ANGLESEA RIVER FLOOD STUDY

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Glossary

AHD	Australian Height Datum. A universal reference level used in surveying.
ARI	Average Recurrence Interval, a term used in hydrology to describe the average interval in years between floods of a given magnitude or greater. Note that the actual intervals between such floods are subject to climatic variability and will not precisely match the average because their occurrence is irregular.
DTM	Digital Terrain Model – digital presentation of natural surface levels
HEC-RAS	River Hydraulic model. Developed by the US Army Corps for modelling river flows to determine water levels and other flow characteristics.
1D	One dimension – used to describe the type of hydraulic model. Flow is only considered to be in one dimension (ie. along the river)
2D	Two dimensions – used to describe the type of hydraulic model. Flow can be modelled in both down and across the river floodplain. (e.g. Cell models)
IFD	Intensity – Frequency – Duration. Relates to design rainfall intensity.
LSIO / FO	Land subject to inundation overlay / Floodway overlay
n	Manning n – a measure of stream roughness used to calculate stream velocity.
RORB	Catchment Runoff Model used to estimate catchment flood peaks.
Kc and m	Storage parameters used in the RORB model
IL	Initial loss (mm's) - Rainfall loss before runoff starts. Used in catchment runoff models
CL	Continuing loss rate (mm/hr) Rainfall loss rate during a storm event.
Rc	Runoff coefficient – Rainfall loss rate during a storm event.
Units	
Km	Length in kilometres
Sq km	Area in square kilometres
m^3/sec	Flow rate - cubic metres per sec
mm	Length in millimetres
mm/hr	Rate millimetres per hour

1.0 PURPOSE

The Corangamite Catchment Management Authority has completed a detailed hydrological study of Anglesea River catchment to determine design flow estimates for the hydraulic floodplain modelling of the Anglesea Township.

This study was required to update the flood information held by the CCMA received from the Flood Data Transfer Project completed for DSE in 2000. This work calibrates a detail RORB model with 2 small historic events to improve the reliability of the design flow estimates for modelling the Anglesea River floodplain. This work forms the basis of new flood overlays to be introduced into the Surf Coast Planning Scheme.

2.0 CATCHMENT HYDROLOGY

2.1 General Description of Catchment

Anglesea River at the Great Ocean Road has a catchment area of 125 square kilometres. The headwaters of the river is located in the top of the Otway Rangers and approximately 90% of the catchment is forested within a state park with moderate stream gradients (Figure 1 and Figure 2).

Two main catchments, north branch (Anglesea River) and the South Branch (Salt Creek), run parallel west to east joining together at the Alcoa Power Station just north of Anglesea. The catchment of the northern branch is 65km^2 with 91% forested and the southern branch is 51km^2 with 95% forested. The average slope of the main tributaries is 0.7%. Figure 1 shows the catchment extent and land cover.

The description of the land system is taken from “A Study of the Land in the Catchments of the Otway Ranges and adjacent plains” by A.J.Pitt for the Soil Conservation Authority in 1981. [Ref 6] The Anglesea River catchment falls into the Anglesea land system (7.2) and is described by the following:

“*Stretching inland from the coast between Bells Beach and Moggs Creek lies a dissected plain on Tertiary sediments. Long straight slopes emanate from spurs and ridges. The coastal margins are retreating and often abut the sea in steep cliffs or massive landslips and earthflows.*

The parent material is very variable, ranging from lateralized sediments on the ridges to relatively unweathered alluvium in the drainage lines. Thus the soils are particularly variable.

In general, plant nutrient levels are low and surface horizons are weakly structured. Plant communities are mainly open forests less than 15m in height; the height decreases towards the coast under the influence of salt-bearing winds. The area is highly regarded for its diversity of flora. Some parts have been cleared for agriculture. The main hazards to land use are gully erosion and sheet erosion.”

In the component table for this land system 60% of the catchment is covered by Grey sand soil that is listed having a very high permeability with depths > 2m. The extent of this soil is shaded pink in Figure 3.

2.2 Available Data Sources

Information available for this catchment consists of:

a) Observed flow data (Instantaneous flow from one sites in the catchment)

   Site 235222 – Anglesea River (Salt Creek) @ Anglesea (1968-1981, 2010-2012)

b) Daily read rainfall records for stations surrounding the Anglesea River Catchment.

BoM site ID	Name	BoM site ID	Name
87001	Anglesea	87119	Anglesea (VPG)
87124	Buckley	87126	Wurdiboluc Res
87160	Torquay Golf C	90004	Barwon Downs
90037	Eastern View	90061	Pennyroyal
90180	Aireys Inlet	90187	Boonah
90188	Benwerrin		

c) Pluviograph rainfall data is available from BoM AWS and flood warning stations from around 2000. Very little pluviograph rainfall data is available in the 1970’s near this catchment.

2.3 RORB Model Formation

A runoff routing model like RORB is required to give design hydrographs as input into the hydraulic model of the Anglesea River.

A 35 subarea catchment model of the Anglesea River was formed using GIS information held by the Authority. Ten metre contour intervals were used to determine the catchment boundaries and graphical tools used to calculate areas. Stream lengths were measured from the GIS hydro25 layer. Both the contours and stream data originated from the 1:25,000 topographic maps.

The subarea size was determined to ensure that sufficient subareas existed on both the North and South Branches to be able to make reliable estimation of peak flow runoff for each catchment. The subarea size varied from 220 to 720 hectares, with an average size of 360 hectares. The north and south branch catchments have 15 and 14 subareas respectively.

The maximum distance of any subarea from the Great Ocean Road is 18.8km for Subarea A and the average distance for all subareas is 12.4km (i.e. Dav).

Figure 1 shows the layout of the subareas and reaches in the catchment. The location of the gauging station is also shown as a red triangle. Figure 2 shows the layout against the crown land shown shaded green. Figure 3 shows the catchment layout over the soils map with the majority of the catchment shown to have Grey Sands Earth category (coloured pink on the plan). With such an extent of deep sandy soils in the catchment, the rainfall losses are expected to be high.

Appendix A is the basic RORB catchment data file formed following the guidance of the RORB User Manual [Ref 2].

2.4 Calibration of the RORB Model

Only two historic flood event are available that can be fitted to recorded hydrographs to calibrated the RORB catchment storage parameters (Kc and m). Storage parameters that gave the best fit to observed data was Kc= 36 with m= 0.7.

The storm pattern used and subarea rainfall totals for the calibration run are shown in Appendix A table.

No catchment rainfall pluviograph data is available for the November 1978 flood. The nearest available data comes from Warrnambine on the other side of the Otways.

Flood Event	Salt Creek (Site 235222)	Great Ocean Road	Rainfall Losses IL (mm)/ RC
Nov 1978	12.3	33	42 / 0.87
Jan 2011	5.2	12	70 / 0.22

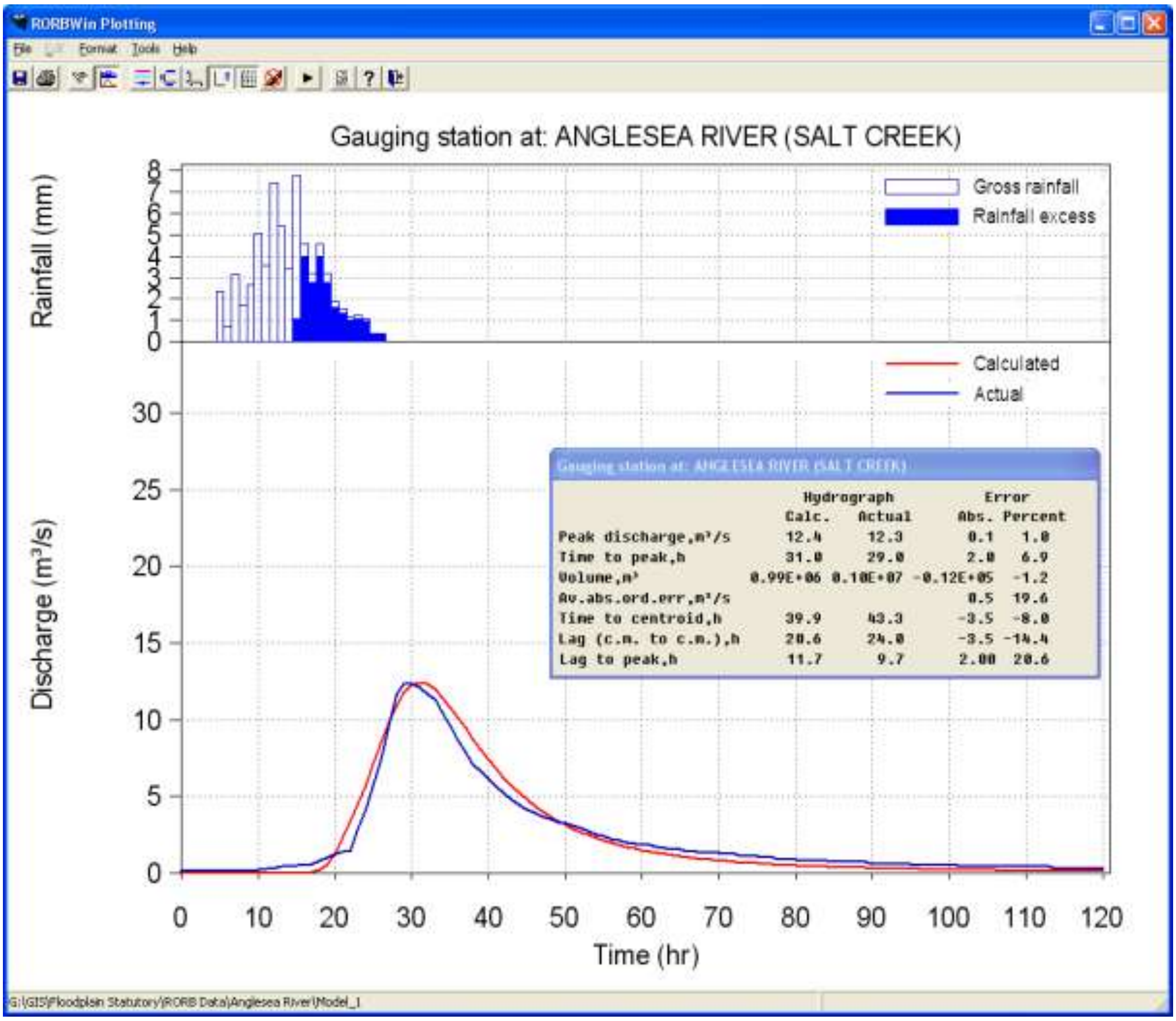
No base flow adjustment is required for this catchment (less than 0.1 m3/s).

Appendix B shows the RORB plots of the calibration runs for these flood event.

The Nov 1978 fit to the observed flood hydrograph is reasonable in both shape and timing. The Jan 2011 fit shape is good but has a 10 hour time delay to the observed peak. This event has a relatively small peak flow with an average recurrence interval (ARI) of less than 2 years. The majority of the catchment rainfall for both events was taken up by the initial loss. This may be typical for this catchment being medium undulating with sandy soils and mostly forested.

The November 1978 fit results are shown below.

KC= 36 m= 0.8 IL= 42mms RC= 0.87



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Gauging station at: ANGLESEA RIVER (SALT CREEK)
                             Hydrograph          Error
                           Calc.    Actual     Abs. Percent
Peak discharge,m³/s         12.4     12.3       0.1    1.0
Time to peak,h              31.0     29.0       2.0    6.9
Volume,m³               0.99E+06 0.10E+07 -0.12E+05   -1.2
Av.abs.ord.err,m³/s                             0.5   19.6
Time to centroid,h          39.9     43.3      -3.5   -8.0
Lag (c.m. to c.m.),h        20.6     24.0      -3.5  -14.4
Lag to peak,h               11.7      9.7      2.00   20.6
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Figure 1 – Anglesea River Catchment

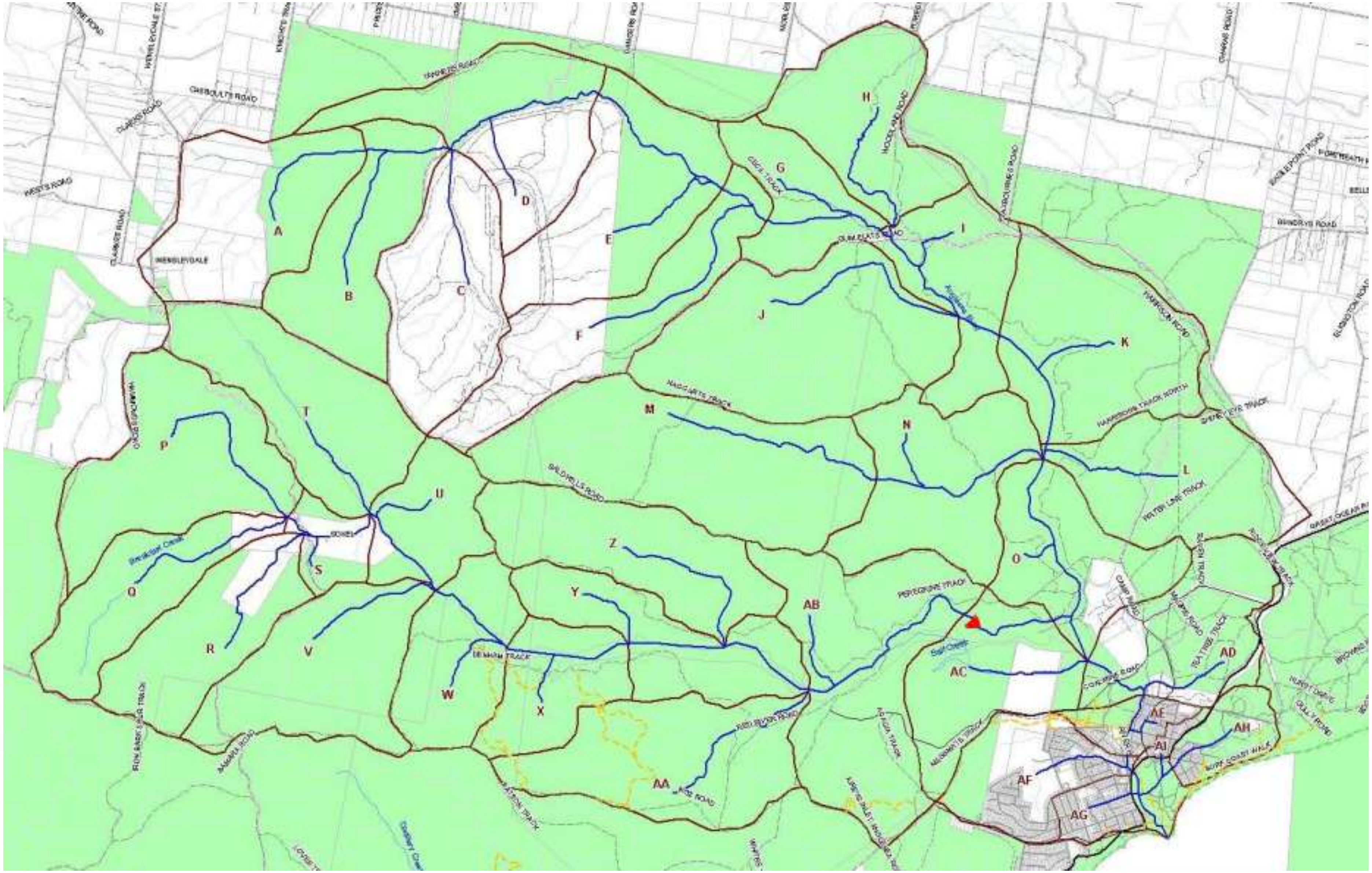


Figure 2 – Anglesea River Catchment Land Tenure (Crown land shaded light green)

