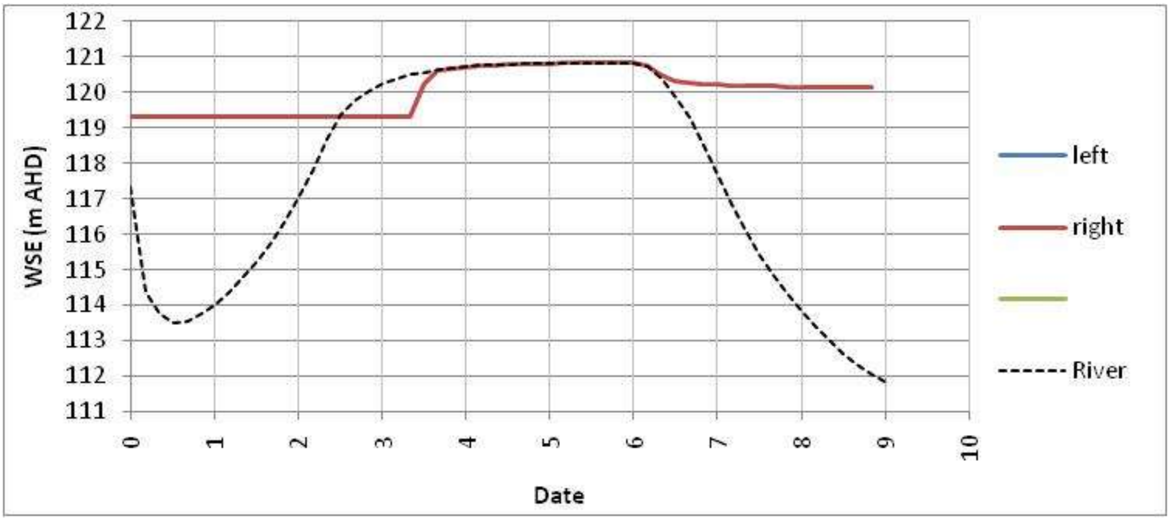

Figure 7-4 Model E2 upstream extraction line 60,000 ML/d

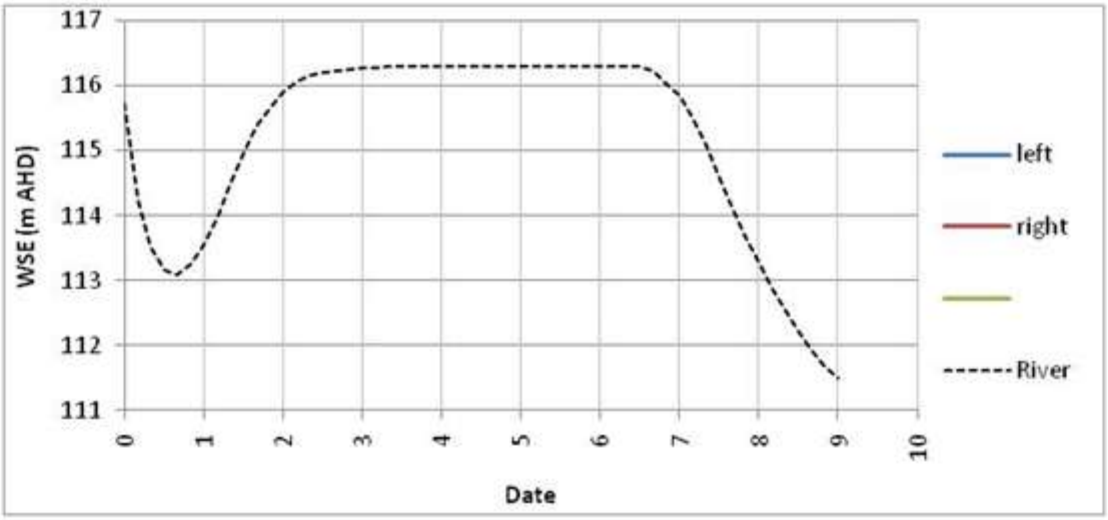

Figure 7-5 Model E2 downstream extraction line 20,000 ML/d

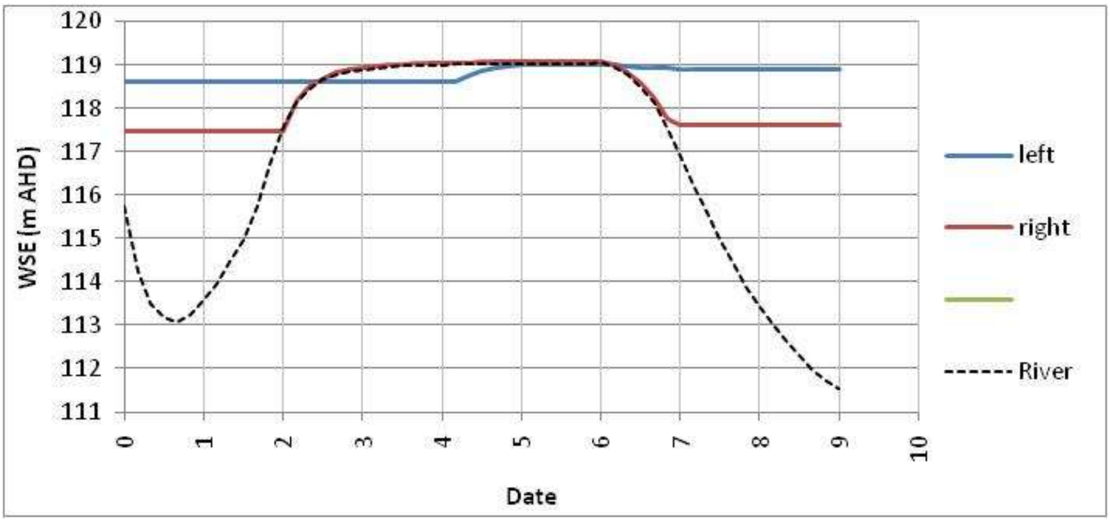

Figure 7-6 Model E2 downstream extraction line 40,000 ML/d

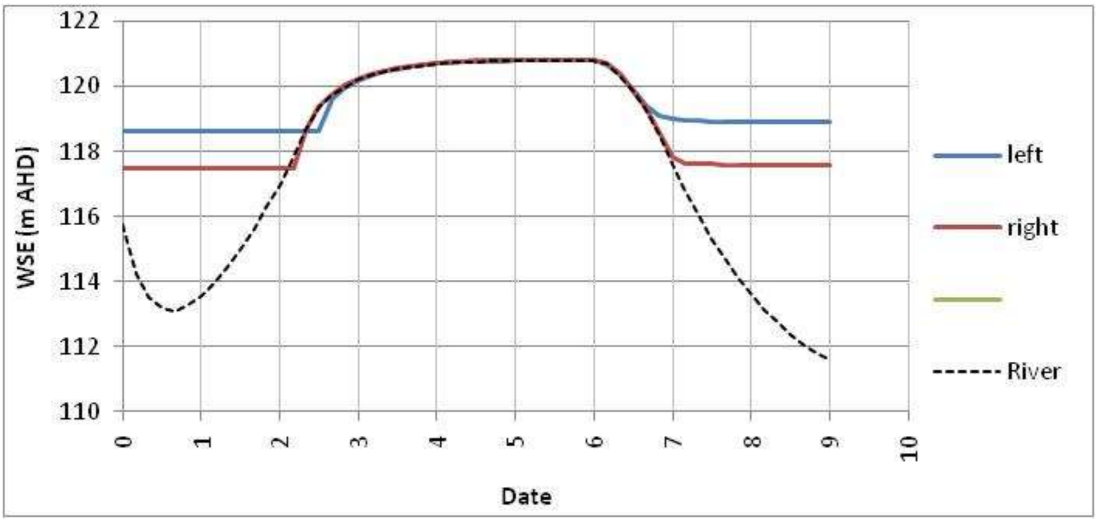

Figure 7-7 Model E2 downstream extraction line 60,000 ML/d

7.3.2 Model Reach F

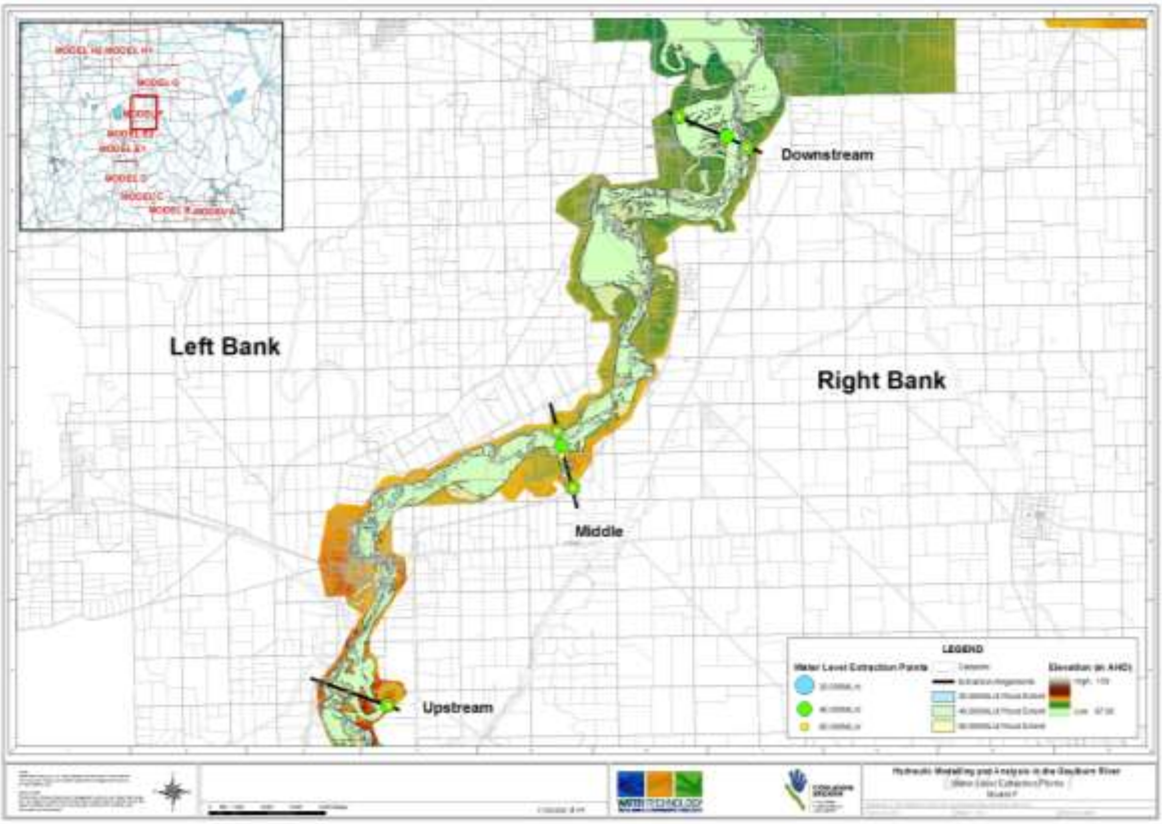

Figure 7-8 Overview of model reach F with hydrograph extraction points

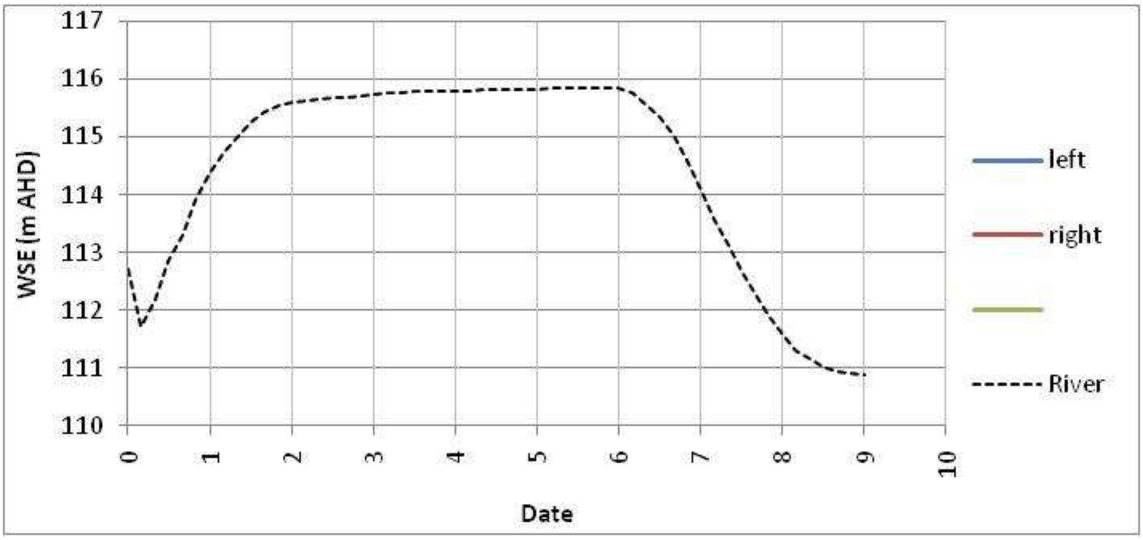

Figure 7-9 Model F upstream extraction line 20,000 ML/d

Figure 7-10 Model F upstream extraction line 40,000 ML/d

Figure 7-11 Model F upstream extraction line 60,000 ML/d

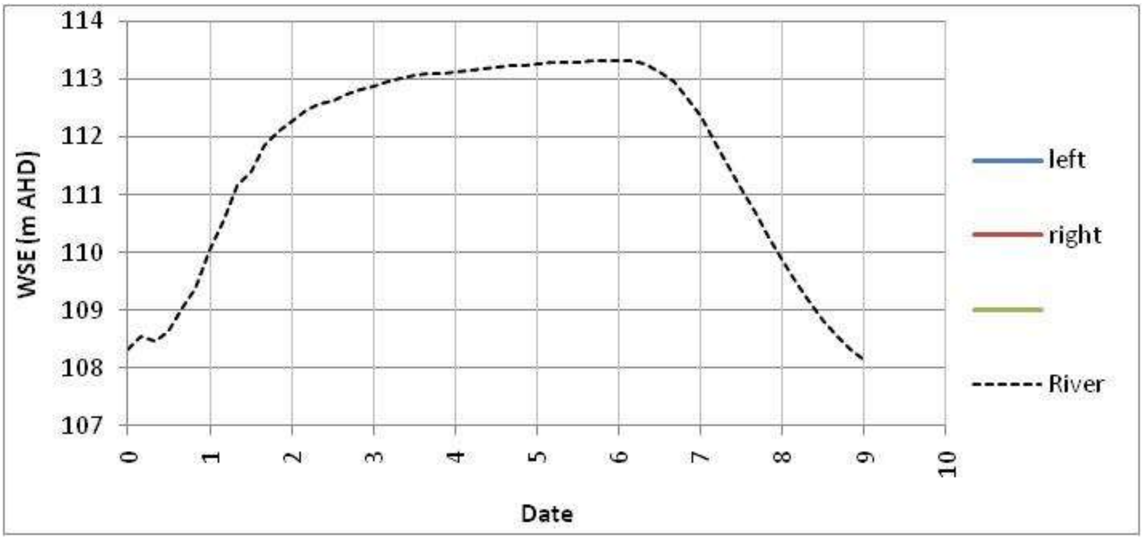

Figure 7-12 Model F middle extraction line 20,000 ML/d

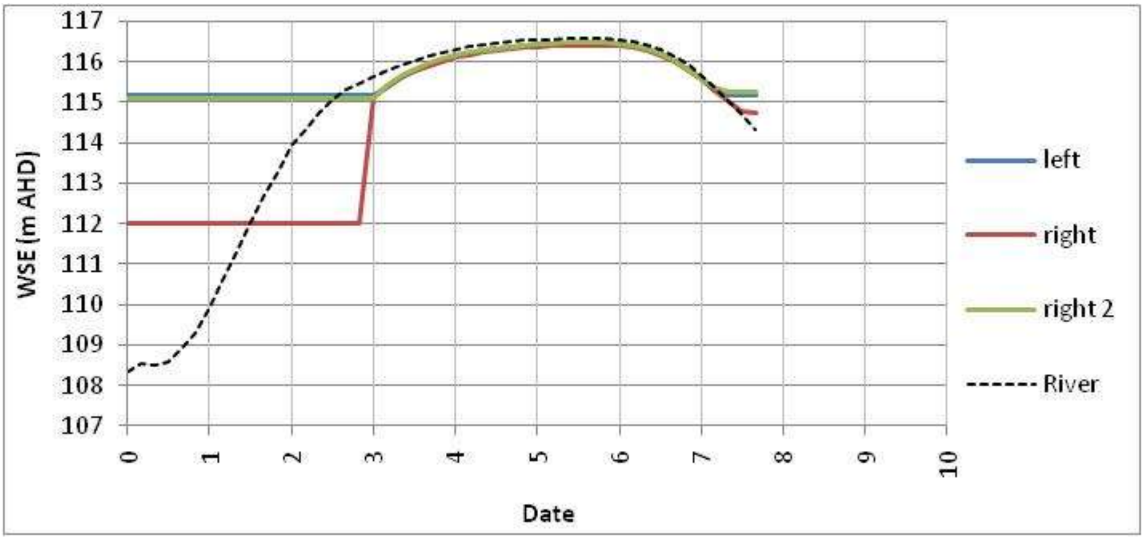

