City Wide Flood Constraints Project
Townsville City Council
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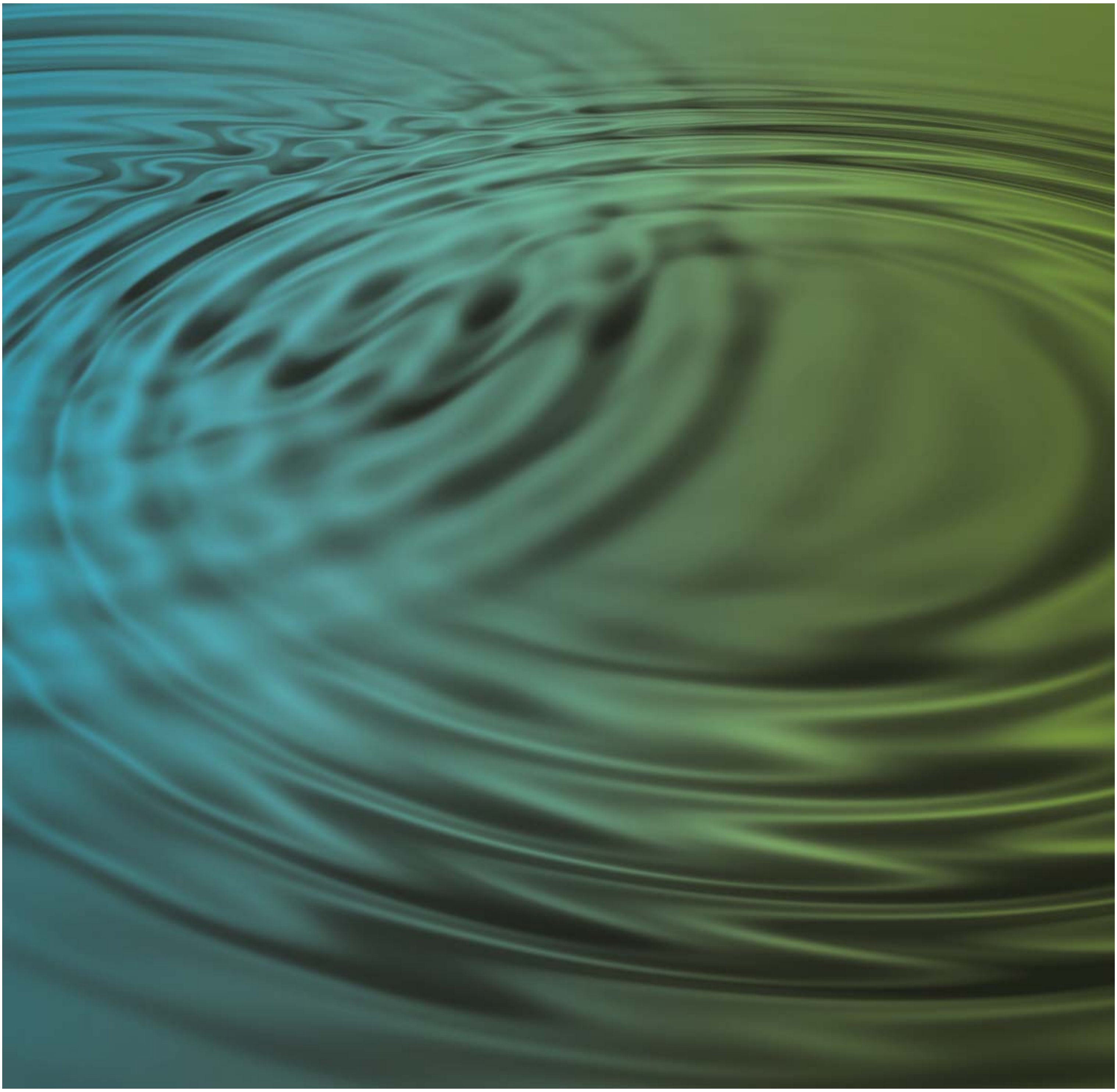
Upper & Middle Bohle Flood Study

Base-line Flooding Assessment



Upper & Middle Bohle Flood Study

Base-line Flooding Assessment

Client: Townsville City Council

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Executive Summary

AECOM Australia Pty Ltd (AECOM) was engaged by Townsville City Council (TCC) to develop refined base-case hydrologic and hydraulic flood models for the Upper and Middle Bohle areas as part of the *City Wide Flood Constraints Project*.

For the purposes of this study, the area of interest was identified as the land encompassing the Bohle River catchment from Mt. Bohle in the north to around Kelso Drive in the south. It is worth noting that the upper reaches of Ross River were included in the model to facilitate the representation of break out overflows affecting the area of interest from Ross River during extreme flood events.

The *Upper & Middle Bohle Flood Study (UMBFS)* builds on a number of previous flood assessments carried out in the vicinity. Where needed, existing hydrologic and hydraulic models have been updated and refined in line with the *Preparation of Flood Studies and Reports - Guidelines* (2010) developed by TCC.