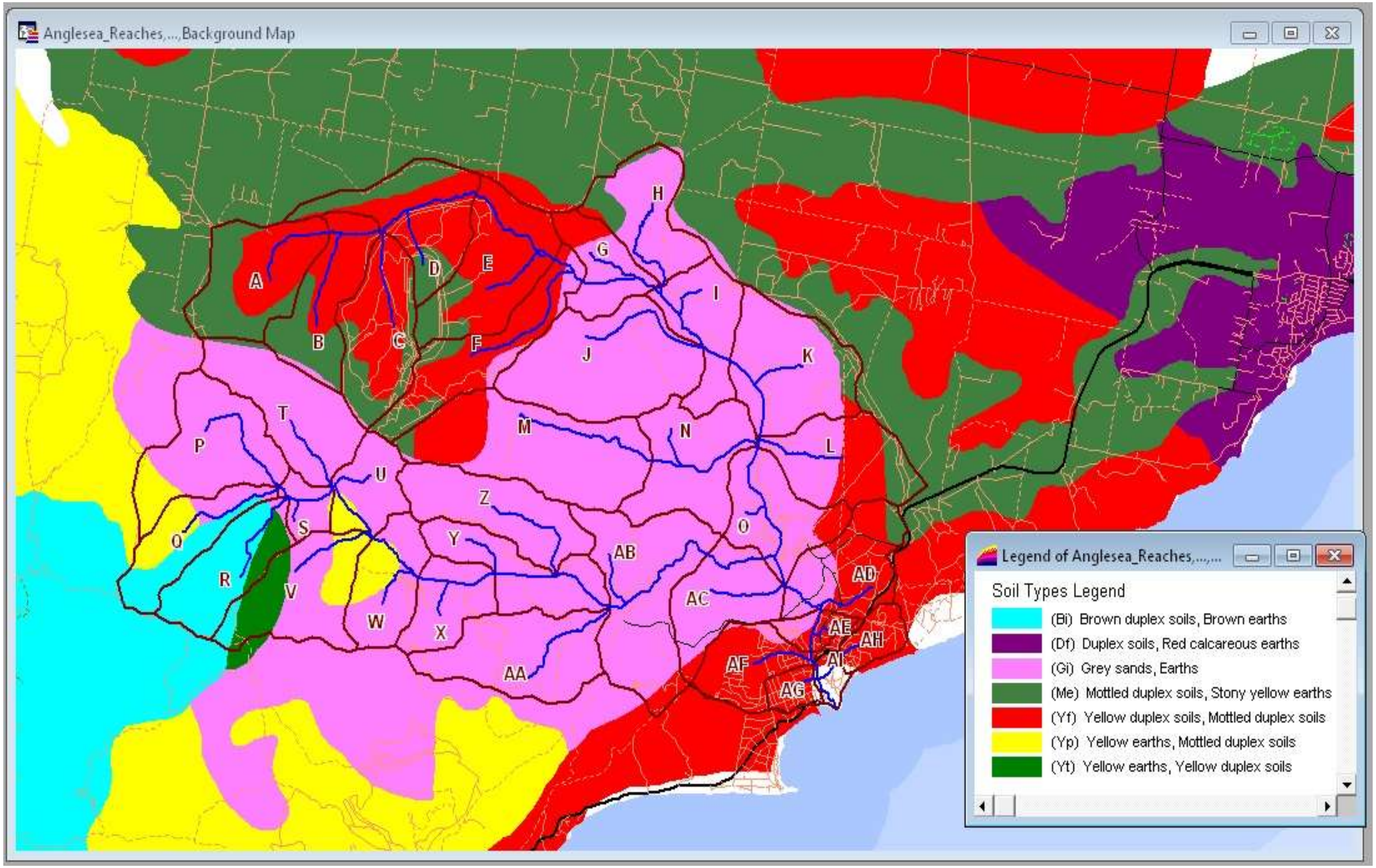


Figure 3 – Anglesea River Catchment Soils Map

2.5 Statistical Analysis of Peak Flows on Salt Creek at Alcoa (Anglesea)

A continuous flow record exists at site 235222 (Salt Creek) from 1968 to 1981 and from 2010 to today. The continuous flow record at this site is 17 years.

A standard statistical analysis (partial series) of peak flows at site 235222 (Salt Creek) has been performed. A log Pearson (LP3) distribution was fitted to the observed data points giving design peak flow estimates for frequencies 1, 2, 5, 10, 20, 50 and 100 yr ARI. Reliable estimates up to 20 yr ARI is expected from this data set.

The degree of confidence in this analysis does rely on the rating curve used at this site. Rural Water Commission and now Thiess Services have maintained this site and the highest gauging performed to date was at 0.36 m (86 Ml/day) in July 1978. The current rating curve extends up to 1.6 m staff reading (1800 Ml/day).

Data was downloaded from the Data Warehouse site for 1976 to 2013. Additional data is available back to 1967 from the RWC's "Victorian Surface Water Information to 1987- Volume 2"

The five top flood events recorded at site 235222 are shown in the table below.

Rank	Flood Event	Peak Level (m)	Flow (Ml/day)	ARI (yrs)
1	Sept 1976	1.42	1552	18
2	Dec 1978	1.25	1250	10
3	Nov 1978	1.14	1068	7
4	Aug 1978	0.99	802	4
5	Dec 1970	0.94	782	3.5
	…..			
11	Jan 2011	0.64	488	1.5

The estimated design discharges based on the best fit to the recorded data is shown in the table below for Site 235222 (Salt Creek).

The estimates have been based on a LP3 fit to the highest ranked partial series data. The LP3 fit was adjusted at the low and high ends to fit the plotted points better.

Log 10 stats of this data in Ml/day are :	Mean	2.770
	Standard Deviation	0.204
	Skew	0.55

ARI (yrs)	Peak Flow (m3/sec)	Peak Flow (Ml/day)	95% Confidence Limit (Ml/day)	5% Confidence Limit (Ml/day)
1	3.5	300	160	360
2	6.9	600	460	700
5	10	900	670	1100
10	14	1200	800	1500
20	19	1600	900	2100
50	27	2300	1000	3100
100	35	3000	1100	4200

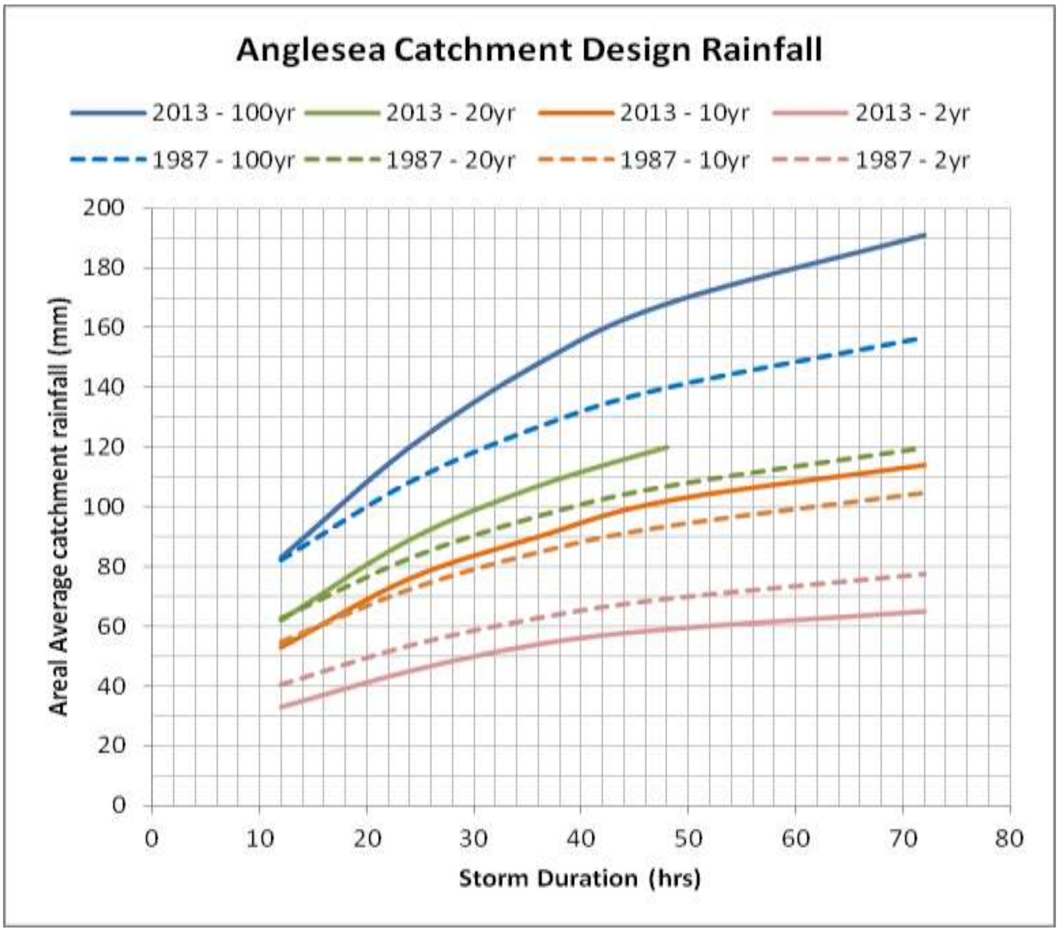
Appendix C shows the data and graph of the fitted frequency curve against recorded data with 5 and 95% confidence limits.

2.6 Design Run Parameters for RORB Model

The following calibrated RORB model catchment storage parameters were used :

Kc = 36 and m = 0.70

The Bureau of Meteorology has just released Intensity-Frequency-Duration (IFD) data for Australia. This new data has significant differences in totals from the previous data presented in Australian Rainfall & Runoff Vol 1 (AR&R) [Ref 1]. The graph below shows the difference in average catchment rainfall between the old and new estimates for the Anglesea River catchment. This study has used the new IFD data.

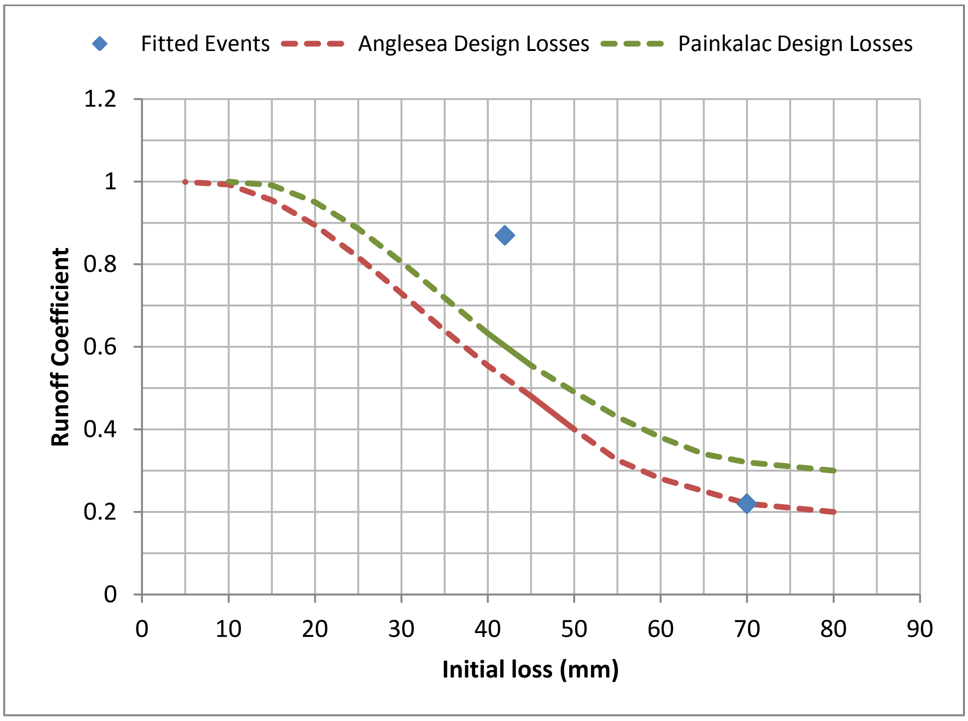


Design rainfall totals for each subarea were estimated for ten representative points evenly spaced over the catchment area. New IFD values for these 10 sites were taken from the BoM web site for 12, 24, 48 and 72 hour duration. Intermediate storm duration of 36 hours was created assuming a Log Normal relationship.

For each duration a graphical grid of these rainfall depths was created using triangulation in Mapinfo. The subarea design depths were then read from each graphical grid giving a variation from the top to the bottom for all subareas in the model. The new IFD data has not been incorporated into RORB multiple design run mode at this stage so individual design runs files were created for ARI and storm duration. Appendix D shows the BoM IFD output for a particular site (Anglesea VPG) for a range of ARI and storm duration. Appendix E shows the design subarea rainfall totals used for the RORB design runs and a map showing design rainfall isohyets for the 100yr ARI 48 hour duration storm.

The RORB model was then ran in design mode for each ARI / storm duration and design rainfall loss rates were calibrated to match the peak flow estimates from the statistical analysis at the gauging site 235222. The longer storm duration was found to generate the highest peak flow for ARI's 1 to 100 years.

The fitted loss rates were found to be consistent with ARI except for the 2 year ARI storm events. A relationship between Initial and runoff coefficient was established to allow a fitting process. The graph below shows the relationship assuming a maximum Rc of 1.0 for IL < 10mm and minimum Rc of 0.2 for IL > 80mm. No real basic for this relationship has been developed at this stage due to lack of recorded flood events but it follows a similar pattern found for the Anglesea River catchment. The part used for design runs is shown as the solid red line.



The table below shows the adopted rainfall losses used in the RORB design calibrations runs to best match the statistical analysis at Salt Creek at the Alcoa Power Station (Site 235222). These losses are considered to be high but acceptable due to the highly forested, moderate sloping and sand soil catchment. Similar high rainfall losses was found for the Anglesea River catchment.

ARI (yrs)	Critical storm duration (hrs)	Losses		Peak Q (m^3/s)	
		IL (mm)	Rc	Rorb Model	Stat Analysis
1	72	44	0.49	3.5	3.5
2	72	37	0.60	6.8	6.9
5	48	44	0.49	9.8	10
10	48	45	0.48	14	14
20	48	46	0.47	19	19
50	36	46	0.47	27	27
100	48	45	0.48	35	35

No allowance for base flow has been made. Base flows from observed events predict that base flow will be less than 0.1 m^3/s during flood event.

2.7 Climate Change Effect on Design Rainfall

Climate change impact on flood producing rainfall events on the Anglesea River catchment is difficult to estimate at this time with both increasing and decreasing trends predicted. In a recent paper on climate change for the Corangamite Region prepared by CSIRO (Atmospheric Research) [Ref 4] indicates that :-

- Annual rainfall totals are likely to decrease, ranging from +10% to -25% by 2070;
- Projected rainfall decreases are strongest in the spring and then winter, the most likely time for floods from this catchment (ie 8 of top 10 from 1975 to 2012);
- Extreme short duration rainfall events may become more intense and more frequent with thunderstorms.