Figure 7-13 Model F middle extraction line 40,000 ML/d

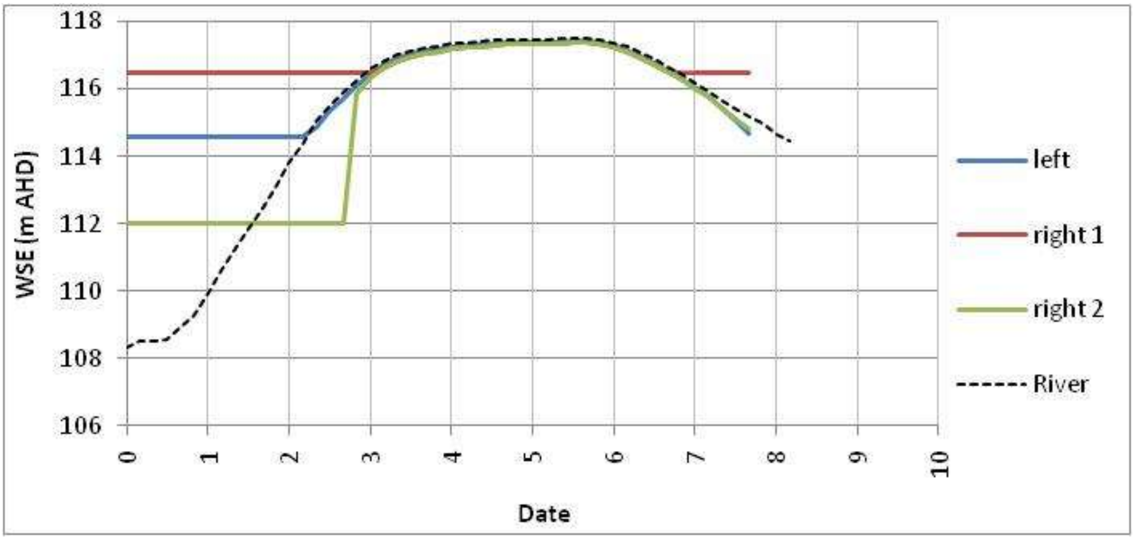

Figure 7-14 Model F middle extraction line 60,000 ML/d

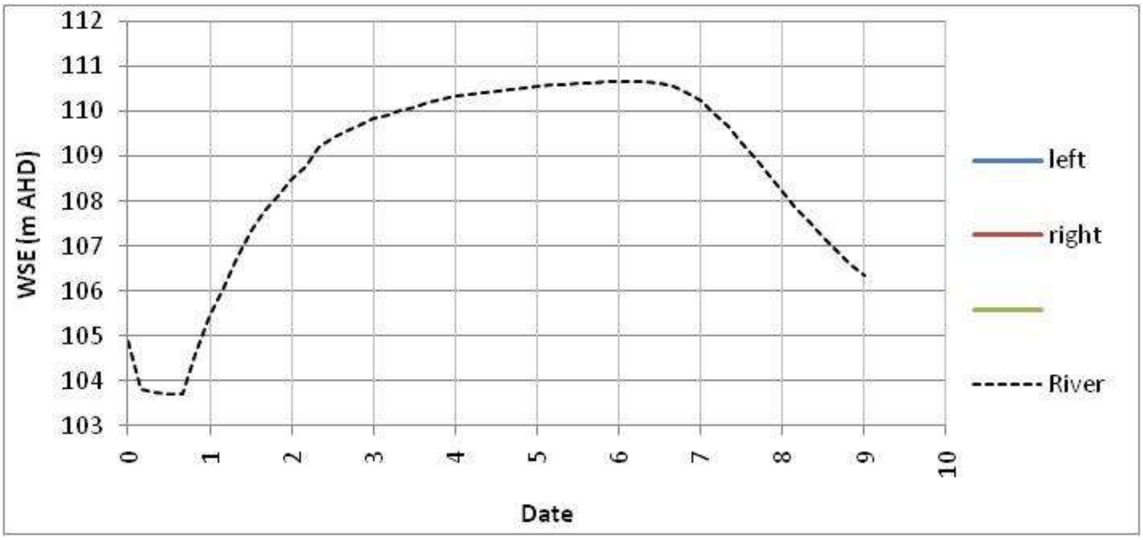

Figure 7-15 Model F downstream extraction line 20,000 ML/d

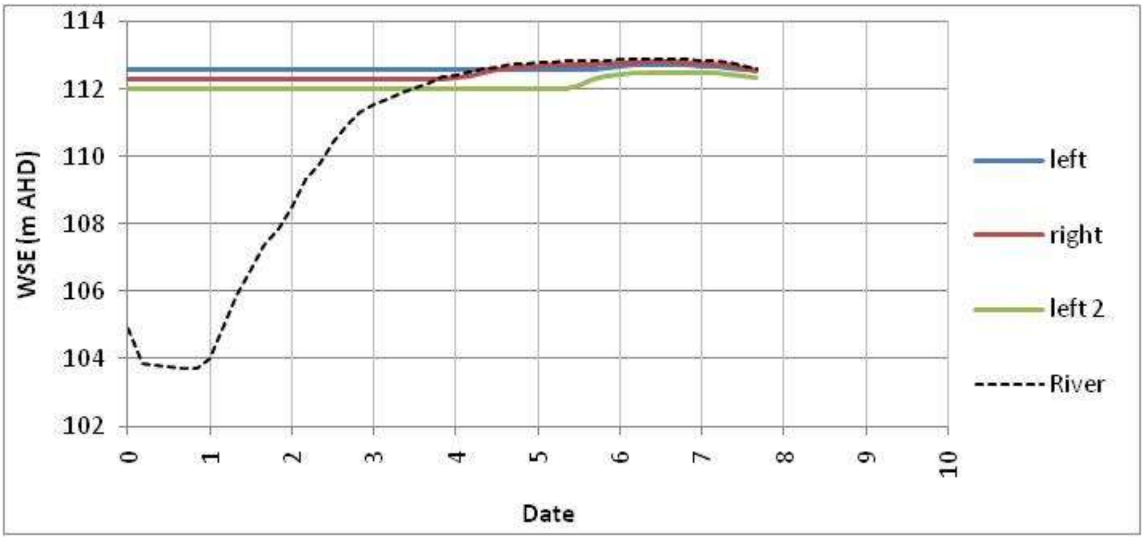

Figure 7-16 Model F downstream extraction line 40,000 ML/d

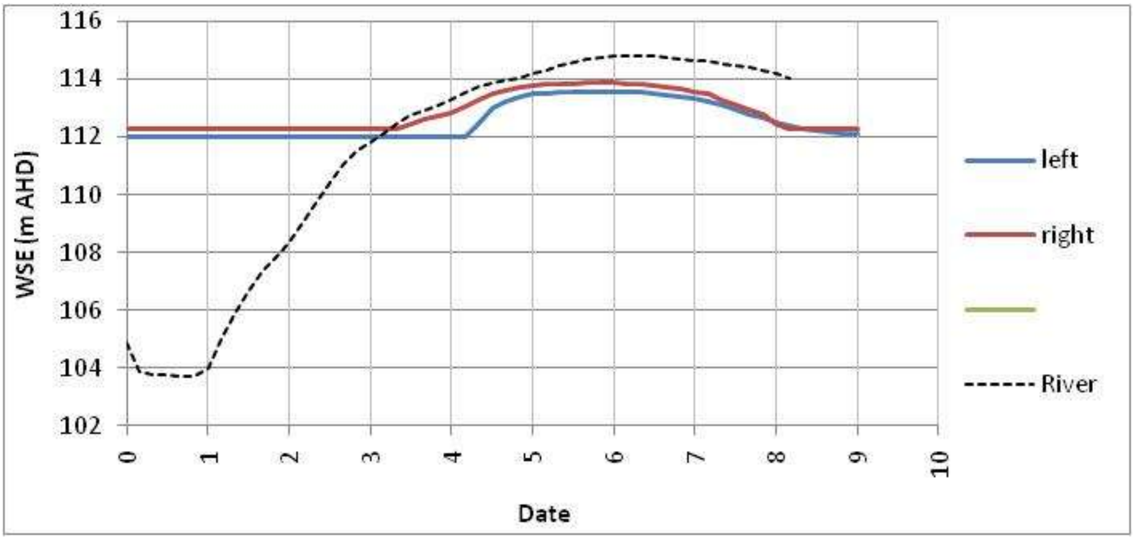

Figure 7-17 Model F downstream extraction line 60,000 ML/d

7.3.3 Model Reach G

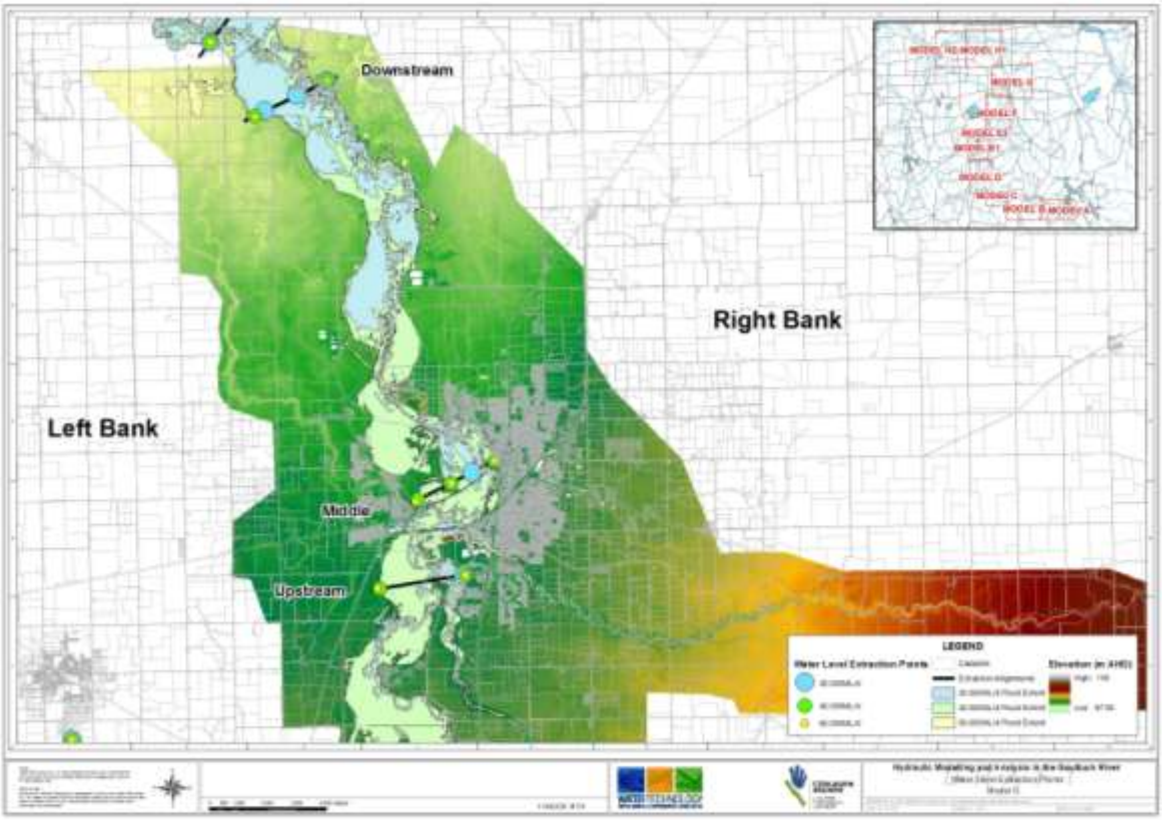

Figure 7-18 Overview of model reach G with hydrograph extraction points

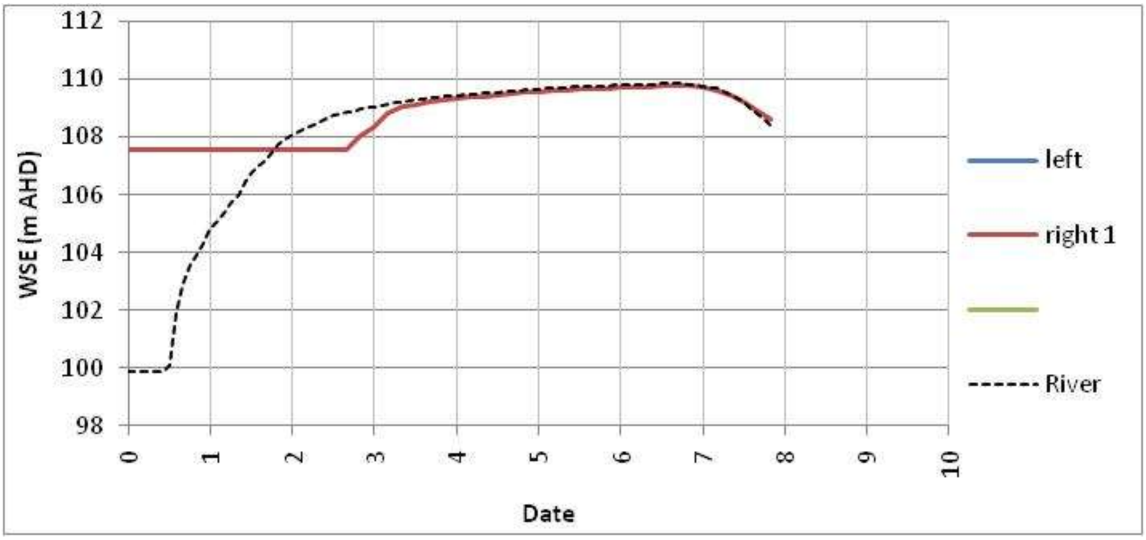

Figure 7-19 Model G upstream extraction line 20,000 ML/d

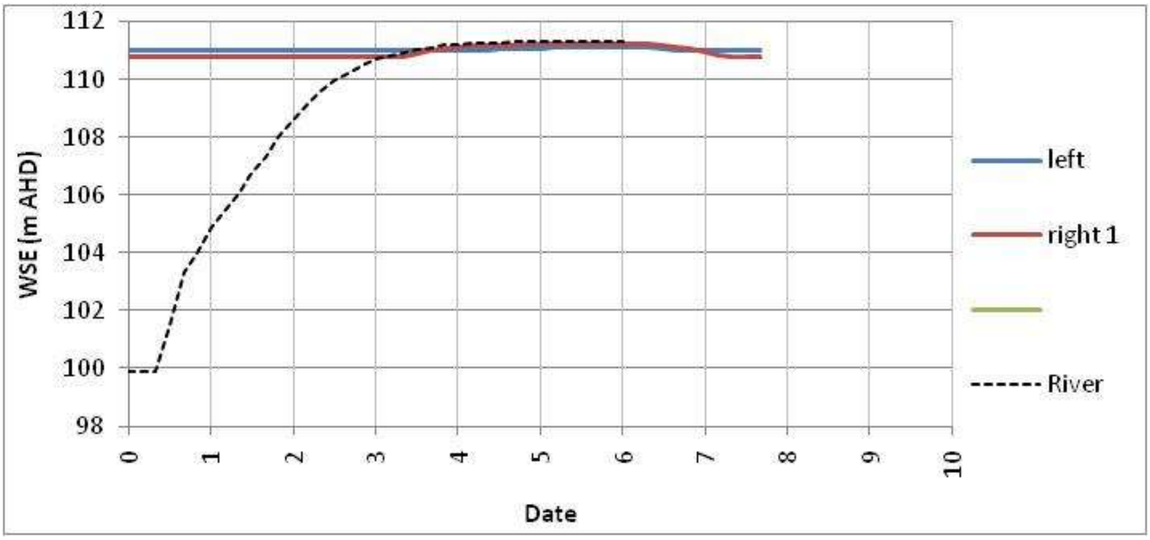

Figure 7-20 Model G upstream extraction line 40,000 ML/d

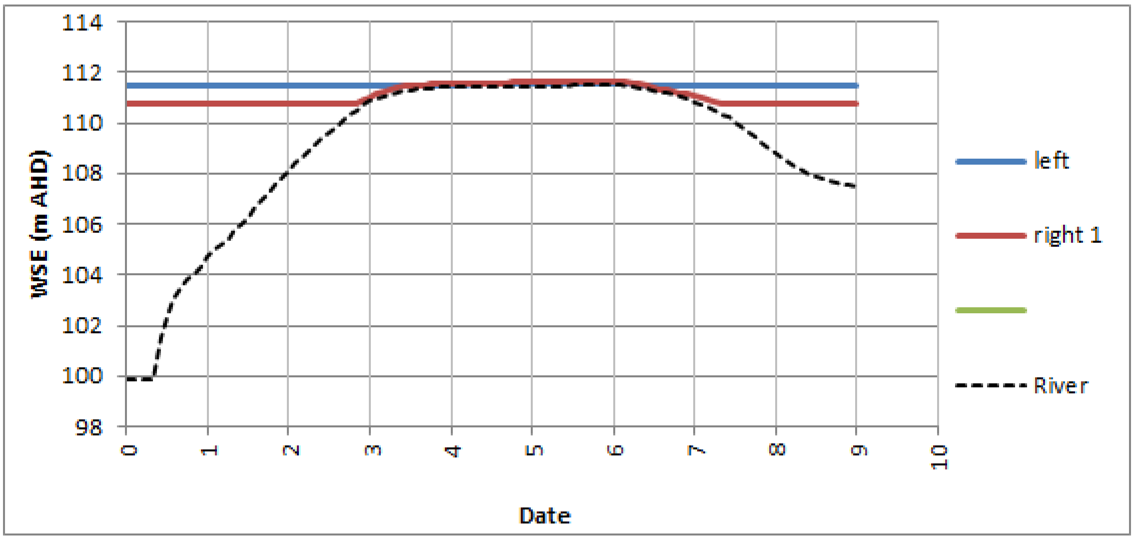

Figure 7-21 Model G upstream extraction line 60,000 ML/d