Upstream boundary conditions were derived using inflow hydrographs for the catchments upstream of the Upper Bohle River hydraulic model and inflow hydrographs from the appropriate hydrologic models informed the upstream boundary conditions for the Middle Bohle River hydraulic model. Downstream boundary conditions were derived using discharge rating curves for the Upper Bohle model at the outflow boundary. For the Middle Bohle model an open ocean boundary was applied for the outflow of the Bohle River and a discharge rating curve was used for the Louisa Creek outflow of the model.

Two separate MIKE FLOOD hydraulic models were developed for the Upper and Middle Bohle areas. Base-line flooding conditions were assessed for a range of storm events including 2-yr Average Recurrence Interval (ARI) through to the Probable Maximum Flood (PMF) event. The Rain-on-Grid method was adopted to represent the localised runoff generated from the study area.

The models were calibrated to the January 2008 rainfall event. The modelled results were compared to the gauged data and recorded levels within the area of interest and the results were found to be within an acceptable range for both hydraulic models

It was observed that water levels in the Bohle River and area adjacent to the Bohle River between the Ring Road and Hervey Range Road were higher than those predicted with previous models. After extensive checking as to the reasons behind these increases, the following explanations were found;

- Timing of the peak flow discharge of the Little Bohle River (which is a tributary of the Bohle River) and the main Bohle River coincide in the modelling undertaken as part of this project. It was investigated and found that in the previous modelling in the area, the peak flow discharge between the two waterways had a slight lag.
- Ground levels captured in the latest LiDAR data for the area adjacent to the Bohle River between the Ring Road and Hervey Range Road were found to be lower than those used in previous studies and therefore more susceptible to be affected by break out flows.

The critical storm durations adopted for the areas of interest were the 6 and 12 hour storm duration for the Upper Bohle and 2 and 12 hour storm duration for the Middle Bohle sections. These values were determined by assessing the full range of storm durations for the 100-yr ARI base case. These critical durations were used to inform the hydraulic modelling for the 2 to 500-yr ARI events. The 2000-yr ARI and PMF events were assessed using the 6, 9, and 12 h critical durations for the Upper Bohle model and the 2, 12 and 72 h critical durations for the Middle Bohle model.

A summary of the flooding results for the Upper & Middle Bohle study areas are included in Table EX-1 and EX-2 respectively. These tables include indicative rainfalls for design events to facilitate evaluation against real events.

It is recommended that opportunities to reduce the extent and consequences of flooding within the study area are sought through the implementation of suitable flood mitigation measures at strategic locations. Furthermore, it is recommended that finished floor levels for properties in areas deemed to be affected by flooding is carried out to facilitate the development of suitable flood risk management strategies by Council

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Table EX-1 Summary of Upper Bohle Modelling Results