At this stage no change in design rainfall due to climate change is proposed in this study.

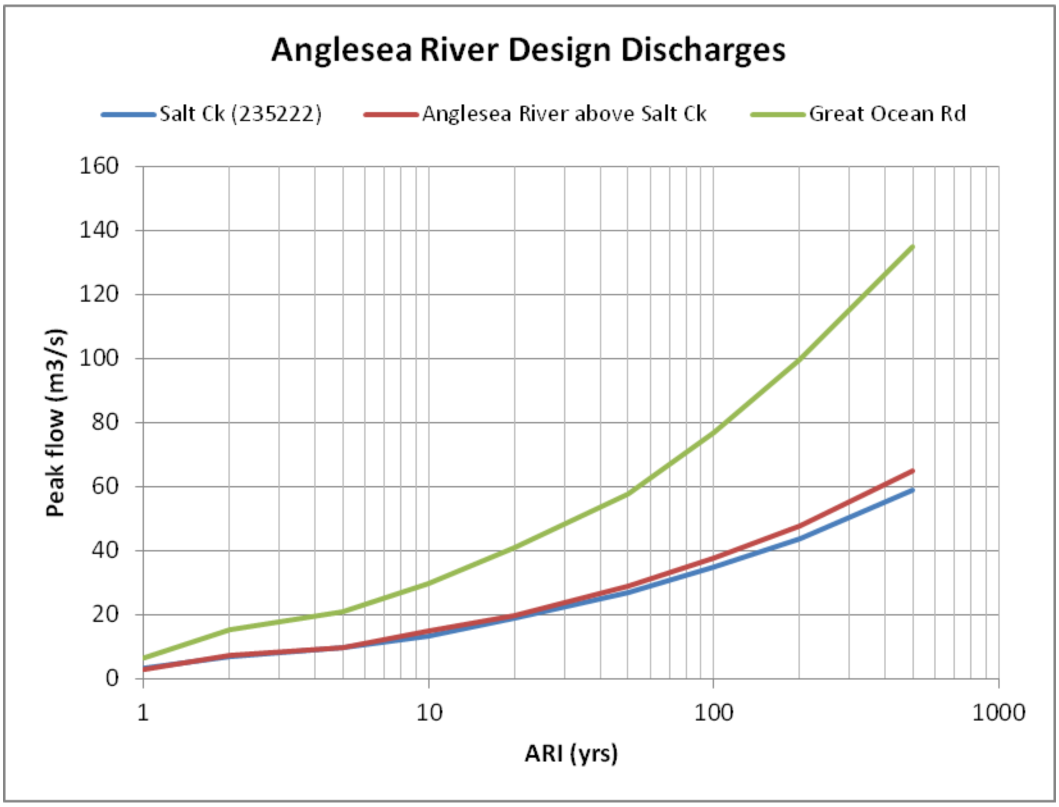
2.8 Results of RORB Modelling

The critical design storm duration was found to vary from 36 to 72 hours depending on design frequency. The long critical storm durations for this catchment is a result of high initial loss used in the design runs, especially for the more frequent floods.

The peak flows for the Anglesea River resulting from this work is shown in the table below. The 100yr ARI estimate for the Anglesea River at Great Ocean Road is 77 m3/sec. The peak flows from both the north and south tributaries at Alcoa are peaking at similar flows values and time.

The adopted design flows for the Anglesea River are shown in the table below at four locations.

ARI (yrs)	Salt Creek (235222) (m^3/s)	Anglesea River above Salt Creek (m^3/s)	Anglesea River at Coalmine Road (m^3/s)	Great Ocean Road (m^3/s)
1	3.5	3.0	6.4	6.5
2	6.8	8.3	15	16
5	9.8	10	20	21
10	14.1	15	29	30
20	19	20	40	41
50	27	29	57	58
100	35	38	75	77
200	59	62	98	100



Anglesea River Flood Frequency Curves

3.0 FLOODPLAIN HYDRAULIC MODELLING

The Anglesea River Estuary level is controlled by a sand bar (berm) at the ocean end of the estuary. The sand bar height builds up from sand blown along the beach and by normal wave action along the beach. The height of the sand bar varies from 1.2 to 2.1 m AHD and is mechanically opened when the estuary water level exceeds 1.7 m AHD. The time for a catchment flood event to peak at Great Ocean Road varies between 24 to 36 hours from the start of rain allowing little warning time to lower the sand bar or open the estuary artificially to the sea. A flood event will scour a channel through the sand bar when it is overtopped with an estimated base width of 15 to 25 metres and a depth up to 1.2 metres.

Unfortunately there is little recorded data on the sand bar breach channel dimensions (ie. width, slope and invert level) and the CCMA will in future record this information after flood events. The boundary condition of this sandbar for any hydraulic model of the Anglesea River estuary is critical in estimating flood levels along the floodplain. A conservative assumptions on sand bar height and breach channel dimensions have been made in this report .

3.1 Sea Surge into Estuary

Current and future ocean tide levels are also is an important boundary condition for a hydraulic model of the Anglesea River estuary. The CSIRO released a paper on “The effect of climate change on extreme sea levels along Victorian coast” in November 2009 [Ref 4].

The table below gives the expected peak tidal surge levels at Lorne Victoria for the future assuming a sea level rise based on IPCC 2007 A1FI scenario. The levels shown are mean sea levels in deep water and therefore *do not include wave setup and wave run-up.*

ARI (yrs)	Current Climate (m AHD)	Year 2030 (m AHD)	Year 2070 (m AHD)	Year 2100 (m AHD)
	Sea Level rise	0.15	0.47	0.82
1	0.80			1.56
2	0.95			1.75
5	1.15			1.98
10	1.32	1.47	1.79	2.14
20	1.46	1.61	1.93	2.28
50	1.59	1.74	2.06	2.41
100	1.69	1.84	2.16	2.51

The current policy for CMA’s with respect to sea surge events is to use current climate levels with a higher freeboard of 500mm. For a starting height of the estuary berm at 2.0 m AHD, it is unlikely that sea surges will be a critical flood event for the Anglesea River floodplain for some time.

However, it is likely that sea level rise will naturally increase the height of the estuary berm with time that will result in an increase in flood frequency on the land side of the berm. This will require careful management of the berm height in the future.

3.2 Recommended Design Scenario

A HEC-RAS model of the Anglesea River estuary was created using the following data:

- Cross sections of the floodplain taken from the Coastal LiDAR data set with a reported accuracy of 0.1m vertically. The average distance between cross sections is 180 metres. The location of the cross sections are shown in section 3.6 map as blue lines across the floodplain;
- Run the HEC-RAS model in 1D full dynamic mode;
- Design hydrographs are taken from the RORB model output corresponding to the critical storm duration for the peak flow;
- Normal tide cycle is assumed at the downstream boundary condition. An average tide levels between the neap and king tide times are used;
- The starting level of the estuary berm is 2.0 m AHD and allow the berm to naturally begins to breach once it has overtopped with 50mm of water;
- The starting level of the estuary before the flood is 1.6 m AHD.
- The breach channel is assumed to develop to full size within 5 hours of the berm overtopping;
- The maximum breach channel is 20 metres wide and 1.2 metres deep during the peak flood flow. The breach channel width will continue to grow as the peak flood flow has passed.

During the assumed breach time of 5 hour, 3000 m^3 of sand is scoured out requiring an average sand content of 3900 ppm in the flow that passes in that time. The average flow velocity during the breach development is 1.3 m/sec and the breach time is considered a reasonable assumption for the berm to fully breach.

The Jan 2011 flood event was not big (12 m^3/s) but some information on a natural breach of the berm is known. The estuary level before the flood was 1.55 m AHD and the estuary level after the event was 0.9 m AHD. The following photographs show the before and after the flood event but no survey measurements of the Anglesea River berm were recorded. The before photo shows that the berm height was about 1.7 m AHD and a breach channel from a previous opening existed.

Estuary berm on the 11 Nov 2011 before the flood

Estuary breach after the Jan 2011 flood

The photographs show that the berm cut by the flood is wider and shallower than what occured at the Anglesea River estuary. The critical part is estimating the dam break channel dimensions in the design model.

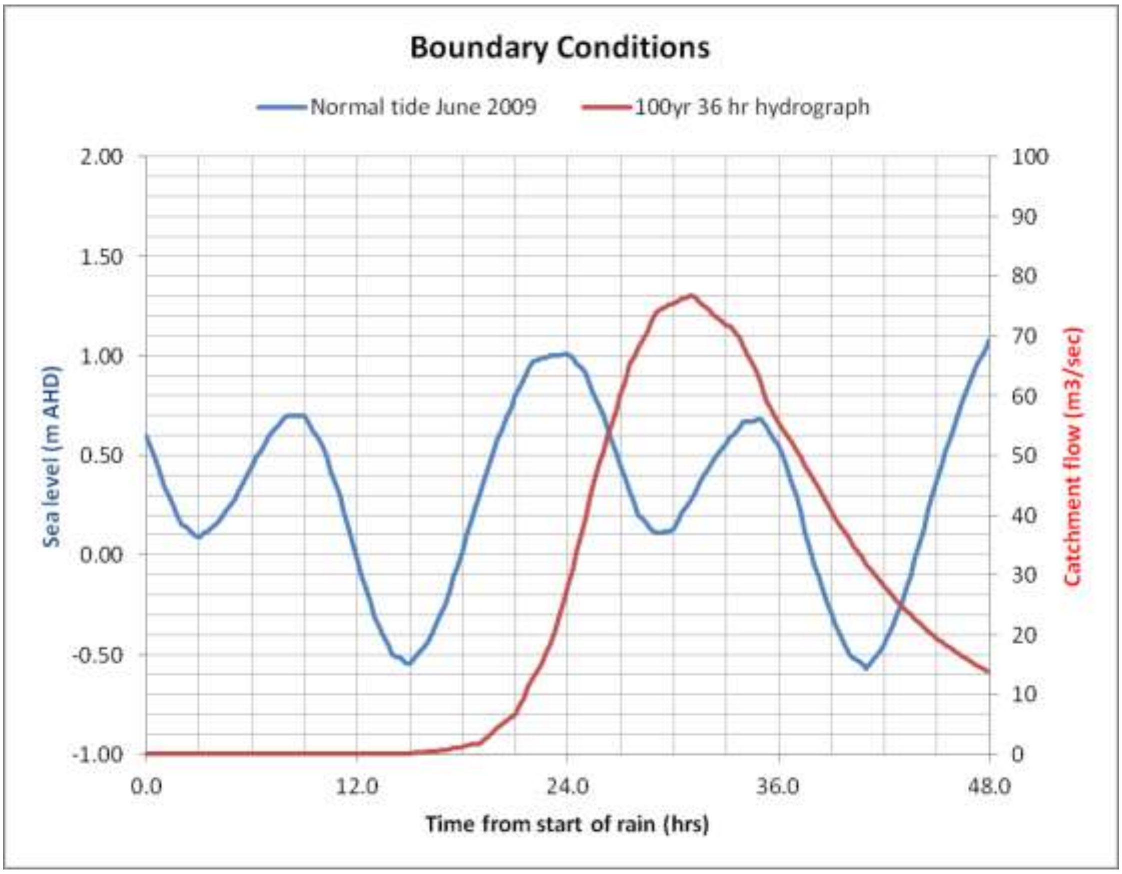
The November 2011 flood exposed the remains of the old rock wall that was constructed across the estuary to maintain a higher lake level. This wall was damaged from a flood and was abandon. Parts of the wall have been removed by Surf Coast Shire Council in 2013.

3.3 Hydraulic Model parameters

The channel roughness in the hydraulic model has been estimated to be:

- Normal river section lower section, n = 0.025
- Outside normal river section, n = 0.04 to 0.05
- Breach channel in sand, n = 0.02

The boundary conditions for the tide and flow input is shown below. The peak of the flow coincides closely with a high tide.



The berm breach mechanism is setup in HEC-RAS as an inline dam breach structure.

The breach channel to the sea will have a slope steeper than 1/100 and will be super-critical flow and therefore will not have hydraulic influence upstream on the dam break mechanism used in this unsteady model. Hydraulic calculations have confirmed that a breach channel fully formed with a slope of 1/100 will be super-critical flow for a range of flows 5 to 200 m^3/sec.

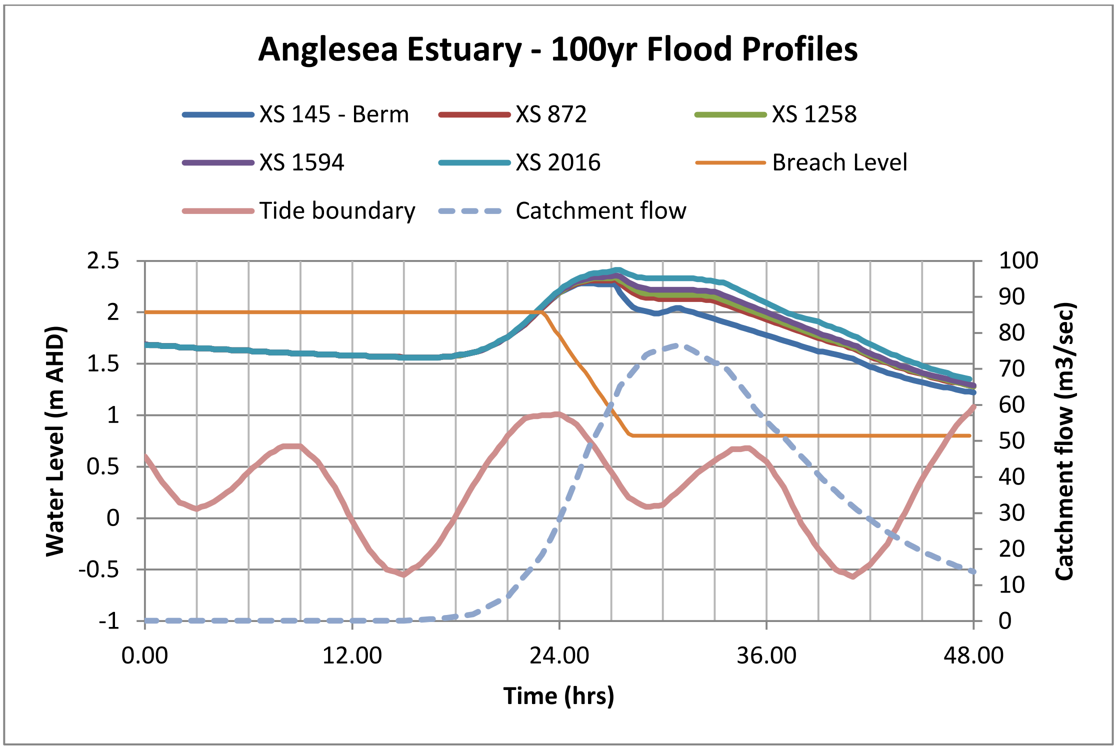
The breach channel is assumed to form and hold the channel shape specified in the dam break setup for the duration of the flood event. In reality the breach channel will continue to enlarge beyond that is specified for the dam break, especially at the channel sides. However it is considered that the dam break mechanism is a reasonable assumption to estimate peak levels on the Anglesea River Estuary as they occur when the breach channel is forming.

The characteristic of the adopted dam breach mechanism is shown in Appendix H. Model results of sediment transport required by the assumed breach mechanism is confirmed by applying Yang Sediment Transport Function during the breach time.