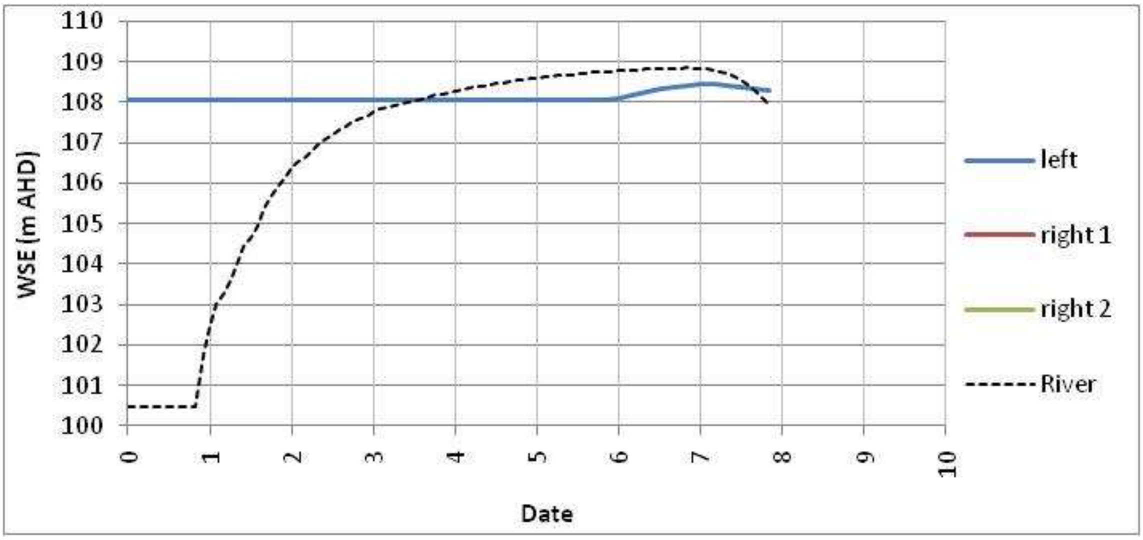

Figure 7-22 Model G middle extraction line 20,000 ML/d

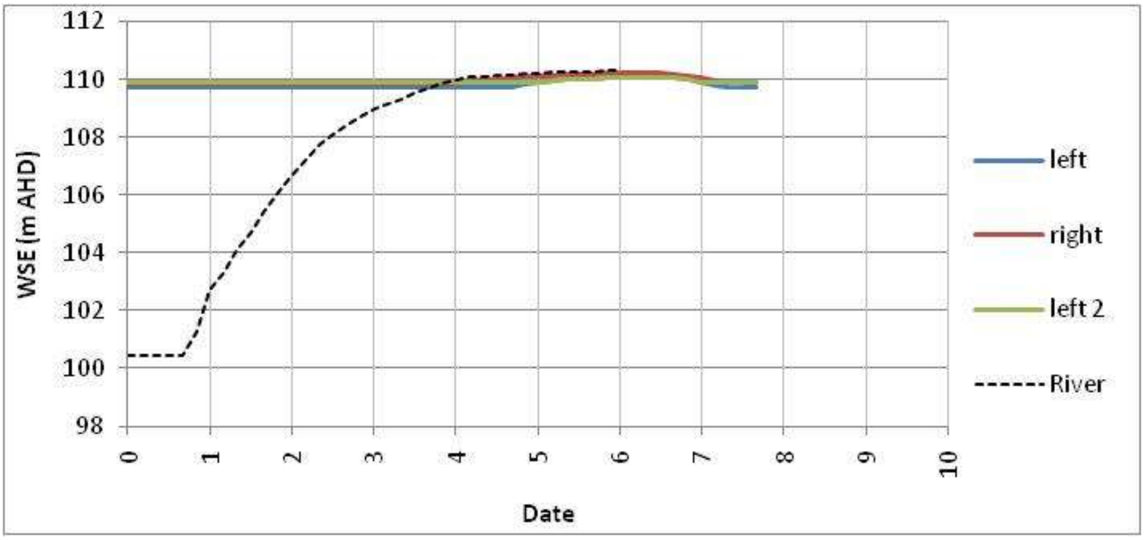

Figure 7-23 Model G middle extraction line 40,000 ML/d

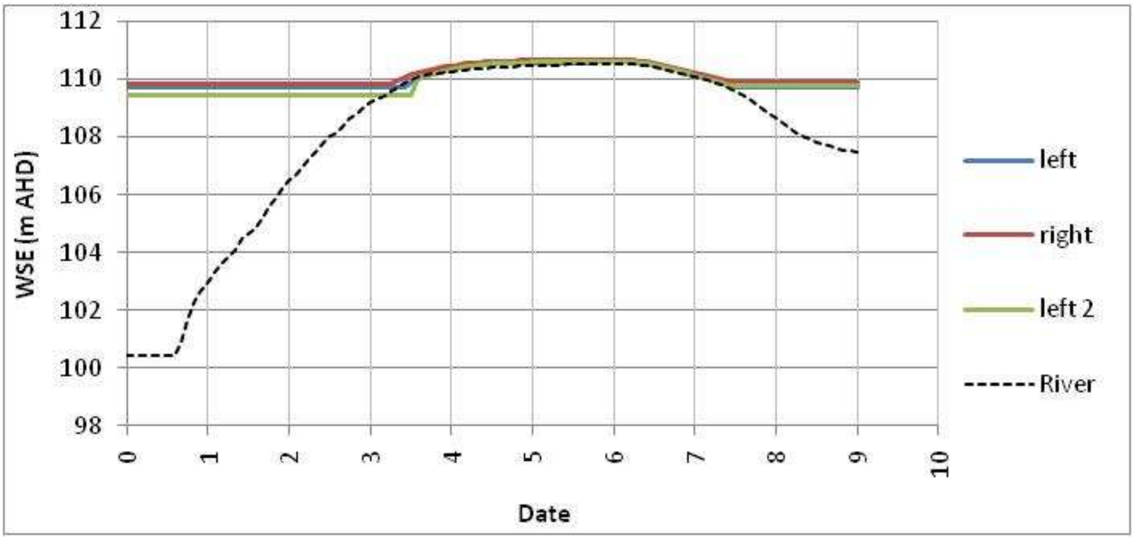

Figure 7-24 Model G middle extraction line 60,000 ML/d

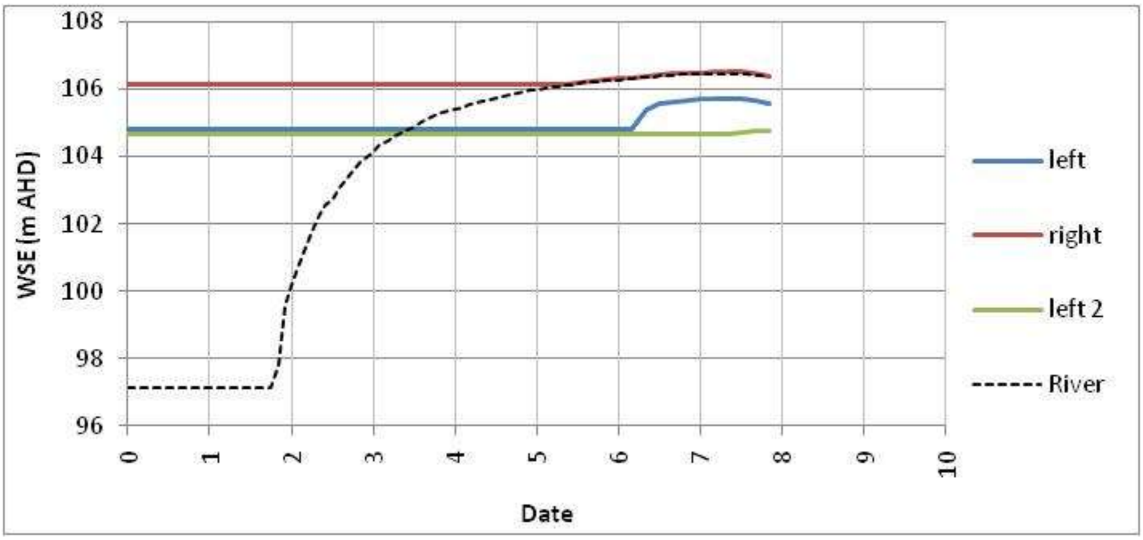

Figure 7-25 Model G downstream extraction line 20,000 ML/d

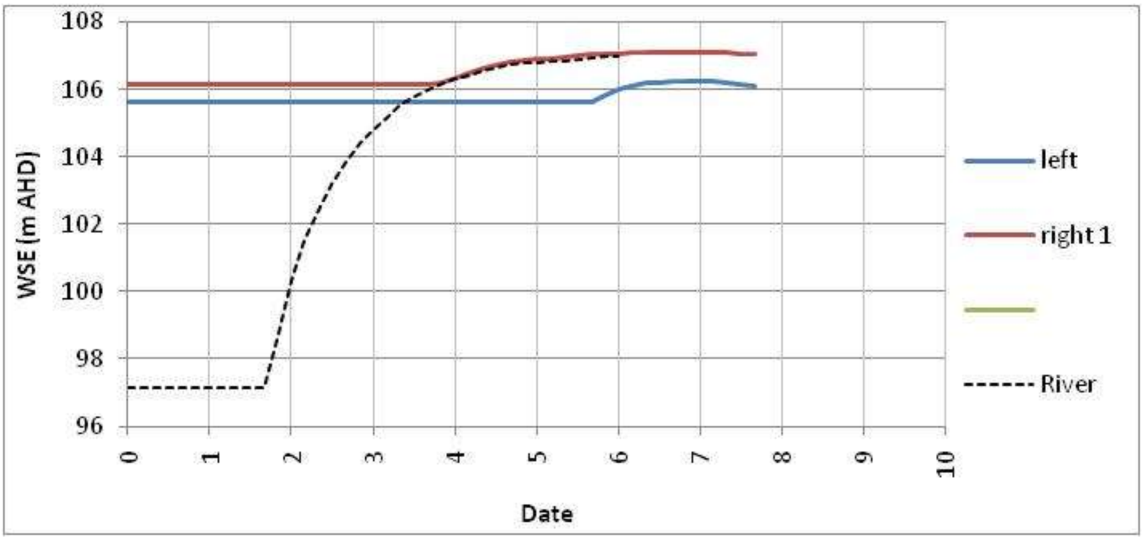

Figure 7-26 Model G downstream extraction line 40,000 ML/d

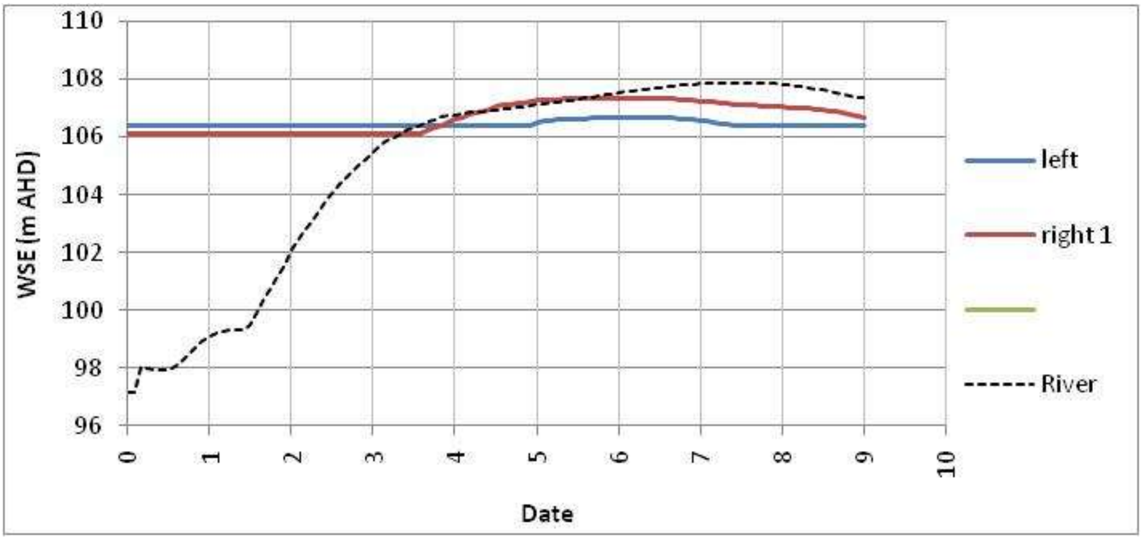

Figure 7-27 Model G downstream extraction line 60,000 ML/d

7.3.4 Model Reach H1

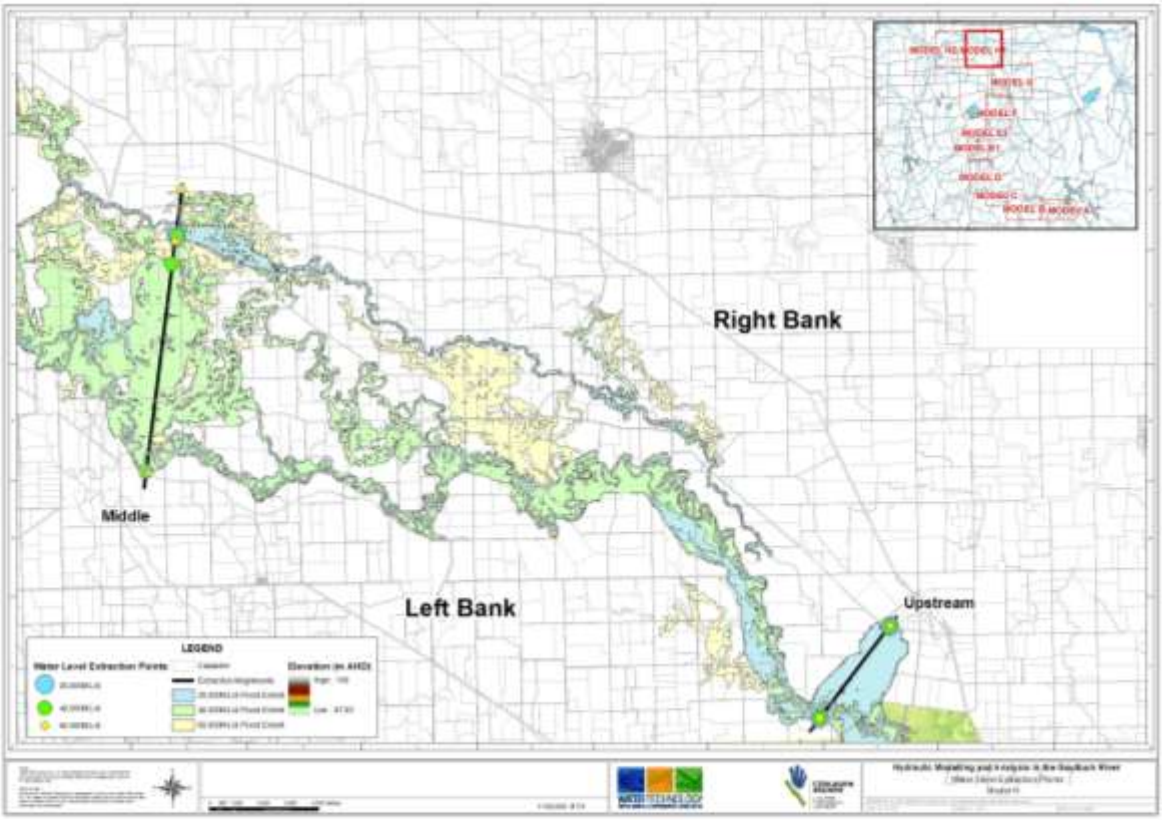

Figure 7-28 Overview of model reach H1 with hydrograph extraction points

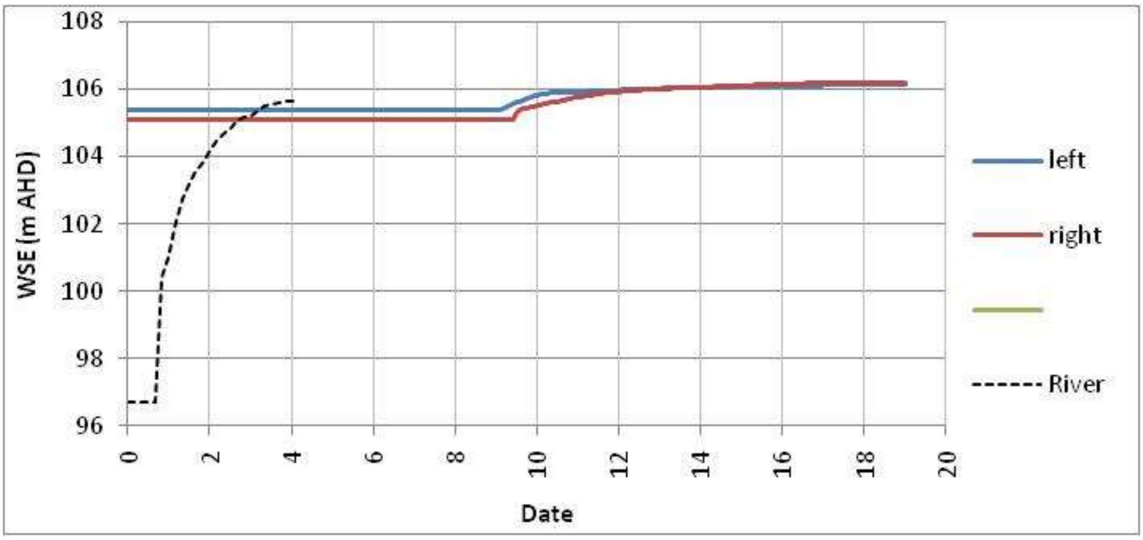

Figure 7-29 Model H1 upstream extraction line 20,000 ML/d

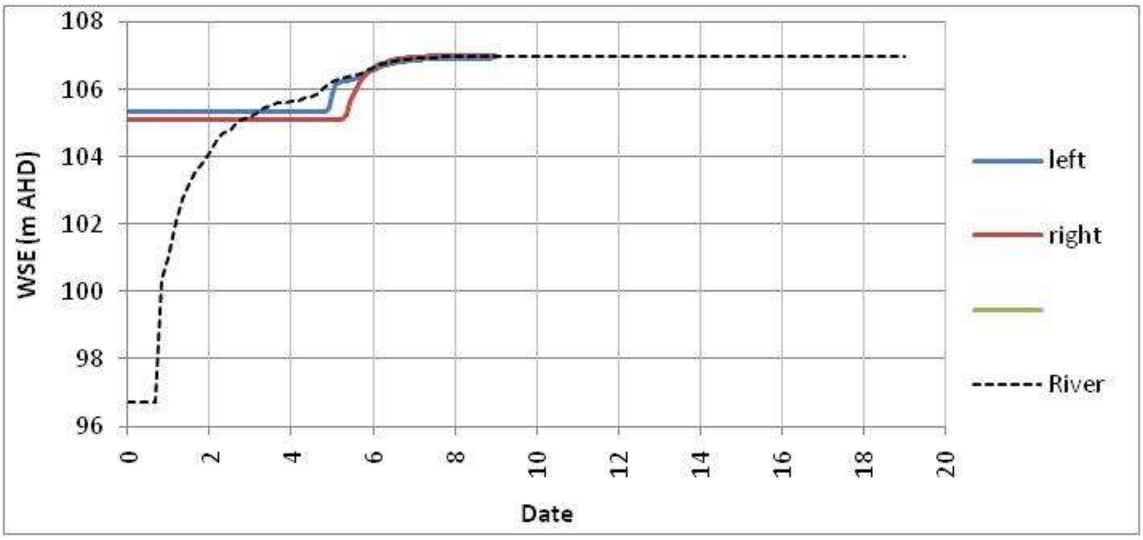