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
2-yr ARI	55 mm in 1 hour 73 mm in 2 hours 87 mm in 3 hours 102 mm in 4.5 hours 115 mm in 6 hours 136 mm in 9 hours 153 mm in 12 hours 183 mm in 18 hours 208 mm in 24 hours 320 mm in 72 hours	290	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way)		Flows contained mainly within the channel, with minor break outs predicted around the Hammond Way and Melrose Crescent areas (Bohle River and Black's Gully confluence). Slight overflow from Bohle River into Spring Creek (around the Bohle River/Black's Gully confluence). Localised areas of velocity higher than 1.25 m/s downstream of Allambie Lane. Some rural residential properties inundated (water depth generally below 0.3 m).
5-yr ARI	71 mm in 1 hour 96 mm in 2 hours 114 mm in 3 hours 135 mm in 4.5 hours 153 mm in 6 hours 182 mm in 9 hours 206 mm in 12 hours 248 mm in 18 hours 281 mm in 24 hours 435 mm in 72 hours	480	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way)		Increased floodplain inundation around the Bohle River/Black's Gully confluence. Increase in overflow from Bohle River into Spring Creek (around the Bohle River/Black's Gully confluence). Significant increase in inundation in various areas (e.g. northern end of Kelso Drive (up to 0.75 m water depth)). Slight increase in localised areas of velocity higher than 1.25 m/s downstream of Allambie Lane. Inundation of residential area adjacent to Riverway Drive and Hammond Way intersection (less than 0.5 m water depth). Residential areas in close proximity to Black's Gully affected.
10-yr ARI	80 mm in 1 hour 110 mm in 2 hours 131 mm in 3 hours 156 mm in 4.5 hours 176 mm in 6 hours 211 mm in 9 hours 239 mm in 12 hours 287 mm in 18 hours 327 mm in 24 hours 505 mm in 72 hours	635	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) **Riverway Drive (adjacent to Yut Fay Avenue)**		Increased inundation around the Bohle River/Black's Gully confluence (up to 1.5 m water depth). Increase in overflow from Bohle River into Spring Creek (water depth around 0.75 m). Increased inundation in areas upstream of the Bohle River, adjacent to northern end of Kelso Drive (up to 0.75 m water depth). Slight increase in localised areas of velocity higher than 1.25 m/s downstream of Allambie Lane. Increased inundation of residential area adjacent to Riverway Drive and Hammond Way intersection (less than 0.5 m water depth). Increase in inundation of residential areas around Black's Gully.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
20-yr ARI	92 mm in 1 hour 128 mm in 2 hours 153 mm in 3 hours 182 mm in 4.5 hours 207 mm in 6 hours 248 mm in 9 hours 282 mm in 12 hours 339 mm in 18 hours 385 mm in 24 hours 598 mm in 72 hours	955	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Increased floodplain inundation around the Bohle River/Black's Gully confluence. Increase in overflow from Bohle River into Spring Creek (water depth around 1 m). Velocity higher than 1.25 m/s now predicted to encroach upstream of Allambie Lane. Increased inundation of residential area adjacent to Riverway Drive and Hammond Way intersection (less than 0.5 m water depth). Inundation of residential area adjacent to Riverway Drive, Miles Avenue, Salina Drive and Pompeii Street (up to 0.75 m water depth). Increase in inundation of residential areas around Black's Gully.
50-yr ARI	109 mm in 1 hour 150 mm in 2 hours 180 mm in 3 hours 217 mm in 4.5 hours 248 mm in 6 hours 298 mm in 9 hours 339 mm in 12 hours 408 mm in 18 hours 465 mm in 24 hours 721 mm in 72 hours	1190	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Increased floodplain inundation around the Bohle River/Black's Gully confluence, now up to 1.5 m across the floodplain. Increase in floodplain inundation towards downstream boundary of the model (up to 0.75 m water depth). Velocity of 1.75 m/s predicted across northern end of Kelso Drive near Hammond Way intersection.
100-yr ARI	122 mm in 1 hour 168 mm in 2 hours 204 mm in 3 hours 243 mm in 4.5 hours 280 mm in 6 hours 337 mm in 9 hours 384 mm in 12 hours 463 mm in 18 hours 527 mm in 24 hours 819 mm in 72 hours	1450	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Increased floodplain inundation around Black's Gully near Hammond Way/Melrose Crescent, up to 1.5 m water depth across extensive parts of the floodplain in this area. Properties at the southern end of Tennessee Way inundated with water depths of up to 0.75 m.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
200-yr ARI	135 mm in 1 hour 188 mm in 2 hours 225 mm in 3 hours 275 mm in 4.5 hours 312 mm in 6 hours 377 mm in 9 hours 431 mm in 12 hours 519 mm in 18 hours 591 mm in 24 hours 919 mm in 72 hours	1740	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Further increase in inundation around Black's Gully near Hammond Way/Melrose Crescent, water depth now up to 1.5 m across extensive parts of the floodplain in this area. Out of channel flow being seen in the drains at the southern end of Kelso Drive (around Octagonal Crescent), water depths of up to 0.5 m in over bank area which encroaches on a number of properties in this area. Increase in extent of flooding on properties along the roads of Riverway Drive (near Hammond Way intersection), Miles Avenue, Salina Drive and Pompeii Street. Water depths up to 0.75 m predicted. Velocity higher than 1.75 m/s now predicted around Allambie Lane.
500-yr ARI	152 mm in 1 hour 212 mm in 2 hours 258 mm in 3 hours 311 mm in 4.5 hours 360 mm in 6 hours 432 mm in 9 hours 495 mm in 12 hours 597 mm in 18 hours 680 mm in 24 hours 1059 mm in 72 hours	1880	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Further increase in inundation around Black's Gully near Hammond Way/Melrose Crescent, now up to 2 m across extensive parts of the floodplain in this area. Increase in overflow from Bohle River into Spring Creek (water depth around 1.5 m). Increase in floodplain inundation around the upstream reaches of Black's Gully adjacent to Carbine Court with properties showing inundation depths of between 0.75 and 1 m. Increase in extent of flooding on properties along the roads of Riverway Drive (near Hammond Way intersection), Miles Avenue, Salina Drive and Pompeii Street. Water depths up to 1 m predicted. Increase in properties at the southern end of Tennessee Way inundated with water depths of up to 1 m. Velocity higher than 1.75 m/s now predicted around Allambie Lane.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
2000-yr ARI	172 mm in 1 hour 266 mm in 2 hours 347 mm in 4.5 hours 414 mm in 6 hours 816 mm in 24 hours 1418 mm in 72 hours	2095	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)		Large amounts of inundation across Black's Gully and the Bohle River with water depths of 1.5 to 2 m across extensive parts of the floodplain. Large flooding across residential areas with water depths of up to 0.75 m in places. Velocities up to 1.25 m/s seen in Bohle River, adjacent to Melrose Crescent (Black's Gully/Bohle River confluence) and also Black's Gully adjacent to Tennessee Way.
PMF	360 mm in 1 hour 470 mm in 2 hours 641 mm in 4.5 hours 708 mm in 6 hours 1632 mm in 24 hours 2959 mm in 72 hours	3000	Allambie Lane (Spring Creek Floodway) Allambie Lane (Bohle River Floodway) Hammond Way (Black's Gully South) Kelso Drive (Drain adjacent to Hammond Way) Riverway Drive (adjacent to Yut Fay Avenue)	Kelso State Primary School inundated.	Significant inundation across the floodplain (both Black's Gully and Bohle River) with depths of up to 2 m encroaching on residential areas. Increase in overflow from Bohle River into Spring Creek (water depth around 2 m). Significant flooding extents across built up residential areas in the model, with water depths over 1 m in some areas. Extensive areas of high velocities (1.25 m/s and higher) throughout both Bohle River and Black's Gully. Areas of high velocities (1.75 m/s and higher) around roadways including Kelso Drive, Hammond Way and Allambie Lane.