3.4 Expected Effect on Flood Levels for Design Scenario

The graph below shows the water surface levels with time for five cross sections along the floodplain. The cross section names represent the distance from the ocean in metres, so XS 872 is 872 metres upstream of the ocean and is approximately 100m downstream of the GOR bridge. The orange line shows the berm height with the breach occurring between 23 and 28 hours, dropping the berm down to 0.8 m AHD. The breach is fully formed about 3 hour before the peak flow arrives from the catchment. The timing of the breach occurring with respect to the peak flow is critical to the resulting water surface levels for all cross sections.

At each cross section the maximum water level occurs at different times due to different combine flows from the catchment flood and flow out of floodplain storage. The peak flood level for all of the cross sections is caused by the berm and consequence breaching. The XS 2418 just downstream of Coalmine Road is far enough upstream for its peak level to be caused by the catchment flood.

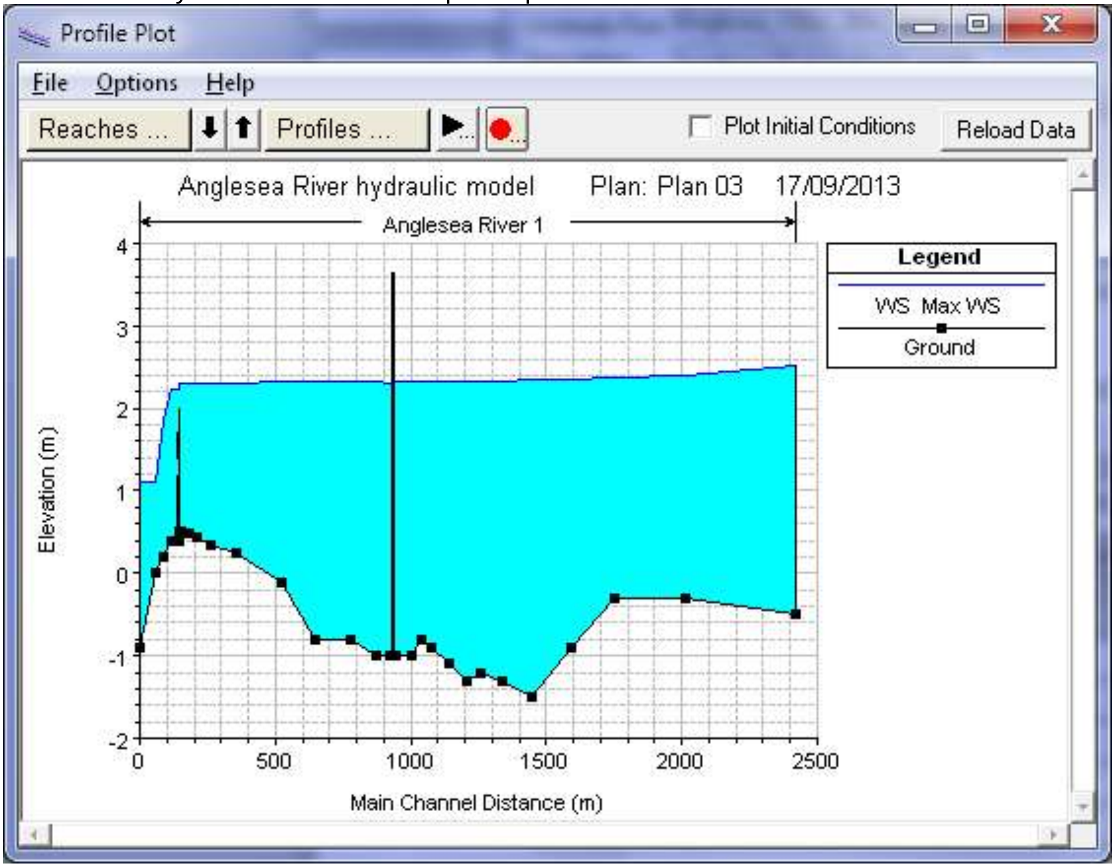


The maximum water surface levels along the floodplain for the 100 year ARI event is shown in the following table with the HEC-RAS profile plot. More detail for each cross section can be found appendix F.

	XS 150	XS 872	XS 1258	XS 1594	XS 1752	XS 2016
Distance from Ocean (m)	150	872	1258	1594	1752	2016
Invert level (m AHD)	0.50	-1.00	-1.20	-0.90	-0.30	-0.30
Maximum WSL (m AHD)	2.30	2.32	2.33	2.36	2.37	2.41
Time of peak level (hrs)	25.5	25.5	25.75	27.25	27.25	27.25
Velocity at peak level (m/sec)	0.47	0.23	0.48	0.52	0.60	0.60

Maximum velocities at the lower cross sections occur after the peak level and reach 0.5 m/sec at best. The maximum velocity through the bridge section is 1.0 m/sec.

HEC-RAS 100yr ARI maximum WSL profile plot.



Flood profiles have been modelled for 5, 10, 20, 50,100 and 200 year ARI flood events using the same berm breach scenario. The results are shown in the table below.

ARI (yrs)	Peak Flow (m^3/sec)	Maximum Water Surface Level (m AHD)					
		XS 150	XS 872	XS 1258	XS 1594	XS 1752	XS 2016
5	21	2.18	2.18	2.19	2.19	2.19	2.20
10	30	2.21	2.22	2.23	2.23	2.24	2.25
20	41	2.24	2.25	2.25	2.26	2.27	2.28
50	58	2.27	2.29	2.30	2.31	2.31	2.33
100	77	2.30	2.32	2.33	2.36	2.37	2.41
200	100	2.45	2.49	2.51	2.54	2.56	2.59

The results for higher frequency floods all have very similar results in the lower reaches of the floodplain with only cm’s difference. This is caused by the influence of the initial berm height and the breaching process.

3.5 Sensitivity of model parameters

Testing of the sensitivity of model parameters on calculated flood levels has been completed for the 100 year ARI 36 hour flood event.
The following model parameters have been tested:

- Berm Height
- Breach channel width and level

- Time for breach channel to form
- Flood peak and high tide timings

The results are shown in the following table. Parameters Breach channel width and invert level are shown to be not sensitivity to change. However starting berm height and time for full breach channel to develop are sensitivity to change and can result in significant increases in water surface levels.

Model sensitivity testing results:

100 year ARI - 36 hour flood event

Model Parameter	Starting Value	Peak Water Surface Level (m AHD)					
		XS 150	XS 872	XS 1258	XS 1594	XS 1752	XS 2016
Starting Berm Height (m AHD)	1.8	2.19	2.24	2.26	2.29	2.31	2.35
	2.0	**2.30**	**2.32**	**2.33**	**2.36**	**2.37**	**2.41**
	2.2	2.43	2.45	2.46	2.48	2.49	2.52
Full Breach channel width (m)	15	2.31	2.34	2.36	2.38	2.40	2.43
	20	**2.30**	**2.32**	**2.33**	**2.36**	**2.37**	**2.41**
	25	2.29	2.31	2.32	2.34	2.35	2.39
Full Breach channel invert (mAHD)	1.0	2.31	2.33	2.35	2.37	2.39	2.42
	0.8	**2.30**	**2.32**	**2.33**	**2.36**	**2.37**	**2.41**
	0.6	2.29	2.31	2.32	2.34	2.36	2.40
Time for breach channel to fully developed (hours)	3.0	2.21	2.23	2.24	2.25	2.26	2.33
	5.0	**2.30**	**2.32**	**2.33**	**2.36**	**2.37**	**2.41**
	7.0	2.37	2.40	2.42	2.44	2.46	2.48

The starting values and results bolded in the table above is the design base case.

The properties that are flooded from the 100 year ARI flood event are located between chainage 1000 and 2000 metres and are represented in the table above by XS 907 and XS 1695.

The base case model peak water levels occur just after the berm breach begins so breach channel width and invert will not impact on the peak results.

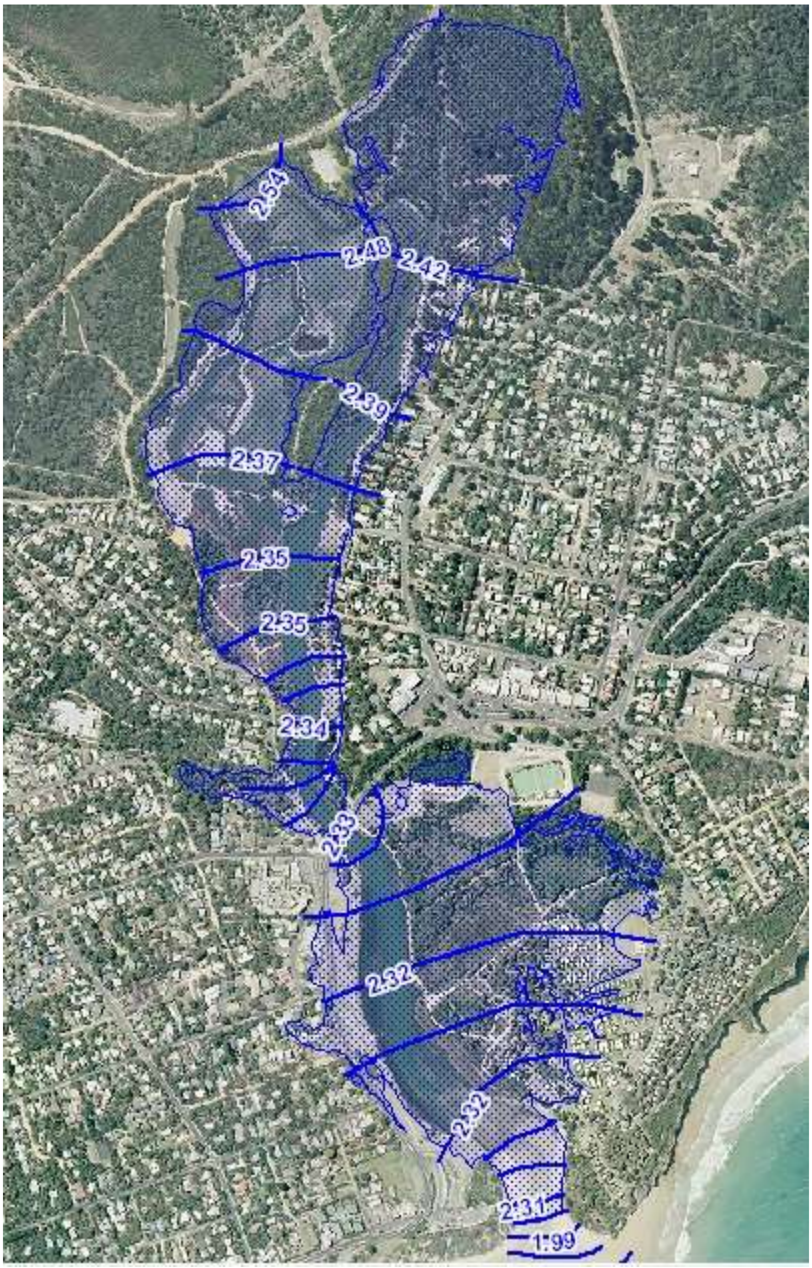
The starting berm height has the most significant impact on resulting flood levels in the lower and middle reaches. If the berm height is higher than the base case, then the time when overtopping begins is delayed and closer to the peak flood flow. The next significant impact is the time for berm breach to fully develop. If the breach time is increased then flood levels increase as the delay again moves closer to the flood flow peak.

Further monitoring of the berm height of the estuary over time and documenting the berm breach development during flood and opening events is required. Survey of berm breaches after floods is also required to record channel width and invert level. Photographic record (say) every 10 mins could be taken from a safe distance during the breach development to confirm the assumptions made for the breach mechanism.

3.6 Recommended flood extent and levels

The design scenario for the hydraulic model is adopted at this stage with a recommendation of monitoring the berm height of the estuary and surveying the breach channel as soon as possible after a flood event.

The 100 year ARI flood levels have used the total energy levels at each cross section reflecting the water level at the floodplain edge. The map below shows the resulting extent. The blue lines across the floodplain are the cross sections in the HEC-RAS model and the number represent the 100 year ARI flood levels.



References

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2. “RORB version 5 Runoff Routing program – User Manual” by E.M Laurenson, R.G Mein and R.J Nathan. January 2006.
3. “Climate Change in the Corangamite Region”, prepared by CSIRO (Atmospheric Research) on behalf of the Victorian Govt (DSE), 2004.
4. “The Effect of Climate Change on Extreme Sea Levels along Victorian Coast”, Prepared by CSIRO for DSE ‘Future Coast’ program. McInnes etal, Nov 2009.
5. “HEC-RAS River Analysis System – User’s Manual” by US Army Corps of Engineers. Version 4.1, January 2010.
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8. “Entrance Modelling and the Influence on ICOLL Flood Behaviour” by D Lyons and D Williams, BMT WBM Newcastle, 2012.

1 APPENDICES

A	**RORB Model catchment file**
B	**Calibration of RORB Model**
C	**Statistic Analysis of peak flows at Site 235222 (Salt Creek at Alcoa Power Station)**
D	**AR&R IFD Data**
E	**Design Subarea Rainfall totals**
F	**Design Discharges – RORB output**
G	**HECRAS model outputs**
H	**Berm Breach Characteristics**