Figure 7-30 Model H1 upstream extraction line 40,000 ML/d

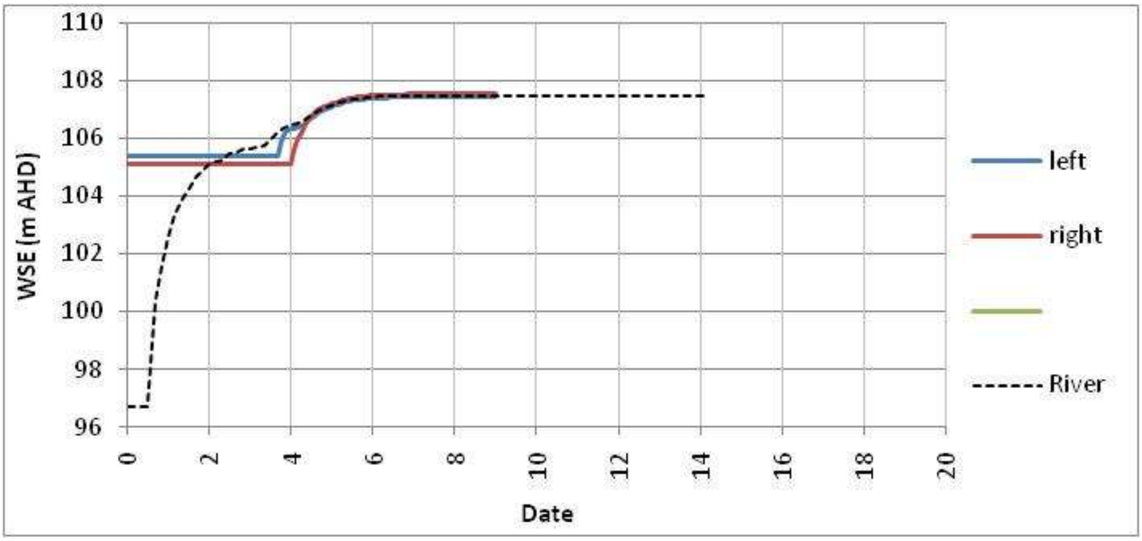

Figure 7-31 Model H1 upstream extraction line 60,000 ML/d

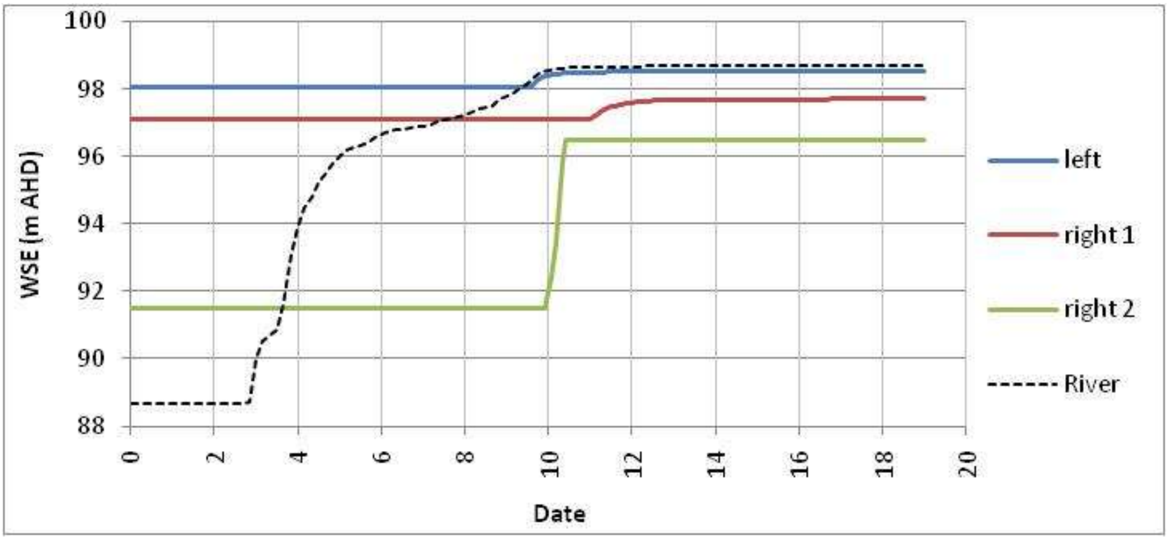

Figure 7-32 Model H1 middle extraction line 40,000 ML/d

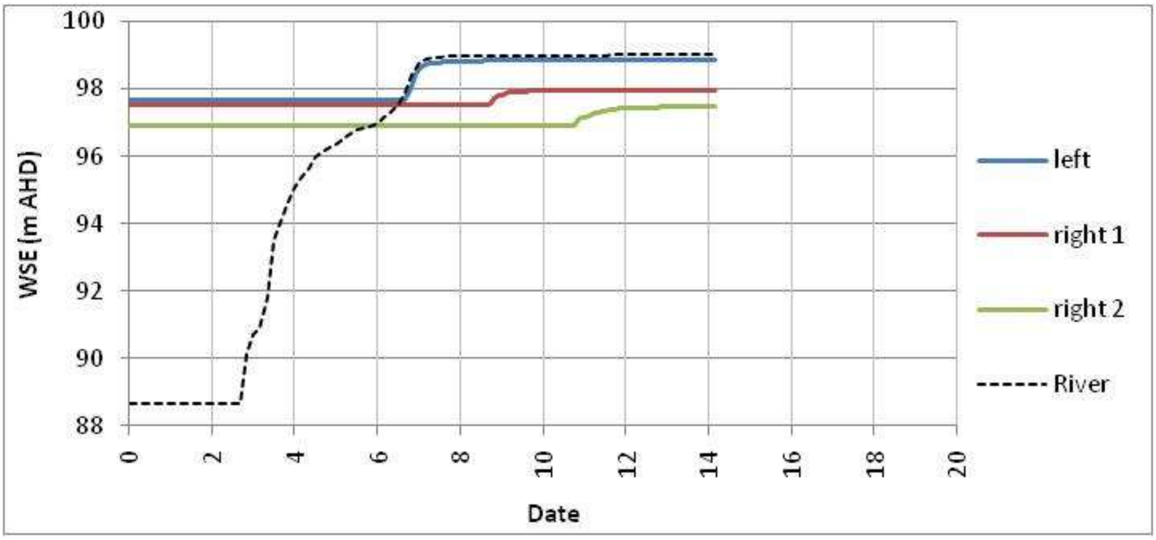

Figure 7-33 Model H1 middle extraction line 60,000 ML/d

7.3.5 Model Reach H2

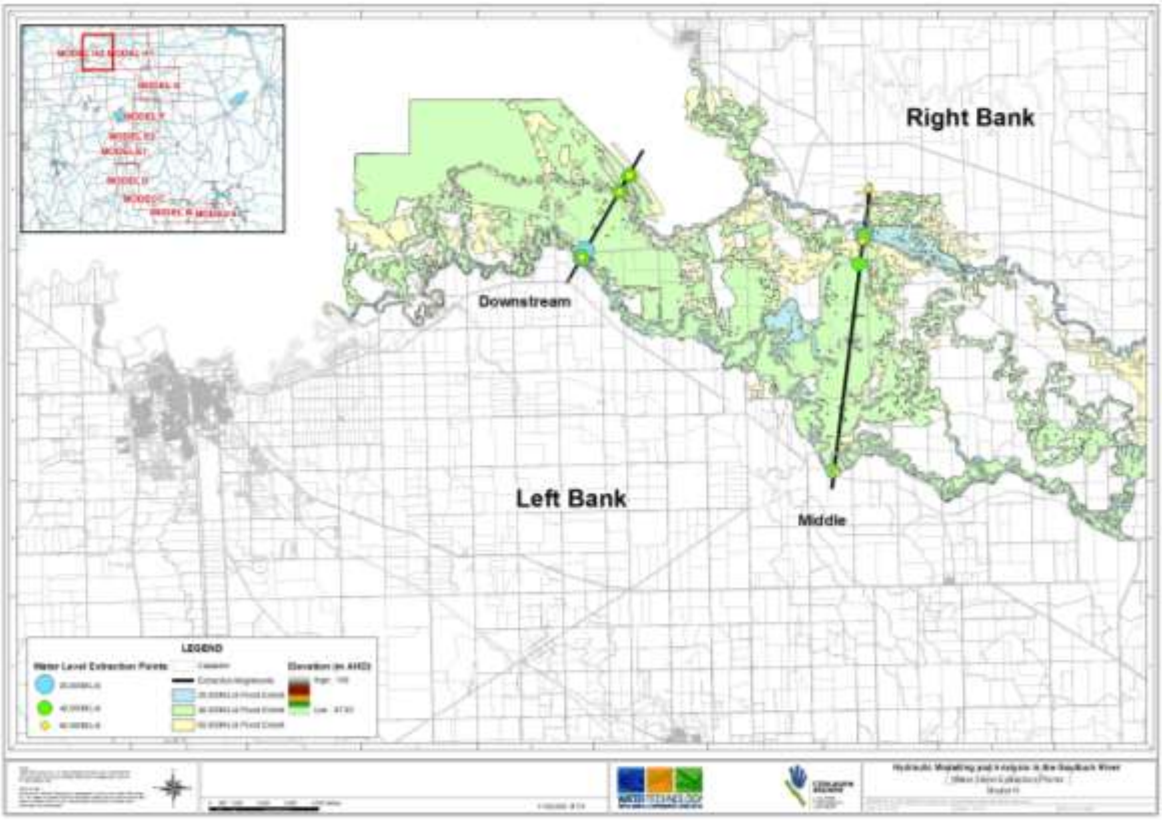

Figure 7-34 Overview of model reach H2 with hydrograph extraction points

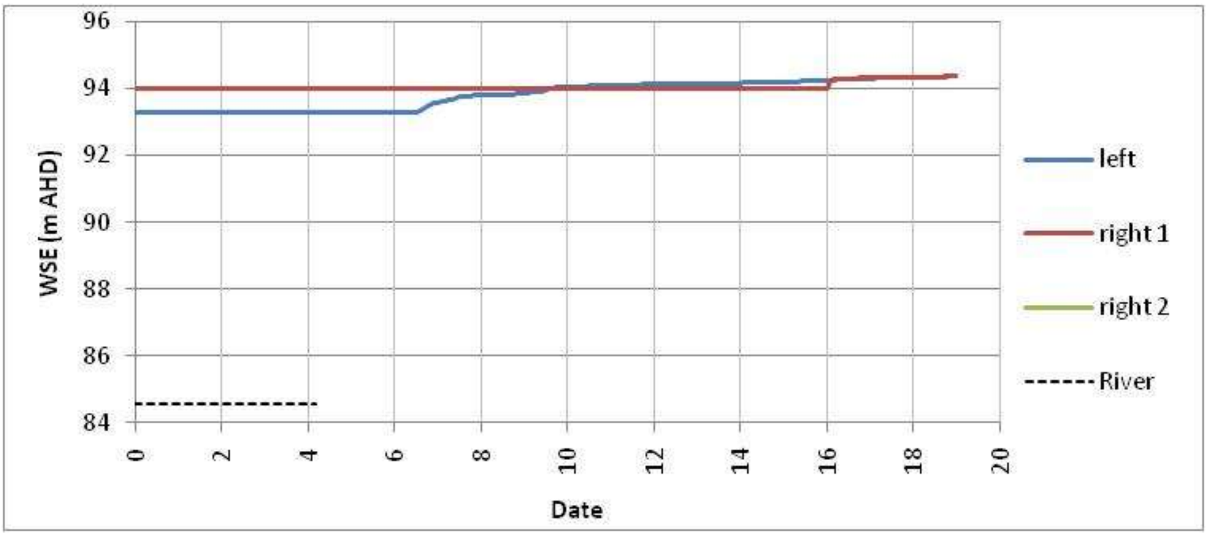

Figure 7-35 Model H2 downstream extraction line 20,000 ML/d

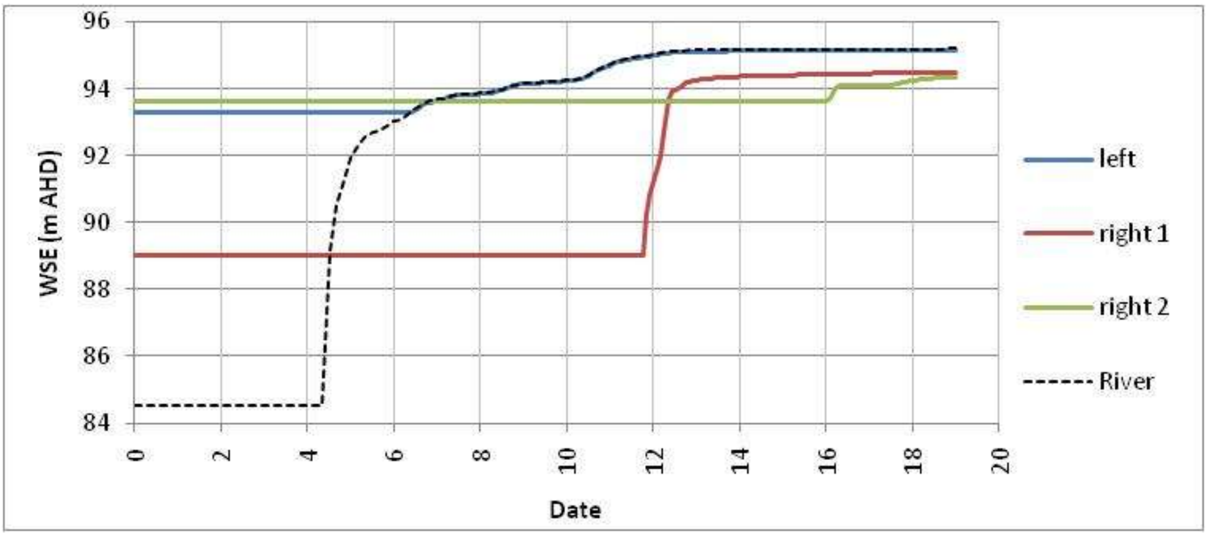

Figure 7-36 Model H2 downstream extraction line 40,000 ML/d

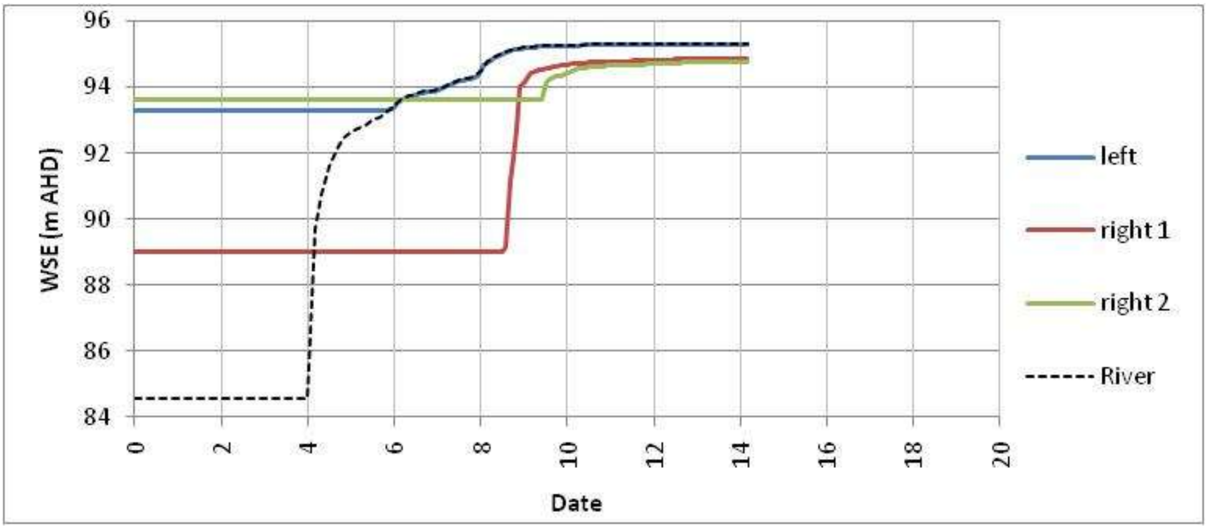

Figure 7-37 Model H2 downstream extraction line 60,000 ML/d

8. SUMMARY