Notes:

[1] Numbers of inundated residential properties are based on 200 mm water depth within the lot which does not necessarily mean finished floor levels are exceeded and the building flooded as this data is not available for comparison.

[2] Only locations with at least 200 mm water depth within the lot are deemed to be affected. It must be noted, however, that this does not necessarily mean finished floor levels are exceeded and the building flooded as this data is not available for comparison.

Table EX-2 Summary of Middle Bohle Modelling Results

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
2-yr ARI	55 mm in 1 hour 73 mm in 2 hours 87 mm in 3 hours 102 mm in 4.5 hours 115 mm in 6 hours 136 mm in 9 hours 153 mm in 12 hours 183 mm in 18 hours 208 mm in 24 hours 320 mm in 72 hours	300	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River)		Flows contained mainly within the channel, no noticeable break out flows occurring. Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 1 m/s predicted). No significant impact predicted for residential areas (i.e. water depth generally below 0.3 m).
5-yr ARI	71 mm in 1 hour 96 mm in 2 hours 114 mm in 3 hours 135 mm in 4.5 hours 153 mm in 6 hours 182 mm in 9 hours 206 mm in 12 hours 248 mm in 18 hours 281 mm in 24 hours 435 mm in 72 hours	485	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) **Shaw Road (Bohle River Tributaries)**		Flows contained mainly within the channel, no noticeable break out flows occurring. Ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School and Beck Drive (southern end). Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 1.5 m/s predicted). Localised areas of high velocities near Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive. No significant impact predicted for residential areas (i.e. water depth generally below 0.3 m).
10-yr ARI	80 mm in 1 hour 110 mm in 2 hours 131 mm in 3 hours 156 mm in 4.5 hours 176 mm in 6 hours 211 mm in 9 hours 239 mm in 12 hours 287 mm in 18 hours 327 mm in 24 hours 505 mm in 72 hours	653	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries)		Flows contained mainly within the channel, some break out flow seen at the confluence of Kirwan-Bohle Drains A and B and Kern Drain (not impacting any residential areas). Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School and Beck Drive (southern end). Flooding noticed at the Willows Golf Course as a result of channel capacity locally exceeded at the Bohle River. Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 1.5 m/s predicted). Localised areas of high velocities near Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
					Areas of high velocity upstream of the Kern Drain crossing of Golf Links Drive (up to 1.25 m/s). No significant impact predicted for residential areas (i.e. water depth generally below 0.3 m).
20-yr ARI	92 mm in 1 hour 128 mm in 2 hours 153 mm in 3 hours 182 mm in 4.5 hours 207 mm in 6 hours 248 mm in 9 hours 282 mm in 12 hours 339 mm in 18 hours 385 mm in 24 hours 598 mm in 72 hours	988	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries)		Flows contained mainly within the channel, some break out flow seen at the confluence of Kirwan-Bohle Drains A and B and Kern Drain (not impacting any residential areas) and also Kern Drain upstream of Hervey Range Road causing flooding around Shalom Christian College. Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School, Beck Drive (southern end), Cannon Park and Shalom Christian College. Increased flooding at the Willows Golf Course Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted). Localised areas of high velocities near Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive. Areas of high velocity upstream of the Kern Drain crossing of Golf Links Drive (in excess of 1.25 m/s). Break out flows beginning to encroach on properties around Landel and Florentor Court.
50-yr ARI	109 mm in 1 hour 150 mm in 2 hours 180 mm in 3 hours 217 mm in 4.5 hours 248 mm in 6 hours 298 mm in 9 hours 339 mm in 12 hours 408 mm in 18 hours 465 mm in 24 hours 721 mm 72 hours	1220	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries)		Out of channel flow seen at the confluence of Kirwan-Bohle Drains A and B and Kern Drain and also at the upstream end of Kern Drain (downstream of Hervey Range Road crossing) (not encroaching on any residential areas). Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School, Beck Drive (southern end), Cannon Park, Shalom Christian College and Greenwood Park adjacent to Kirwan-Bohle Drain B. Increased flooding at the Willows Golf Course Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted). Areas of high velocity upstream of the Kern Drain crossing of Golf