Appendix A – RORB catchment file

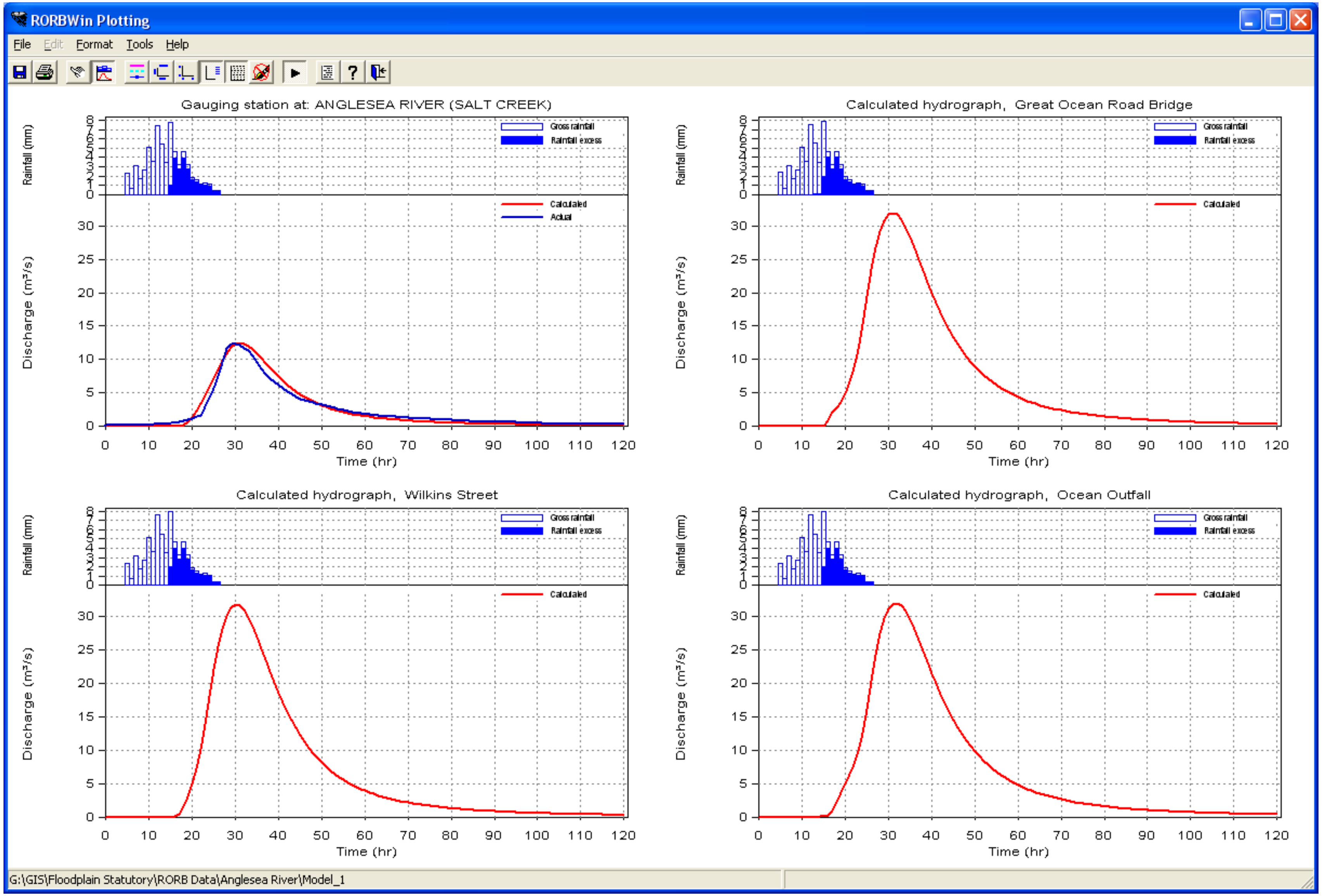
```
Anglesea River Model
C     Rorb Model - Design Runs
C     Existing catchment conditions
C     T Jones CCMA (July 2013)
C     ---------------------------------------------------
C     Model 1 - reaches based on L (kms)
C     Kc= 36.0    m= 0.70
C     Fitted to 2 events - Apr2001, Nov1978 ??
C     Dav= 12.38 kms    Area= 125.3 sq kms
C     Design parameters
C     IL= 45mm    Rc= 0.48 (varies with ARI)
C                 or CL= 4.1 mm/hr for 100yr ARI
C     New BoM IFD rainfall depths
C
0,          Mixed Reaches
1,1,2.14,-99,     Subarea A ( 4.46 km2 )
3,          Store hydrograph
1,1,1.89,-99,     Subarea B ( 3.69 km2 )
4,          Add hydrograph
5,1,0.85,-99,     Route down reach
3,          Store hydrograph
1,1,1.81,-99,     Subarea C ( 4.2 km2 )
4,          Add hydrograph
5,1,0.69,-99,     Route down reach
3,          Store hydrograph
1,1,1.08,-99,     Subarea D ( 4.38 km2 )
4,          Add hydrograph
5,1,3.60,-99,     Route down reach
3,          Store hydrograph
1,1,1.63,-99,     Subarea E ( 4.89 km2 )
4,          Add hydrograph
5,1,0.68,-99,     Route down reach
3,          Store hydrograph
1,1,3.02,-99,     Subarea F ( 4.14 km2 )
4,          Add hydrograph
5,1,1.38,-99,     Route down reach
3,          Store hydrograph
1,1,1.16,-99,     Subarea G ( 2.25 km2 )
4,          Add hydrograph
5,1,0.64,-99,     Route down reach
3,          Store hydrograph
1,1,2.42,-99,     Subarea H ( 3.58 km2 )
4,          Add hydrograph
5,1,0.52,-99,     Route down reach
3,          Store hydrograph
1,1,0.78,-99,     Subarea I ( 3 km2 )
4,          Add hydrograph
5,1,0.91,-99,     Route down reach
3,          Store hydrograph
1,1,2.93,-99,     Subarea J ( 6.63 km2 )
4,          Add hydrograph
5,1,1.26,-99,     Route down reach
3,          Store hydrograph
1,1,1.12,-99,     Subarea K ( 5.12 km2 )
4,          Add hydrograph
5,1,1.11,-99,     Route down reach
3,          Store hydrograph
1,1,1.86,-99,     Subarea L ( 4.05 km2 )
4,          Add hydrograph
```

```
5,1,0.13,-99,     Route down reach
3,          Store hydrograph
1,1,3.70,-99,     Subarea M ( 7.17 km2 )
3,          Store hydrograph
1,1,0.80,-99,     Subarea N ( 4.27 km2 )
4,          Add hydrograph
5,1,1.86,-99,     Route down reach
4,          Add hydrograph
5,1,1.32,-99,     Route down reach
3,          Store hydrograph
1,1,0.47,-99,     Subarea O ( 3.44 km2 )
4,          Add hydrograph
5,1,1.10,-99,     Route down reach
7
Anglesea River u\s Salt Creek
3,          Store hydrograph
C           Start Marshy River catchment
1,1,2.56,-99,     Subarea P( 5.04 km2 )
3,          Store hydrograph
1,1,2.35,-99,     Subarea Q ( 3.03 km2 )
4,          Add hydrograph
5,1,0.43,-99,     Route down reach
3,          Store hydrograph
1,1,2.13,-99,     Subarea R ( 3.45 km2 )
4,          Add hydrograph
3,          Store hydrograph
1,1,0.40,-99,     Subarea S ( 0.98 km2 )
4,          Add hydrograph
5,1,0.95,-99,     Route down reach
3,          Store hydrograph
1,1,1.51,-99,     Subarea T ( 4.5 km2 )
4,          Add hydrograph
5,1,0.09,-99,     Route down reach
3,          Store hydrograph
1,1,0.88,-99,     Subarea U ( 2.17 km2 )
4,          Add hydrograph
5,1,1.27,-99,     Route down reach
3,          Store hydrograph
1,1,1.84,-99,     Subarea V ( 4.31 km2 )
4,          Add hydrograph
5,1,1.19,-99,     Route down reach
3,          Store hydrograph
1,1,1.10,-99,     Subarea W ( 2.96 km2 )
4,          Add hydrograph
5,1,0.67,-99,     Route down reach
3,          Store hydrograph
1,1,0.68,-99,     Subarea X ( 2.37 km2 )
4,          Add hydrograph
5,1,1.04,-99,     Route down reach
3,          Store hydrograph
1,1,1.06,-99,     Subarea Y ( 3.37 km2 )
4,          Add hydrograph
5,1,1.23,-99,     Route down reach
3,          Store hydrograph
1,1,2.39,-99,     Subarea Z ( 4.09 km2 )
4,          Add hydrograph
5,1,1.34,-99,     Route down reach
3,          Store hydrograph
1,1,2.46,-99,     Subarea AA ( 4.74 km2 )
4,          Add hydrograph
5,1,0.36,-99,     Route down reach
3,          Store hydrograph
```

```
1,1,1.09,-99,      Subarea AB ( 6.2 km2 )
4,           Add hydrograph
5,1,3.96,-99,      Route down reach
7
Gauge Site 235222 - Salt Creek
4,           Add hydrograph
5,1,0.61,-99,      Route down reach
3,           Store hydrograph
1,1,1.61,-99,      Subarea AC ( 3.38 km2 )
4,           Add hydrograph
5,1,0.91,-99,      Route down reach
7
Coalmine Road
3,           Store hydrograph
1,1,1.22,-99,      Subarea AD ( 3.61 km2 )
4,           Add hydrograph
5,1,0.55,-99,      Route down reach
3,           Store hydrograph
1,1,0.48,-99,      Subarea AE ( 0.81 km2 )
4,           Add hydrograph
5,1,0.51,-99,      Route down reach
3,           Store hydrograph
1,1,1.29,-99,      Subarea AF ( 2.48 km2 )
4,           Add hydrograph
7
Great Ocean Road Bridge
5,1,0.41,-99,      Route down reach
3,           Store hydrograph
1,1,0.68,-99,      Subarea AG ( 0.73 km2 )
4,           Add hydrograph
3,           Store hydrograph
1,1,1.13,-99,      Subarea AH ( 1.10 km2 )
3,           Store hydrograph
1,1,0.29,-99,      Subarea AI ( 0.70 km2 )
4,           Add hydrograph
5,1,0.41,-99,      Route down reach
4,           Add hydrograph
5,1,0.74,-99,      Route down reach
7
Ocean Outfall
0,           End of control codes
C      Subareas (35 No. Total area 125.3 km2),
4.46,3.69,4.2,4.38,4.89,4.14,2.25,3.58,3.00,6.63
5.12,4.05,7.17,4.27,3.44,5.04,3.03,3.45,0.98,4.50
2.17,4.31,2.96,2.37,3.37,4.09,4.74,6.20,3.38,3.61
0.81,2.48,0.73,1.10,0.70, -99
C      Fraction Impervious mixed
1,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0
0.3,0.2,0.4,0.1,0.15, -99
```

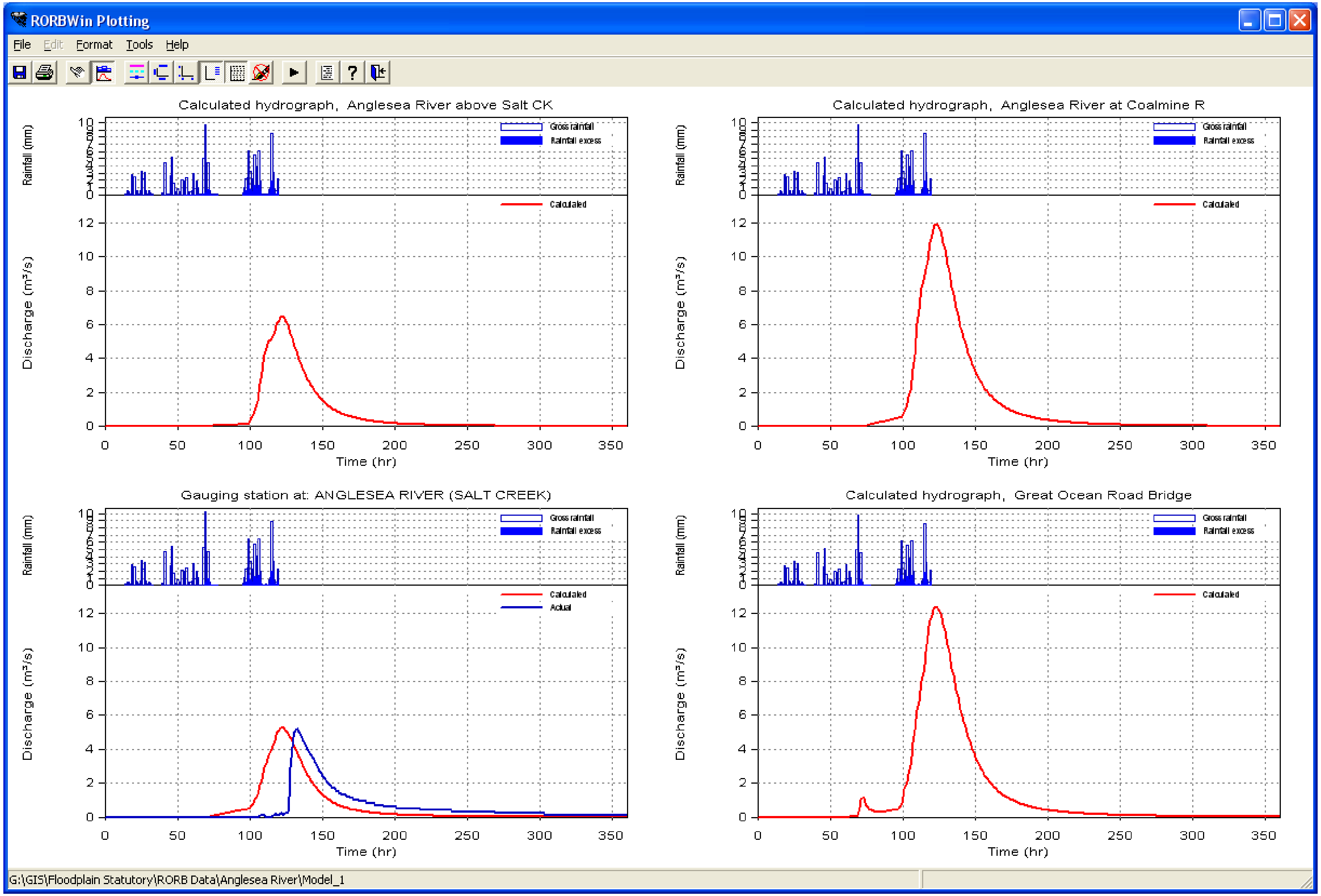
Appendix B – Calibration of RORB Model

Fit Event :18-19 November 1978 Flood Event



```
Routing results:
 ****************
 Anglesea River Model Fit Nov 1986 Flood
 Initial time:
 18-19 Nov 1978 Flood (Start time 9am 18 Nov 1978)
 FIT    run no.  1


 Parameters:  kc =    36.00    m = 0.70

 Loss parameters     Initial loss (mm)     Runoff coeff.
   Interstation area above:
   ANGLESEA RIVER (SALT    42.00              0.87
   Catchment outlet        42.00              0.87



 *** Gauging station at: ANGLESEA RIVER (SALT CREEK)

                           Hydrograph          Error
                          Calc.   Actual    Abs. Percent
 Peak discharge,m³/s     12.42    12.30     0.12   1.0
 Time to peak,h           31.0     29.0      2.0   6.9
 Volume,m³            9.89E+05 1.00E+06-1.23E+04  -1.2
 Av.abs.ord.err,m³/s                        0.45  19.6 over dur. of calcs
 Time to centroid,h       39.9     43.3     -3.5  -8.0
 Lag (c.m. to c.m.),h     20.6     24.0     -3.5 -14.4
 Lag to peak,h            11.7      9.7      2.0  20.6



 *** Calculated hydrograph,  Great Ocean Road Bridge

                           Hydrograph
                          Calc.
 Peak discharge,m³/s     31.95
 Time to peak,h           31.0
 Volume,m³            2.72E+06
 Time to centroid,h       40.2
 Lag (c.m. to c.m.),h     21.0
 Lag to peak,h            11.9
```

Fit Event :9-14 January 2011 Flood Event



G:\GIS\Floodplain Statutory\RORB Data\Anglesea River\Model_1

```
Routing results:
 ****************
 Anglesea River Model Jan 2011 Flood
 Initial time:
 9-27 January 2011 Flood (Start time 9am 9 Jan 2011)
 FIT    run no.  1


 Parameters:  kc =    36.00    m = 0.70

 Loss parameters     Initial loss (mm)     Runoff coeff.
   Interstation area above:
   ANGLESEA RIVER (SALT    70.00              0.22
   Catchment outlet        70.00              0.22


  *** Gauging station at: ANGLESEA RIVER (SALT CREEK)

                           Hydrograph          Error
                          Calc.   Actual    Abs. Percent
 Peak discharge,m³/s     5.295    5.200    0.095   1.8
 Time to peak,h           122.     132.     -10.  -7.6
 Volume,m³            6.95E+05 6.74E+05 2.10E+04   3.1
 Av.abs.ord.err,m³/s                        0.54 103.9 over dur. of calcs
 Time to centroid,h       132.     171.     -40. -23.1
 Lag (c.m. to c.m.),h     29.8     69.4    -39.5 -57.0
 Lag to peak,h            20.0     30.0    -10.0 -33.3



 *** Calculated hydrograph,  Great Ocean Road Bridge

                           Hydrograph
                          Calc.
 Peak discharge,m³/s     12.40
 Time to peak,h           123.
 Volume,m³            1.71E+06
 Time to centroid,h       134.
 Lag (c.m. to c.m.),h     30.6
 Lag to peak,h            19.9
```