This document outlines a series of statistics and analysis that has been undertaken using data collated and model scenario results from the Goulburn River Environmental Flow Hydraulics Study (Water Technology 2010). The key findings are summarised below for each of the six tasks.

Task 1

Significant areas of private land are inundated at 60,000 ML/d, with the lower Goulburn River model reach H having approximately 40% of the total private land inundated. Similarly model reach H also contains just under 50% of the total crown land inundated at 60,000 ML/d.

Task 2

Approximately 8 km, or 4% of the total levee length is overtopped at 60,000 ML/d, this is generally at the downstream end of the floodplain around Yambuna. At 20,000 ML/d there is not much levee with water impacting on it, only around 18km. At 30,000 ML/d this dramatically increases to 116 km, and further increasing to 170 km at 60,000 ML/d. If floodplain reinstatement was desirable, then perhaps these areas of levee impacted at the lower flows would be worth investigating further, as if removed would allow wider inundation at low flows.

Task 3

Three effluents were identified, Deep Creek, Wakiti Creek and Hancock Creek, all with culverts or regulating structures. Deep Creek is the first to commence to flow around 20,000 ML/d. If rating curves of these effluents are required then it is suggested that some historic hydrographs be modelled and rating curves developed from these. This will ensure the dynamics of the system is captured, rather than developing relationships based on an artificial rising limb or steady state flows. As a starting point the calibration runs modelled as part of the original Lower Goulburn Floodplain Rehabilitation Project (Water Technology, 2005) could be analysed.

Task 4