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
					Links Drive (up to 1.5 m/s). Localised areas of high velocities near Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive. Break out flows encroaching significantly on properties around Landel and Florentor Court as well as St. Andrew's Close. Properties around Rivergum Court affected further by out of channel flows from the Bohle River.
100-yr ARI	122 mm in 1 hour 168 mm in 2 hours 204 mm in 3 hours 243 mm in 4.5 hours 280 mm in 6 hours 337 mm in 9 hours 384 mm in 12 hours 463 mm in 18 hours 527 mm in 24 hours 819 mm in 72 hours	2065	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries) **Hervey Range Road (Kern Drain)** **Dalrymple Road (Kern Drain)**		Out of channel flow seen at the confluence of Kirwan-Bohle Drains A and B and Kern Drain, at the upstream end of Kern Drain (downstream of Hervey Range Road crossing) (encroaching on residential areas) and around Kern Drain upstream of the Golf Links Drive crossing. Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School, Beck Drive (southern end), Cannon Park, Shalom Christian College and Greenwood Park adjacent to Kirwan-Bohle Drain B. Increased flooding at the Willows Golf Course Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted). Localised areas of high velocities in residential areas in Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive. Areas of high velocity upstream of the Kern Drain crossing of Golf Links Drive (up to 1.5 m/s) as well as Dalrymple Road crossing of Kern Drain (in excess of 2 m/s). Break out flows encroaching significantly on properties around Landel and Florentor Court as well as St. Andrew's Close, Fairway Close and Nineteenth Avenue. Properties around Rivergum Court and through the suburb of Rasmussen affected by break out flows from the Bohle River.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
200-yr ARI	135 mm in 1 hour 188 mm in 2 hours 225 mm in 3 hours 275 mm in 4.5 hours 312 mm in 6 hours 377 mm in 9 hours 431 mm in 12 hours 519 mm in 18 hours 591 mm in 24 hours 919 mm in 72 hours	3765	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries) Hervey Range Road (Kern Drain) Dalrymple Road (Kern Drain)	Dairy Farmers Stadium inundated.	Significant out of channel flow seen along Kern Drain, Kirwan-Bohle Drain B and Bohle River. Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School and Cannon Park. Significant inundation seen around the Willows Golf Course, Shalom Christian College and at the southern end of Beck Drive. Areas of high velocity downstream of the Hervey Range Road crossing (velocities of in excess of 2 m/s predicted) encroaching further downstream. Localised areas of high velocities in residential areas in Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive. Areas of high velocity upstream of the Kern Drain crossing of Golf Links Drive (in excess of 1.5 m/s) as well as Dalrymple Road crossing of Kern Drain (in excess of 2 m/s). Break out flows encroaching significantly on properties around Landel and Florentor Court as well as St. Andrew's Close, Fairway Close, Nineteenth Avenue and Golf Links Drive. Properties around Rivergum Court significantly affected by out of channel flows from the Bohle River as well as inundation of residential properties through the suburbs of Rasmussen, Condon, Kirwan, Thuringowa Central and Mount Louisa. Properties within the Shaw and Mount Louisa areas beginning to see inundation to a depth of up to 0.5 m.
500-yr ARI	152 mm in 1 hour 212 mm in 2 hours 258 mm in 3 hours 311 mm in 4.5 hours 360 mm in 6 hours 432 mm in 9 hours 495 mm in 12 hours 597 mm in 18 hours 680 mm in 24 hours	5675	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries) Hervey Range Road (Kern Drain) Dalrymple Road (Kern	Dairy Farmers Stadium inundated.	Significant out of channel flow seen along Kern Drain, Kirwan-Bohle Drain A and B and Bohle River and tributaries causing inundation of properties adjacent to these waterways including the suburbs of Rasmussen, Condon, Kirwan, Mount Louisa and Thuringowa Central. Increase in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School and Cannon Park. Significant inundation seen around the Willows Golf Course, Shalom Christian College and the southern end of Beck Drive.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
	1059 mm in 72 hours		Drain) **Ring Road (Bohle River)** **Ring Road (Little Bohle River)**		Areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted) encroaching further downstream. Localised areas of high velocities in residential areas in Mount Louisa and also in the Bohle River main channel adjacent to Beck Drive (extending further downstream). Areas of high velocity upstream of the Kern Drain crossing of Golf Links Drive (up to 1.75 m/s) as well as Dalrymple Road crossing of Kern Drain (in excess of 2 m/s). Break out flows encroaching significantly on properties around Landel and Florentor Court as well as St. Andrew's Close, Fairway Close, Nineteenth Avenue and Golf Links Drive. Properties within the Bohle Plains area beginning to see some inundation (water depths up to 0.5 m). Properties within the Shaw and Mount Louisa areas to experience inundation to a depth of up to 0.75 m. Overflows to Louisa Creek are noticed during this large event.
2000-yr ARI	172 mm in 1 hour 266 mm in 2 hours 347 mm in 4.5 hours 414 mm in 6 hours 816 mm in 24 hours 1418 mm in 72 hours	7780	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries) Hervey Range Road (Kern Drain) Dalrymple Road (Kern Drain) Ring Road (Bohle River) Ring Road (Little Bohle River)	Dairy Farmers Stadium, Loam Island Community Facility, Thuringowa State High School, Riverway Arts Centre and Kirwan State High School inundated.	Significant out of channel flow seen along Kern Drain, Kirwan-Bohle Drain A and B and Bohle River and tributaries causing wide-spread inundation of properties adjacent to these waterways including the suburbs of Rasmussen, Condon, Kirwan, Mount Louisa and Thuringowa Central. Large increases in ponding seen in areas around Kirwan State High School, Tony Ireland Stadium/Weir State School, Cannon Park and residential areas along Thuringowa Drive. Significant inundation seen around the Willows Golf Course, Shalom Christian College and the southern end of Beck Drive Wide-spread areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted). Localised areas of high velocities in residential areas in Mount Louisa Areas of high velocities in the Bohle River main channel adjacent to Beck Drive now considered wide-spread.