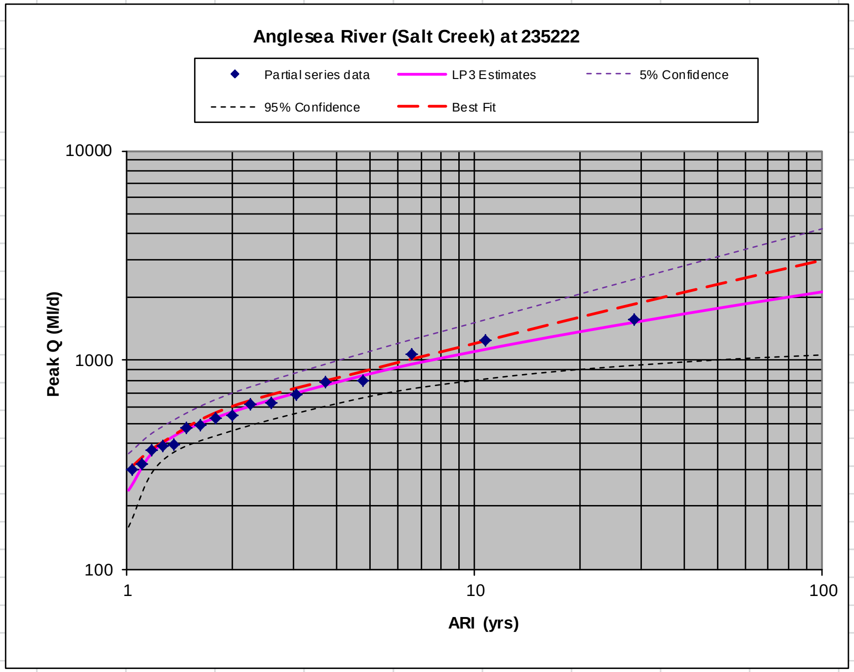
Appendix C - Statistic Analysis of peak flows at Site 235222 (Salt Creek at Alcoa Power Station)

Partial Flow Series (1968-1981, 2010-2012)
17 year complete record

Rank	Date	Peak Flow (Q>300) (Ml/d)	(m3/s)
12	Sep-70	475	5.5
5	Dec-70	782	9.1
10	Feb-71	526	6.1
13	Nov-71	394	4.6
15	Dec-71	369	4.3
7	Aug-73	623	7.2
9	Aug-74	546	6.3
14	Oct-75	389	4.5
1	Sep-76	1552	18.0
8	Oct-76	612	7.1
6	Jun-78	685	7.9
4	Aug-78	802	9.3
3	Nov-78	1068	12.4
2	Dec-78	1250	14.5
16	Jun-80	320	3.7
17	Oct-80	300	3.5
11	Jan-11	488	5.6

Record 17 years
All flows checked for independence

Rank	Year	Plotting Pos	Max Inst flow (Ml/d)	Log10(Q)	Max Inst flow (m3/s)
1	Sep-76	28.7	1552	3.191	18.0
2	Dec-78	10.8	1250	3.097	14.5
3	Nov-78	6.6	1068	3.029	12.4
4	Aug-78	4.8	802	2.904	9.3
5	Dec-70	3.7	782	2.893	9.1
6	Jun-78	3.1	685	2.836	7.9
7	Aug-73	2.6	623	2.794	7.2
8	Oct-76	2.3	612	2.787	7.1
9	Aug-74	2.0	546	2.737	6.3
10	Feb-71	1.8	526	2.721	6.1
11	Jan-11	1.6	488	2.688	5.6
12	Sep-70	1.5	475	2.677	5.5
13	Nov-71	1.4	394	2.595	4.6
14	Oct-75	1.3	389	2.590	4.5
15	Dec-71	1.2	369	2.567	4.3
16	Jun-80	1.1	320	2.505	3.7
17	Oct-80	1.0	300	2.477	3.5



Flow Stats (Max Year Value)

Average	658	Ml/day
Medium	546	Ml/day
Max	1552	Ml/day
Min	300	Ml/day

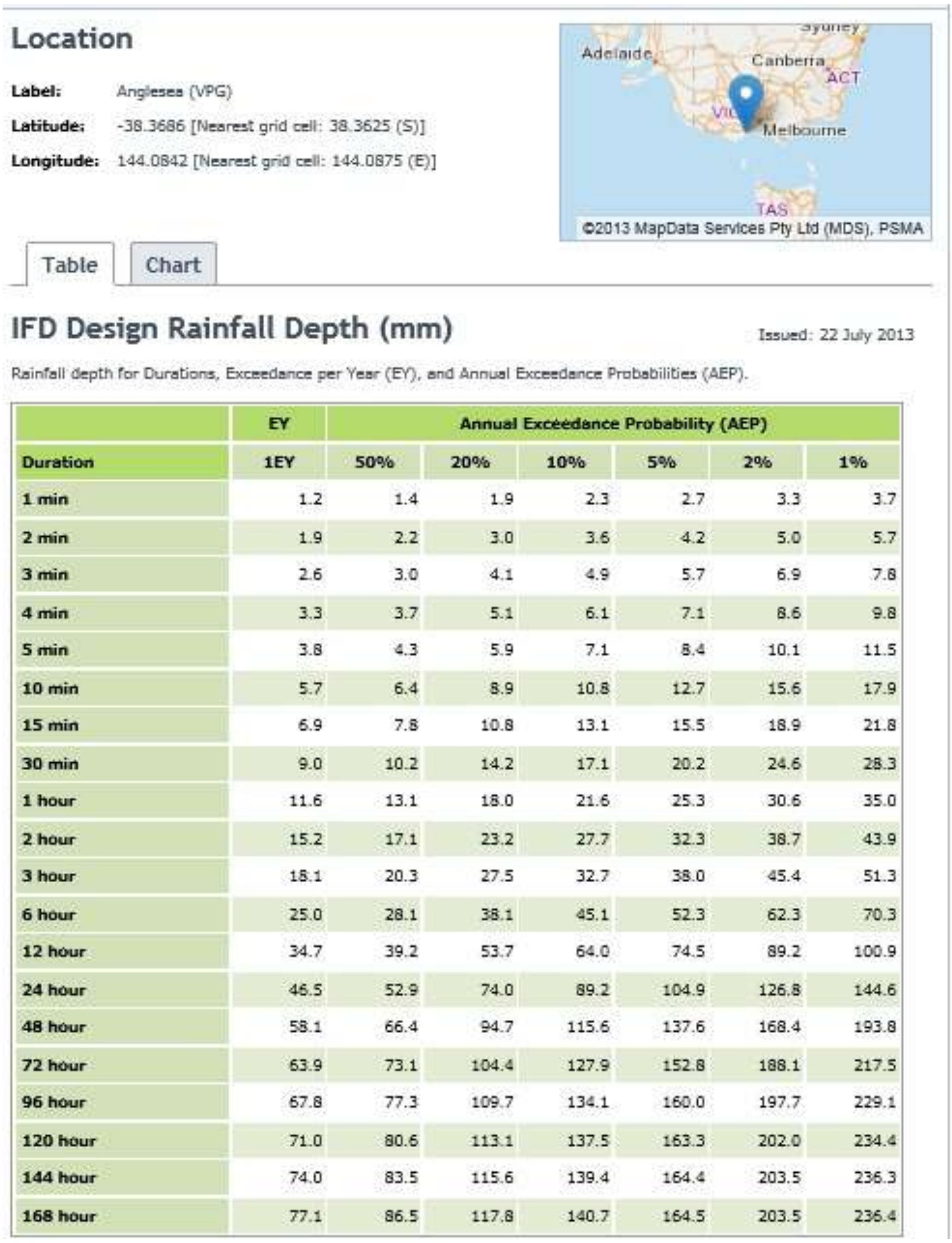
ARI	Ky	Peak Flow Qy (Ml/d)	Peak Flow Qy (m3/s)			Best Fit Original (ml/d)	Best Fit Original (m3/s)	ARI	δ	Confidence Limits 5%	Confidence Limits 95%
1.01	-1.918	239	2.8	2.770	M logs	300	3.5	1.01	2.1493	358	160
1.25	-0.857	393	4.6	0.204	S logs	400	4.6	1.25	1.0113	476	325
2	-0.091	564	6.5	0.55	G logs	600	6.9	2	1.1007	694	459
5	0.804	859	10			900	10	5	1.3202	1101	671
10	1.326	1099	13			1200	14	10	1.6895	1509	800
20	1.786	1364	16			1600	19	20	2.2062	2064	901
50	2.335	1766	20			2300	27	50	3.0232	3116	1001
100	2.721	2118	25			3000	35	100	3.6961	4238	1058
200	3.087	2516	29					200	4.3972		
500	3.548	3126	36					500	5.3892		

G= 0.55

G= 0.5

Appendix D – AR&R IFD Data

			Average Catchment Rain		
ARI	Storm Duration	Areal Reduction Factor	New BoM IFD data	Old AR&R 1987 data	Percent Change
(yrs)	(hrs)		(mm)	(mm)	(%)
100	12	0.88	83	82	1%
	24	0.9	120	108	11%
	36	0.93	148	127	17%
	48	0.94	168	140	20%
	72	0.95	191	157	22%
50	12	0.88	74	74	1%
	24	0.91	107	107	0%
	36	0.93	130	114	14%
	48	0.94	146	125	17%
	72			140	
20	12	0.88	62	63	-1%
	24	0.91	89	83	7%
	36	0.93	107	97	10%
	48	0.94	120	107	12%
	72			120	
10	12	0.88	53	55	-3%
	24	0.91	76	72	5%
	36	0.93	90	85	6%
	48	0.95	102	94	9%
	72	0.96	114	105	9%
5	12	0.88	45	49	-9%
	24	0.91	63	65	-3%
	36	0.93	74	76	-3%
	48	0.95	84	84	0%
	72			94	
2	12	0.88	33	41	-19%
	24	0.91	45	54	-16%
	36	0.94	54	63	-14%
	48	0.95	59	69	-15%
	72	0.95	65	78	-16%
1	12	0.88	29	33	-12%
	24	0.91	40	44	-9%
	36	0.94	47	51	-8%
	48	0.95	52	57	-8%
	72	0.97	58	63	-8%



Location

Label: Anglesea (VPG)
Latitude: -38.3686 [Nearest grid cell: 38.3625 (S)]
Longitude: 144.0842 [Nearest grid cell: 144.0875 (E)]

IFD Design Rainfall Depth (mm)

Issued: 22 July 2013

Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).

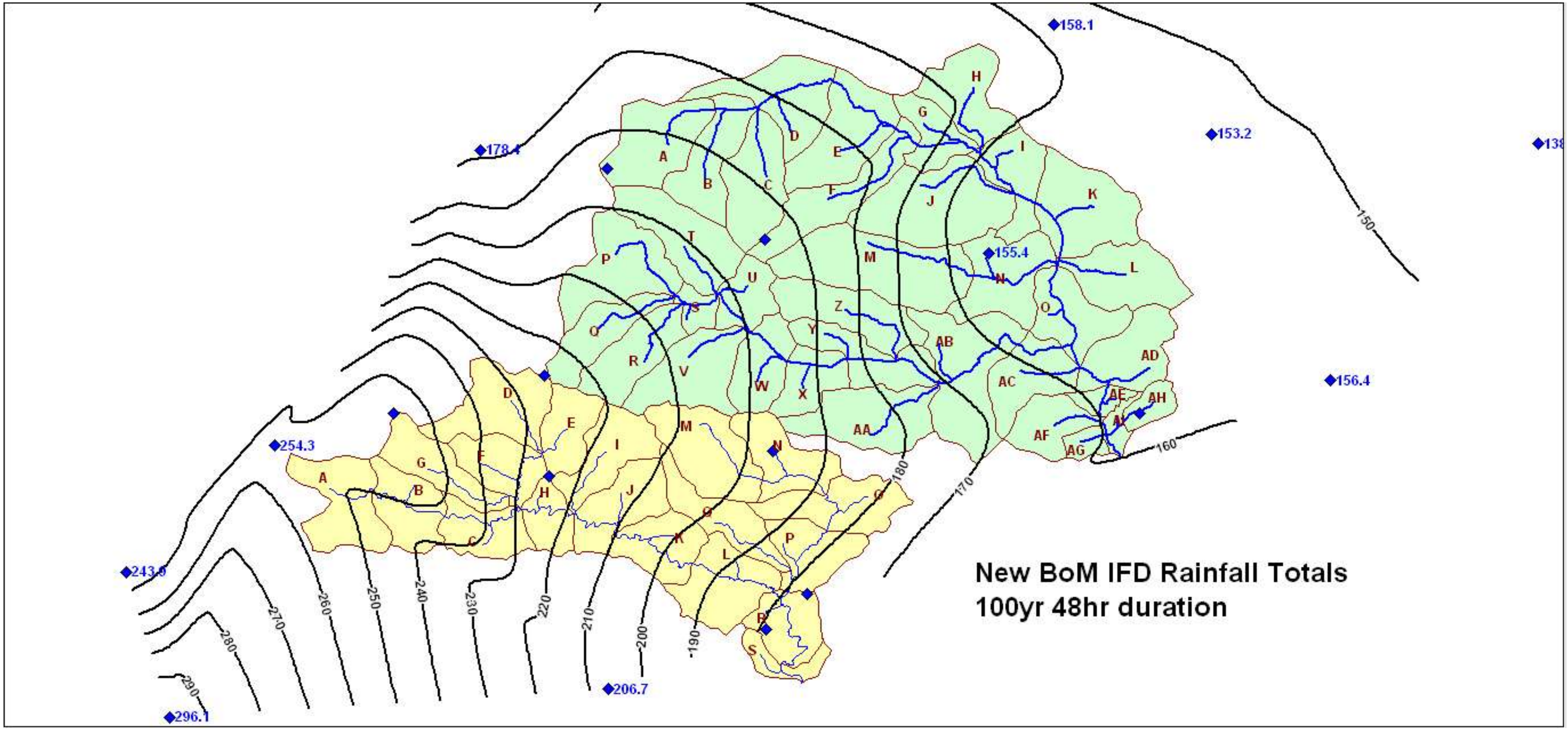
	EY	Annual Exceedance Probability (AEP)					
Duration	**1EY**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 min	1.2	1.4	1.9	2.3	2.7	3.3	3.7
2 min	1.9	2.2	3.0	3.6	4.2	5.0	5.7
3 min	2.6	3.0	4.1	4.9	5.7	6.9	7.8
4 min	3.3	3.7	5.1	6.1	7.1	8.6	9.8
5 min	3.8	4.3	5.9	7.1	8.4	10.1	11.5
10 min	5.7	6.4	8.9	10.8	12.7	15.6	17.9
15 min	6.9	7.8	10.8	13.1	15.5	18.9	21.8
30 min	9.0	10.2	14.2	17.1	20.2	24.6	28.3
1 hour	11.6	13.1	18.0	21.6	25.3	30.6	35.0
2 hour	15.2	17.1	23.2	27.7	32.3	38.7	43.9
3 hour	18.1	20.3	27.5	32.7	38.0	45.4	51.3
6 hour	25.0	28.1	38.1	45.1	52.3	62.3	70.3
12 hour	34.7	39.2	53.7	64.0	74.5	89.2	100.9
24 hour	46.5	52.9	74.0	89.2	104.9	126.8	144.6
48 hour	58.1	66.4	94.7	115.6	137.6	168.4	193.8
72 hour	63.9	73.1	104.4	127.9	152.8	188.1	217.5
96 hour	67.8	77.3	109.7	134.1	160.0	197.7	229.1
120 hour	71.0	80.6	113.1	137.5	163.3	202.0	234.4
144 hour	74.0	83.5	115.6	139.4	164.4	203.5	236.3
168 hour	77.1	86.5	117.8	140.7	164.5	203.5	236.4