This task analysed numerous statistics for inundation within and outside of the levee system downstream of Shepparton. All the statistics showed a similar trend in large increases in inundation within the levee system between the flows of 20,000 and 30,000 ML/d, reflecting a floodplain threshold where large areas of land become inundated. Outside of the levee system the statistics trend reasonably uniformly as the flow in the river increases.

Task 5

The area of trees not inundated in the lower Goulburn River Model Reach H is significantly higher than in other reaches due to the floodplain being much larger, and the floodplain being protected by a levee system. If this levee system was altered or flows reinstated through Loch Garry then there would be significant potential for inundation of large areas of native trees that are not currently experiencing frequent inundation. Further analysis of the maps and the LiDAR may provide some indication of areas of trees not inundated that could be reinstated with localised environmental watering works.

Task 6

The lateral attenuation investigations showed a range of results dependent on the location along the Goulburn River. In the majority of the upper reaches there is only a minor delay in the floodplain rising as the volume is filled, but the river level and the floodplain level generally peak together. This reflects the relatively small floodplain in the upper reaches. In the lower reaches, such as Model Reach H, there is significant delay (up to a week) in the river peaking and then the edge of the floodplain peaking. This reflects the large volume required to fill the floodplain and also the anabranching nature of the lower floodplain, this effect is of course dependant on the flood peak magnitude and the dynamic shape of the hydrograph.