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
					Areas of high velocity extending along the length of the Kern Drain main channel (up to 1.5 m/s). Break out flow upstream of Bohle River Hervey Range Road crossing causing wide spread inundation of properties north of Nineteenth Avenue.. Properties within the Bohle Plains area seeing further inundation (water depths up to 0.75 m). Properties within the Shaw and Mount Louisa areas to experience inundation to a depth of up to 1.5 m. Increase in the overflows arriving to Louisa Creek is noticed during this extreme event.
PMF	360 mm in 1 hour 470 mm in 2 hours 641 mm in 4.5 hours 708 mm in 6 hours 1632 mm in 24 hours 2959 mm in 72 hours	10595	Hervey Range Road (Bohle River) Dalrymple Road (Bohle River) Shaw Road (Bohle River Tributaries) Hervey Range Road (Kern Drain) Dalrymple Road (Kern Drain) Ring Road (Bohle River) Ring Road (Little Bohle River)	Dairy Farmers Stadium, Loam Island Community Facility, Thuringowa State High School, Riverway Arts Centre, Kirwan State High School, **Tony Ireland Stadium and Willows State Primary School** inundated.	Major break out flows experienced between the Bohle River overflowing into Kern Drain causing major inundation of all properties encompassed by the area between these two waterways (water depths in excess of 3 m in areas). Significant out of channel flows seen in the Kirwan-Bohle Drain A and B causing wide spread inundation of in the area (waters depths in excess of 3 m in various locations). Major break out flow from the Ross River during the 72 h duration event around the bend in the Ross River adjacent to Riverway Drive, Ross River Road intersection. This break out causes major flows to travel down Thuringowa Drive and link up with Kirwan-Bohle Drain A and B and the upper reaches of Louisa Creek. Significant inundation through the residential areas of Kirwan, Condon, Rasmussen, Thuringowa Central and Mount Louisa. Wide-spread areas of high velocity downstream of the Hervey Range Road crossing (velocities in excess of 2 m/s predicted). Numerous areas of high velocities (in excess of 1.25 m/s) throughout various suburbs including Thuringowa Central, Kirwan, Shaw and Mount Louisa. Areas of high velocities in the Bohle River main channel wide-spread throughout the length of the channel within the model (in excess of 2 m/s)

Event	Indicative Rainfall (mm/h)	Properties Inundated[1]	Major Evacuation Route Closures	Emergency Management Issues[2]	Flooding Description
					Areas of high velocity extending along the length of the Kern Drain main channel (up to 2 m/s). Properties within the Bohle Plains area seeing further inundation (water depths up to 2 m). Properties within the Shaw and Mount Louisa areas to experience inundation levels in excess of 3 m water depth. Significant overflows to Louisa Creek expected during this extreme event.

Notes:

[1] Numbers of inundated residential properties are based on 200 mm water depth within the lot which does not necessarily mean finished floor levels are exceeded and the building flooded as this data is not available for comparison.

[2] Only locations with at least 200 mm water depth within the lot are deemed to be affected. It must be noted, however, that this does not necessarily mean finished floor levels are exceeded and the building flooded as this data is not available for comparison.

1.0 Introduction

1.1 Overview

AECOM Australia Pty Ltd (AECOM) was engaged by Townsville City Council (TCC) to develop refined base-case hydrologic and hydraulic flood models for the Upper & Middle Bohle area as part of the *City Wide Flood Constraints Project*.

The *City Wide Flood Constraints Project* seeks to develop detailed and accurate flood models of the city for:

- Identifying flood constraints for new planning scheme development;
- Developing concepts for trunk stormwater and flood mitigation infrastructure for future capital investment, and
- Providing flood levels and extents for development control.

1.2 Study Area

The study area, shown in Figure 1-1, was divided in two sections (Upper Bohle and Middle Bohle) to reduce the size of the models needed and facilitate the assessment.

Major watercourses across the study area include the Bohle River and its tributaries (i.e. Black's Gully, Spring Creek, Little Bohle River, Three Mile Creek, North Creek, Kern Drain, Tchooratippa Creek and Kirwan-Bohle Drains A and B). Additionally, the Ross River flows along the eastern boundary of the models and was included to represent break out flows affecting the area of interest during extreme events.