New IFD data sheet from http://www.bom.gov.au/water/designRainfalls/

]

Appendix E – Subarea Design Rainfall Totals

		New BoM IFD areal subarea totals																															
Subarea	**Area (sq kms)**	100yr					50yr				20yr				10yr					5yr				2yr					1yr				
		12 hr	24 hr	36 hr	48hr	72 hr	12 hr	24 hr	36 hr	48hr	12 hr	24 hr	36 hr	48hr	12 hr	24 hr	36 hr	48hr	72 hr	12 hr	24 hr	36 hr	48hr	12 hr	24 hr	36 hr	48hr	72hr	12 hr	24 hr	36 hr	48hr	72hr
	ARF ->	0.88	0.90	0.93	0.94	0.95	0.88	0.91	0.93	0.94	0.88	0.91	0.93	0.94	0.88	0.91	0.93	0.95	0.96	0.88	0.91	0.93	0.95	0.88	0.91	0.94	0.95	0.95	0.88	0.91	0.94	0.95	0.97
A	4.46	88	128	157	179	203	77	114	139	155	65	94	114	127	56	80	95	108	121	47	67	79	89	34	48	57	63	69	31	42	49	54	61
B	3.69	87	127	156	179	203	77	113	138	155	65	94	113	127	56	80	95	108	121	47	67	79	89	34	48	57	63	69	31	42	49	54	61
C	4.2	87	127	156	179	203	77	113	138	155	65	94	113	127	56	80	95	108	121	47	67	79	89	34	48	57	63	69	31	42	49	54	61
D	4.38	83	122	148	168	191	73	108	131	147	61	90	107	120	53	76	90	103	115	44	63	74	84	32	45	53	59	65	29	40	47	52	59
E	4.89	83	121	148	169	192	73	107	131	147	61	89	107	120	53	76	90	103	115	44	63	74	84	32	45	53	59	65	29	40	47	52	59
F	4.14	84	123	146	172	196	75	110	129	149	63	91	106	123	54	77	92	105	117	45	64	76	86	33	46	55	60	66	29	41	48	52	59
G	2.25	80	115	142	160	182	70	101	125	140	59	84	103	115	51	73	87	98	109	43	61	72	80	31	44	52	56	62	28	39	46	49	55
H	3.58	79	113	140	158	180	70	100	123	138	59	83	101	114	51	72	86	97	108	43	60	71	80	31	43	51	56	62	28	38	45	49	55
I	3.00	77	106	131	149	170	69	96	115	134	57	80	95	110	49	68	81	94	105	42	57	67	77	31	41	48	54	60	27	36	43	47	52
J	6.63	78	110	135	152	173	70	99	119	136	58	82	98	112	50	70	83	95	106	42	58	69	78	31	42	50	55	60	27	38	45	49	55
K	5.12	75	105	130	145	165	66	94	114	129	55	78	94	106	48	67	80	90	101	40	56	66	74	29	40	48	52	57	26	36	43	47	52
L	4.05	75	105	130	145	165	67	95	114	129	56	78	94	106	48	67	80	90	101	41	56	66	74	30	40	48	52	57	26	36	43	47	52
M	7.17	81	117	144	165	187	71	105	127	141	60	87	104	116	51	74	88	99	111	43	61	72	81	32	44	52	57	63	28	39	46	50	56
N	4.27	75	105	130	146	166	66	95	114	129	55	78	94	106	48	67	80	90	101	40	56	66	74	29	40	48	52	57	26	36	43	47	52
O	3.44	75	106	130	146	166	66	95	114	129	55	78	94	106	48	67	80	90	101	40	56	66	74	29	40	48	52	57	26	36	43	47	52
P	5.04	95	140	171	195	221	84	123	150	166	71	102	123	136	61	86	104	116	130	51	72	86	95	38	52	62	67	74	32	44	51	58	65
Q	3.03	99	145	177	199	227	87	128	156	172	73	106	128	142	63	89	108	121	135	53	74	89	99	39	53	64	70	77	33	46	54	60	67
R	3.45	98	144	177	199	227	86	127	156	171	72	106	128	140	62	88	108	120	134	52	74	89	98	38	53	64	69	76	33	46	54	60	67
S	0.98	93	137	168	193	219	83	122	148	164	69	101	122	135	60	85	103	115	129	50	70	85	94	37	51	61	66	73	32	44	51	58	65
T	4.50	92	134	165	188	214	81	119	145	160	68	99	119	132	58	84	101	112	125	49	70	83	92	36	50	60	65	71	31	43	51	56	63
U	2.17	91	133	164	186	212	81	118	144	160	68	98	119	132	58	84	100	112	125	49	70	82	92	36	50	59	65	71	31	43	50	55	62
V	4.31	95	141	174	195	221	84	124	153	167	70	103	126	137	60	86	106	117	131	51	72	88	96	37	52	63	67	74	32	44	51	59	66
W	2.96	92	133	164	186	212	80	117	144	159	67	97	119	130	58	83	100	111	124	49	69	82	91	36	50	59	64	71	31	43	50	56	63
X	2.37	88	128	157	180	205	77	113	139	153	65	94	114	126	56	80	96	107	120	47	67	79	88	34	48	57	62	68	30	42	49	54	61
Y	3.37	84	123	152	169	192	76	108	134	151	63	90	110	124	55	78	93	105	118	46	65	76	87	34	47	55	61	67	30	41	48	52	59
Z	4.09	85	122	151	169	192	75	109	133	149	63	91	109	123	54	77	92	105	117	45	64	76	86	33	46	55	60	66	30	41	48	52	59
AA	4.74	84	122	150	171	195	75	109	132	149	63	91	108	123	54	77	91	105	117	45	64	75	86	33	46	54	60	66	29	40	47	52	59
AB	6.20	78	113	138	158	180	69	100	122	134	57	83	100	110	49	71	84	94	105	42	59	70	77	31	42	50	54	60	28	38	45	49	55
AC	3.38	77	109	134	150	171	67	97	118	133	56	81	97	109	48	69	82	93	104	41	58	67	76	30	41	49	54	59	27	37	44	48	53
AD	3.61	76	107	132	146	166	65	95	116	130	55	78	95	107	47	67	80	91	102	39	56	66	75	29	40	48	53	58	26	36	43	47	52
AE	0.81	77	108	133	149	169	66	96	117	130	55	79	96	107	48	68	81	91	102	40	57	67	75	29	41	48	53	58	26	36	43	47	52
AF	2.48	77	112	136	155	176	68	97	120	133	57	81	99	109	49	70	83	93	104	41	58	69	76	30	42	49	54	59	26	36	43	48	54
AG	0.73	77	109	134	152	173	67	96	118	132	56	80	97	108	48	69	82	92	103	41	58	67	76	30	41	49	53	59	26	36	43	48	53
AH	1.10	77	107	132	149	170	65	96	116	130	55	79	95	107	47	67	80	91	102	39	56	66	75	29	40	48	53	58	26	36	43	47	52
AI	0.70	77	108	133	150	171	66	96	117	130	55	79	96	107	48	68	81	91	102	40	57	67	75	29	41	48	53	58	26	36	43	47	52
Total/Ave	**125.3**	**83**	**120**	**148**	**168**	**191**	**74**	**107**	**130**	**146**	**62**	**89**	**107**	**120**	**53**	**76**	**90**	**102**	114	**45**	**63**	**74**	**84**	**33**	**45**	**54**	**59**	**65**	**29**	**40**	**47**	**52**	**58**
	Total/Ave Burst depth	95	134	159	178	201	84	118	140	155	70	98	115	127	60	83	97	107	119	51	69	80	88	37	50	57	62	68	33	44	50	54	60



New BoM IFD Rainfall Totals
100yr 48hr duration

New IFD data for Anglesea River catchment (light green areas)

Appendix F – Design Discharges RORB Model Outputs

Anglesea River Flood Study

					Peak Flow with Kc=36 m=0.7 at			
ARI	Storm Duration	Average Catchment Rain	Losses		Salt Creek	U/S Salt Creek	Coalmine Road	Great Ocean Road
(yrs)	(hrs)	(mm)	IL (mm)	RC	(m3/s)	(m3/s)	(m3/s)	(m3/s)
100	12	83	45	0.48	14	13	27	27
	24	120	45	0.48	29	31	60	61
	36	148	45	0.48	35	37	74	76
	48	168	45	0.48	**35**	**38**	**75**	**77**
	72	191	45	0.48	29	32	61	63
50	12	74	46	0.47	8.9	7.9	17	17
	24	107	46	0.47	22	23	45	46
	36	130	46	0.47	**27**	28	**56**	58
	48	146	46	0.47	26	**29**	56	**58**
	72		46	0.47				
20	12	62	46	0.47	4.5	3.3	7.8	7.8
	24	89	46	0.47	14	14	29	29
	36	107	46	0.47	18	19	38	39
	48	120	46	0.47	**19**	**20**	**39**	**41**
	72		46	0.47				
10	12	53	45	0.48	2.3	1.3	3.4	3.4
	24	76	45	0.48	9.7	9.5	19	19
	36	90	45	0.48	14	14	28	29
	48	102	45	0.48	**14**	**15**	**29**	**30**
	72	114	45	0.48	11	14	24	25
5	12	45	43	0.51	0.7	0	0.6	0.7
	24	63	43	0.51	6.4	5.5	12	12
	36	74	43	0.51	9.8	9.7	20	20
	48	84	43	0.51	**9.8**	**10**	**20**	**21**
	72		43	0.51				
2	12	33	37	0.60	0	0	0	0.6
	24	45	37	0.60	3	1.9	4.7	4.7
	36	54	37	0.60	6.0	5.3	11	11
	48	59	37	0.60	6.2	6.5	13	13
	72	65	37	0.60	**6.8**	**8.3**	**15**	**16**
1	12	29	44	0.49	0	0	0	0.4
	24	40	44	0.49	0	0	0	0.4

	36	47	44	0.49	0.8	0.3	1.0	1.0
	48	52	44	0.49	1.9	1.3	3.0	3.0
	72	58	44	0.49	**3.5**	**3.0**	**6.4**	**6.5**

Notes:

1 Rainfall based on the new BoM IFD data released in July 2013.

2 Rainfall distributed over the catchment based on the new BoM IFD data.

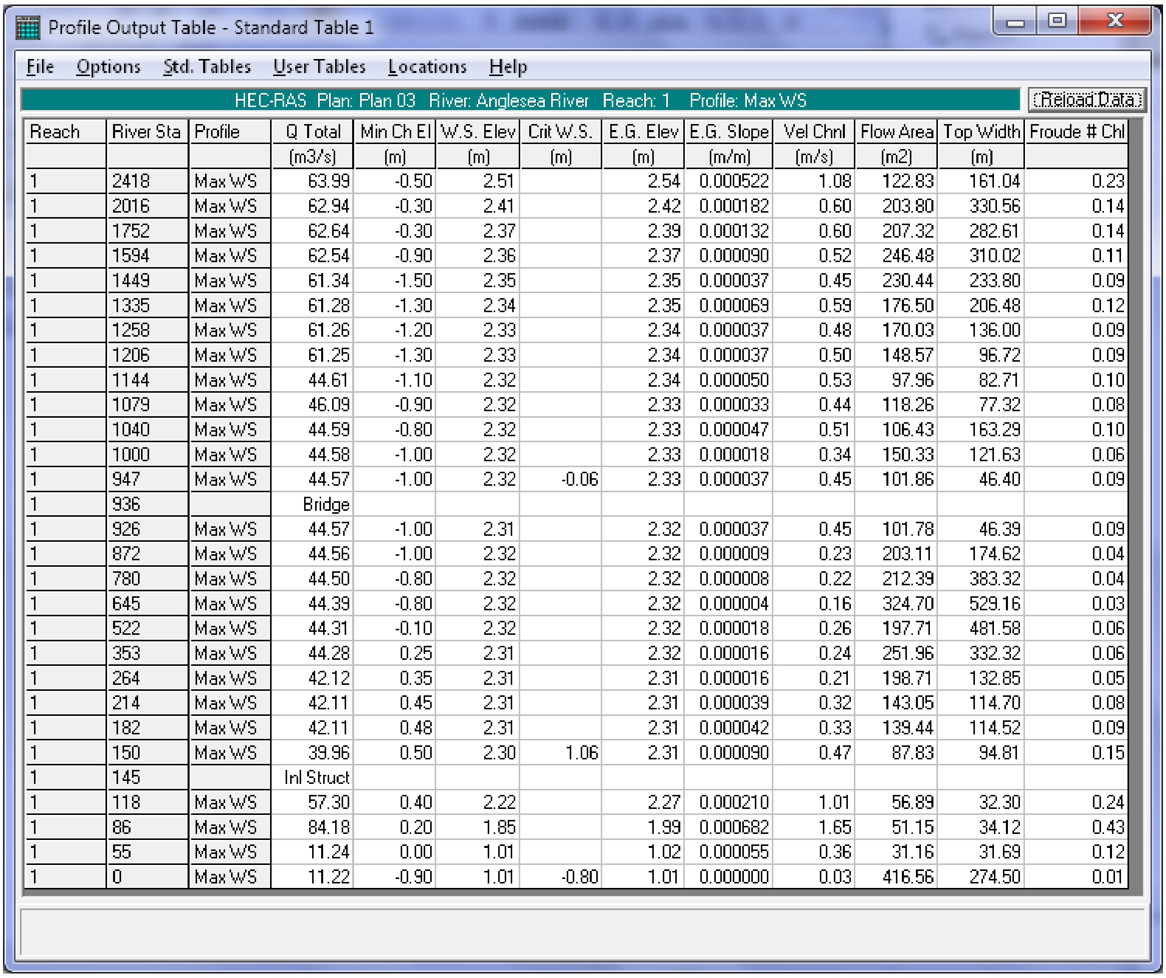
3 Areal reduction of rainfall based on Siriwardena & Weinmann Method.

4 Initial loss - runoff coefficient fitted to match statistical analysis peak flow estimates at site 235222 (Alcoa power station) on Salt creek.

5 Initial loss - runoff coefficient relationship adopted to facilitate fitting design losses.

6 Kc & m adopted from two available fitted storm event.

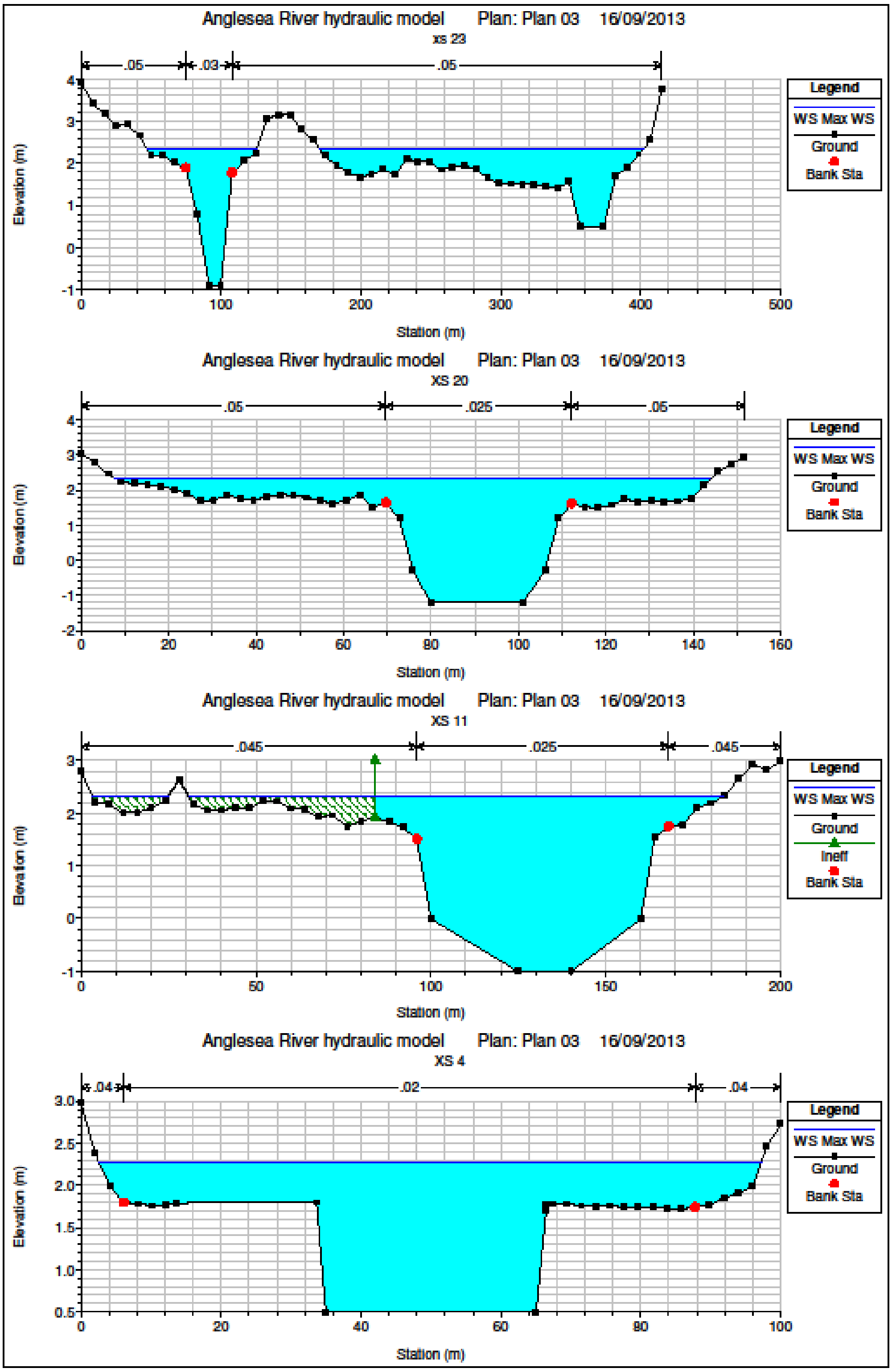
Appendix G – HEC-RAS Model Outputs



HEC-RAS Plan: Plan 03 River: Anglesea River Reach: 1 Profile: Max WS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	2418	Max WS	63.99	-0.50	2.51		2.54	0.000522	1.08	122.83	161.04	0.23
1	2016	Max WS	62.94	-0.30	2.41		2.42	0.000182	0.60	203.80	330.56	0.14
1	1752	Max WS	62.64	-0.30	2.37		2.39	0.000132	0.60	207.32	282.61	0.14
1	1594	Max WS	62.54	-0.90	2.36		2.37	0.000090	0.52	246.48	310.02	0.11
1	1449	Max WS	61.34	-1.50	2.35		2.35	0.000037	0.45	230.44	233.80	0.09
1	1335	Max WS	61.28	-1.30	2.34		2.35	0.000069	0.59	176.50	206.48	0.12
1	1258	Max WS	61.26	-1.20	2.33		2.34	0.000037	0.48	170.03	136.00	0.09
1	1206	Max WS	61.25	-1.30	2.33		2.34	0.000037	0.50	148.57	96.72	0.09
1	1144	Max WS	44.61	-1.10	2.32		2.34	0.000050	0.53	97.96	82.71	0.10
1	1079	Max WS	46.09	-0.90	2.32		2.33	0.000033	0.44	118.26	77.32	0.08
1	1040	Max WS	44.59	-0.80	2.32		2.33	0.000047	0.51	106.43	163.29	0.10
1	1000	Max WS	44.58	-1.00	2.32		2.33	0.000018	0.34	150.33	121.63	0.06
1	947	Max WS	44.57	-1.00	2.32	-0.06	2.33	0.000037	0.45	101.86	46.40	0.09
1	936		Bridge									
1	926	Max WS	44.57	-1.00	2.31		2.32	0.000037	0.45	101.78	46.39	0.09
1	872	Max WS	44.56	-1.00	2.32		2.32	0.000009	0.23	203.11	174.62	0.04
1	780	Max WS	44.50	-0.80	2.32		2.32	0.000008	0.22	212.39	383.32	0.04
1	645	Max WS	44.39	-0.80	2.32		2.32	0.000004	0.16	324.70	529.16	0.03
1	522	Max WS	44.31	-0.10	2.32		2.32	0.000018	0.26	197.71	481.58	0.06
1	353	Max WS	44.28	0.25	2.31		2.32	0.000016	0.24	251.96	332.32	0.06
1	264	Max WS	42.12	0.35	2.31		2.31	0.000016	0.21	198.71	132.85	0.05
1	214	Max WS	42.11	0.45	2.31		2.31	0.000039	0.32	143.05	114.70	0.08
1	182	Max WS	42.11	0.48	2.31		2.31	0.000042	0.33	139.44	114.52	0.09
1	150	Max WS	39.96	0.50	2.30	1.06	2.31	0.000090	0.47	87.83	94.81	0.15
1	145		Inl Struct									
1	118	Max WS	57.30	0.40	2.22		2.27	0.000210	1.01	56.89	32.30	0.24
1	86	Max WS	84.18	0.20	1.85		1.99	0.000682	1.65	51.15	34.12	0.43
1	55	Max WS	11.24	0.00	1.01		1.02	0.000055	0.36	31.16	31.69	0.12
1	0	Max WS	11.22	-0.90	1.01	-0.80	1.01	0.000000	0.03	416.56	274.50	0.01

HECRas 100 year ARI Profile Output Table for maximum Water Surface level



Cross Sections above are looking downstream

XS	Location
24	Chn 1752 m
20	Chn 1258 m
11	Chn 872 m
4	Chn 152 m

The location of the HecRAS cross sections are shown as red lines with their chainage in metres from the ocean.

Appendix H – Berm Breach Characteristics

The breach channel is assumed to form and hold the channel shape specified in the dam break setup for the duration of the flood event. In reality the breach channel will continue to enlarge beyond that is specified for the dam break. However it is considered that the dam break mechanism is a reasonable assumption to estimate peak levels on the Anglesea River Estuary as they occur during the time the breach channel is being formed.

The breach characteristics are:

Berm starting height : 2.0 m AHD
Breach channel base : 20 m
Breach channel invert : 0.8 m AHD
Time to fully form channel breach : 5 hours
Breaching mechanism : Overtopping
Water level to start breach : 2.05 m AHD
Breach progression shape : Half sine curve
Volume of sand removed by breach : 3000 m3
Average flow velocity during breach development : 1.3 m/sec

The berm erosion rates and the associated Yang Sediment Transport concentrations in the development of the breach channel are shown in the graphs below. It is expected that the breach channel to the ocean would initially be steeper than 1/100 and flatten out as the channel is fully formed to 1/200. The assumed breach mechanism concentrations required is shown as the blue line on the three graphs below (a 3, 4 and 5 hour breach time). The Yang sediment transport concentration potential is shown as dashed lines for two breach channel slopes. The 5 hour breach time is best suited for the Anglesea estuary with Yang concentrations exceeding the model requirement.

The maximum erosion rate is 20 m^3/min (6200ppm) with associated stream power of 60 N/m sec. The stream power increases significantly to more than 200 N/m sec when the flow is contained within the breach channel. This occurs after the breach channel has formed.

The procedure outlined in HECRAS Hydraulic Reference Manual for Yang sediment transport functions (Sample Calulations) has been used to determine a suitable breaching mechanism.

Key parameters used in the Yang Sediment Transport procedure:

Water temperature : 55° F (12.8° C)

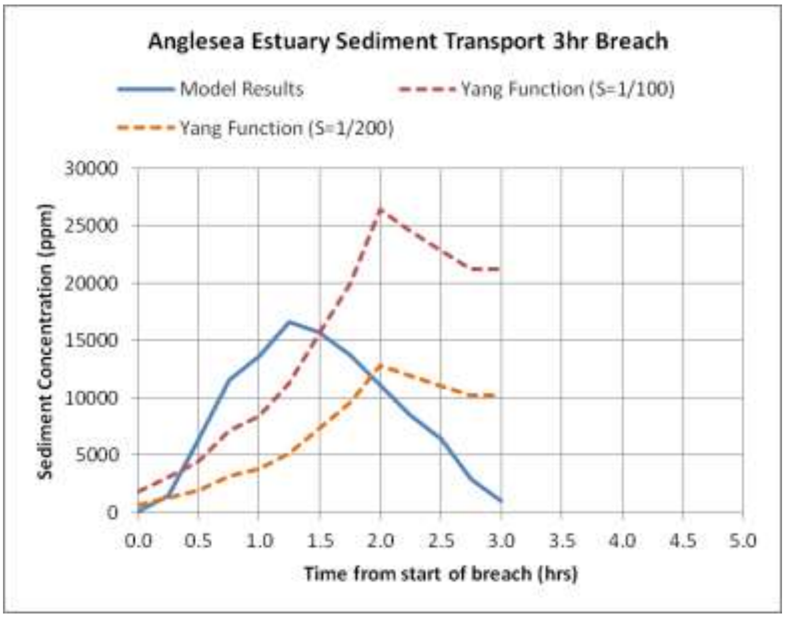
Median Particle Dia : 0.354 mm (Medium Sand 0.25 - 0.5 mm)

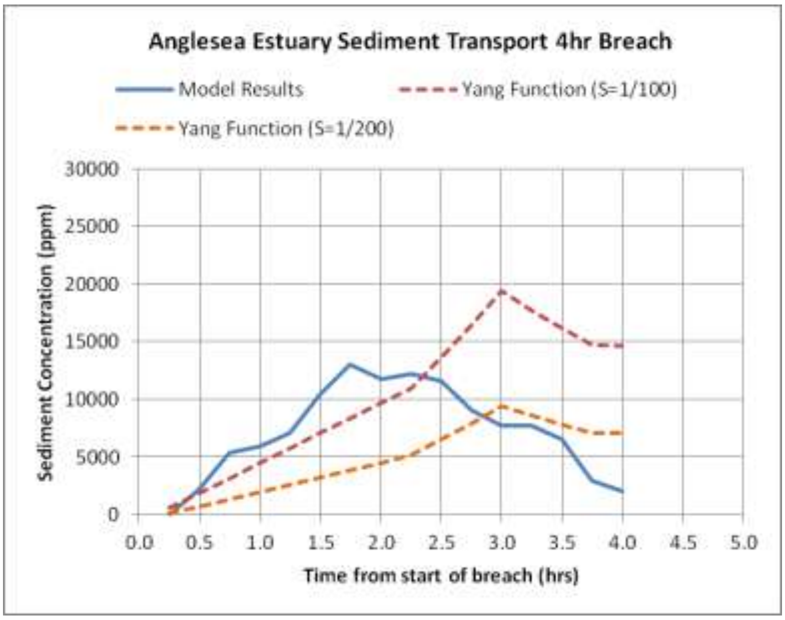
Specific g sediments : 2.65

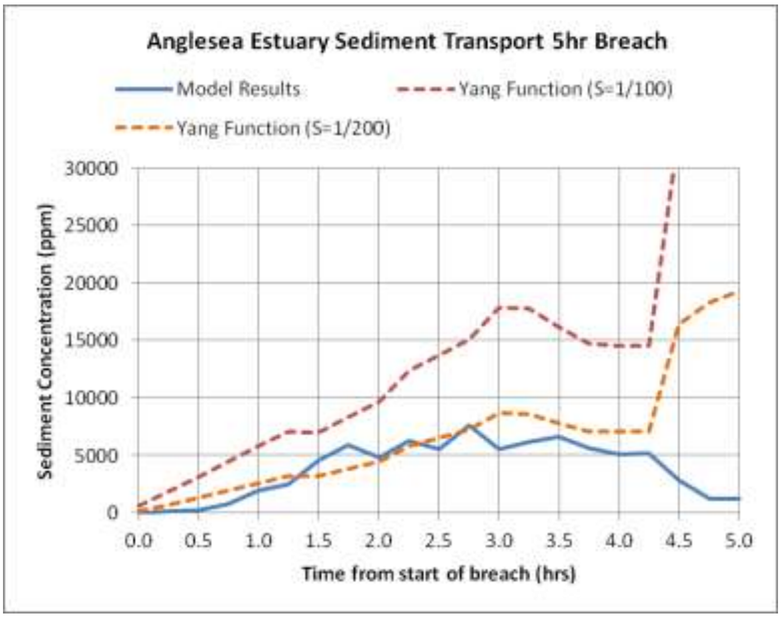
The Painkalac Estuary has more energy (head and flow) available to form a breach than Anglesea River. The photographs on past breaches show that the Anglesea River berm is less eroded when compared to Anglesea River. A 3 hour breach time with a 25 metre base channel has been used for Painkalac Estuary berm.

Recently a few papers have been written that discuss the highly dynamic nature of berm breakouts and the challenges in defining appropriate initial conditions and breach channel dimensions. Most of the examples are along the NSW coast and East Gippsland with ICOLL (intermittently closed and open lakes and lagoons) that are much larger systems than Painkalac Estuary. A paper by D Lyons and D Williams of BMT WBM in 2012 is a good example [Ref 8].

More data is required to compare these rates with other events and estuaries to confirm the assumptions made for the breaching mechanism.


Anglesea Estuary Sediment Transport 3hr Breach
Model Results
Yang Function (S=1/100)
Yang Function (S=1/200)
Sediment Concentration (ppm)
30000
25000
20000
15000
10000
5000
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time from start of breach (hrs)


Anglesea Estuary Sediment Transport 4hr Breach
Model Results
Yang Function (S=1/100)
Yang Function (S=1/200)
Sediment Concentration (ppm)
30000
25000
20000
15000
10000
5000
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time from start of breach (hrs)


Anglesea Estuary Sediment Transport 5hr Breach
Model Results
Yang Function (S=1/100)
Yang Function (S=1/200)
Sediment Concentration (ppm)
30000
25000
20000
15000
10000
5000
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time from start of breach (hrs)