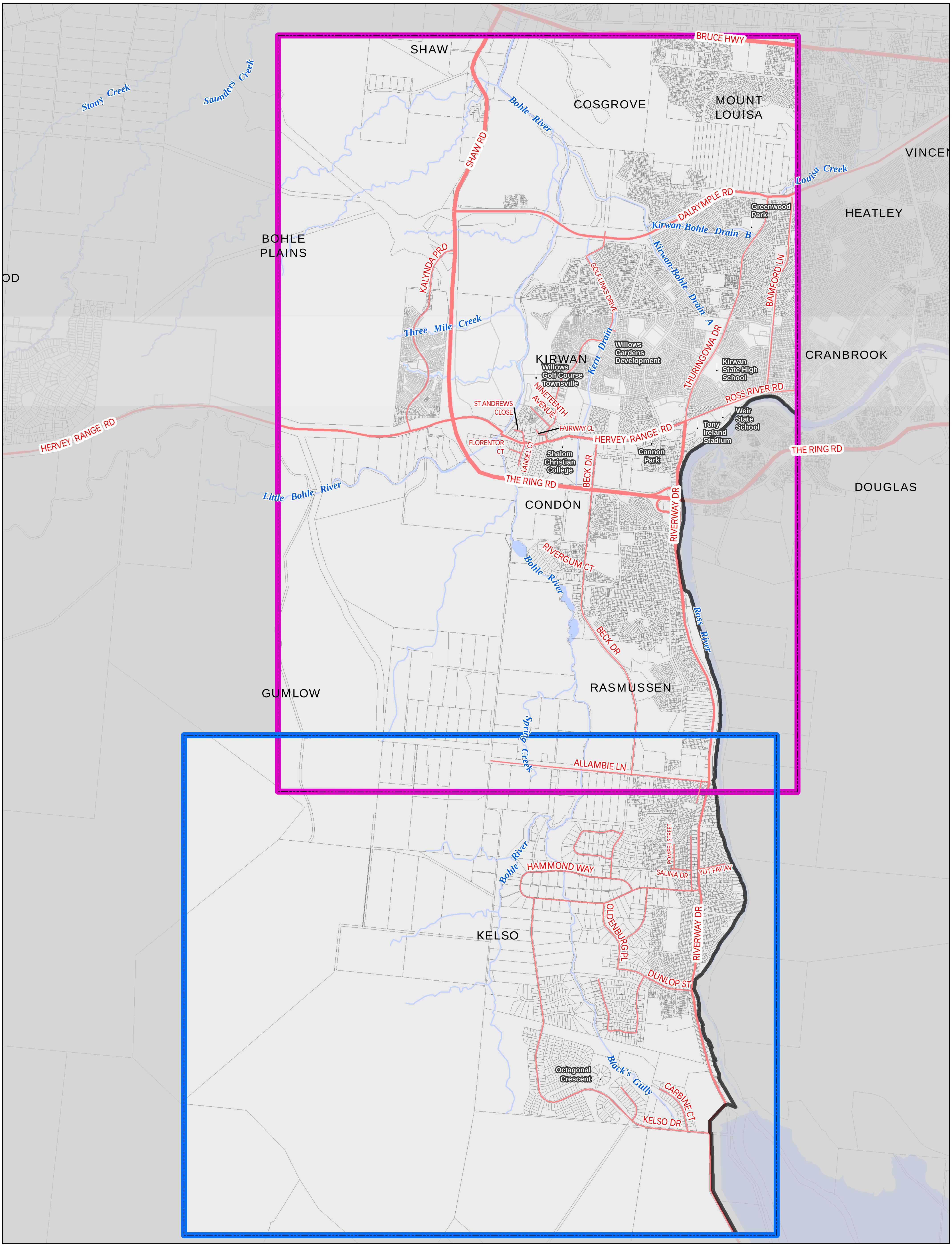
Major road links across the study area include the Townsville Ring Road, Shaw Road, Hervey Range Road, Thuringowa Drive, Ross River Road and Riverway Drive. Existing residential developments within the study area include the suburbs of Bohle, Bohle Plains, Shaw, Mount Louisa, Kirwan, Thuringowa Central, Condon, Gumlow, Rasmussen, Kelso and Pinnacles.

The catchments considered for modelling purposes include Upper Bohle River, Black's Gully, Middle Bohle River, Condon, Little Bohle River, Bohle River (1, 2, 3 and 4), Kirwan, Louisa Creek, Saunders Creek and Stony Creek.

1.3 Scope of Works

The scope of works for the *Upper & Middle Bohle Flood Study* included:

- Collate and review of available data including previous models relevant to the study
- Assess the study area to confirm catchment parameters as well as gain an understanding of hydraulic controls and flow pathways
- Identify and represent new development projects and associated infrastructure from design plans
- Establish suitable upstream boundary conditions by examining previous studies
- Review and update relevant XP-RAFTS hydrologic models where significant changes in land-use have occurred and to account for changes in the new LiDAR
- Identify suitable XP-RAFTS hydrologic models within the study area to derive inflow hydrographs for the 2, 5, 10, 20, 50, 100, 200, 500 and 2000-yr (ARI) storm events and the Probable Maximum Flood (PMF) event
- Review application of Rain-on-Grid method for localised runoff within urbanised areas
- Develop MIKE FLOOD hydraulic models within the study area to determine:
    - Base-Case flood extents, velocity and depth of flow for the 2, 5, 10, 20, 50, 100, 200, 500 and 2000-yr ARI storm events and PMP storm runoff. Runoff resulting from the Probable Maximum Precipitation (PMP) storm is referred to as the PMF
    - Peak flood envelope for the 100-yr ARI storm events under the Base-Case scenario (developed from the range of storms used to assessed the critical duration which includes the 1, 2 ,3, 4.5, 6, 9, 12 and 18 h durations)



UPPER & MIDDLE BOHLE FLOOD STUDY
Locality Plan

Watercourse
Property Boundaries
Middle Bohle Model Extent
Upper Bohle Model Extent

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Figure 1-1

1.4 Study Approach

The assessment of the Upper & Middle Bohle builds on a number of previous flood studies in the vicinity. Where needed, existing hydrologic and hydraulic models have been updated and refined in accordance with the *Preparation of Flood Studies and Reports - Guidelines* (2010) developed by TCC, to account for significant changes.

The hydraulic models developed includes culverts, bridges and stormwater pipes with a capacity greater than or equal to peak discharge from a 2-yr ARI storm event (this was taken as structures with a cross sectional area equivalent or greater than that of a 900 mm diameter pipe). Modelling these structures facilitates the representation of flow through the existing drainage infrastructure and results in a more robust understanding of flooding across the study area.

Inflow boundary conditions were derived using inflow hydrographs from XP-RAFTS hydrologic models for both the Upper & Middle Bohle River hydraulic models. Downstream boundary conditions were derived using discharge rating curves for the Upper Bohle model. An open ocean boundary was used for the downstream boundary of the Bohle River to account for any potential backwater effects from the downstream catchments of the Bohle River and for Louisa Creek a discharge rating curve was used for the downstream boundary. A combination of XP-RAFTS local source points and Rain-on-Grid net precipitation was adopted to represent runoff.

1.5 Spatial Data

TCC provided the following data for the study:

- Topography data in the form of contours and XYZ tiles at 1 metre (m) spacing based on 2009 LiDAR survey (Middle Bohle model)
- Topography data in the form of contours and XYZ tiles at 1 metre (m) spacing based on 2012 LiDAR survey (Upper & Middle Bohle models)
- Aerial photography flown in 2011 with pixel sizes of 0.125 m (to help identify development that has taken place since the 2009 LiDAR was flown)
- Aerial photography flown in 2009 with pixel sizes of 0.125 m
- Digital cadastral database containing property boundaries (TCC, October 2012)
- Structure information for various bridges and culverts identified within the extents of the models
- Information for recent developments not captured in the 2009 LiDAR
- Stormwater network for the urban areas within the modelling extents (TCC, October 2012)
- Bridge and culvert details along the Townsville Ring Road arterial road within the model extent (AECOM, October 2012)

1.6 Previous Reports

There are a number of previous flood/drainage assessments completed by AECOM and others within and around the study area. A summary of the most relevant previous studies referenced throughout this report is provided below. It also should be noted that some of these studies have been used to inform our assessment.

- **Bohle River Floodplain Management Study (Maunsell McIntyre April 2001)**

The *Bohle River Floodplain Management Study* (*BRFMS*) project assessed the hydraulics and mapped the extents of the of the Bohle River floodplain from Kelso Drive to its outlet at Halifax Bay. RORB hydrologic and 1D MIKE 11 hydraulic models were developed to complete the flood extents analysis.

- **Kern Drain Trunk Drainage Assessment (AECOM January 2008)**

Townsville City Council (TCC) commissioned AECOM to undertake this study to establish 50 year ARI hydraulic grade lines for kern drain and to determine the impacts of as-built excavations of the drain. The investigation focused on the timing of catchment flows from Kern drain with various tailwater levels as a result of Bohle River flood flows.

As part of this study, the catchment hydrology assessment undertaken for the *BRFMS* was refined to incorporate all recent developments since the *BRFMS*, as well as to account for site specific investigations. The refined XP-RAFTS hydrologic model was verified to the previous RORB modelling of the catchments from the *BRFMS*.

- **Bohle Plains Flood Planning Report (AECOM April 2010)**

The *Bohle Plains Flood Planning Report* (*BPFPR*) consolidated all modelling studies completed in the Bohle Plains area since the *BRFMS*. The assessment included hydrological and hydraulic modelling of the Bohle River, Saunders Creek, Stony Creek and Black River catchments for the 50-yr ARI storm event.

- **Upper Bohle Plains Flood Study (AECOM July 2011)**

The *Upper Bohle Plains Flood Study (UBPFS)* assessed base case flooding for the Upper Bohle Plains area based on previously developed and calibrated models as part of the *City Wide Flood Constraints Project*. Hydrology models for the Black River, Bohle River 2, Bohle River 3, Saunders Creek and Stony Creek catchments were updated using TCC's LiDAR topography flown in 2009. A MIKE FLOOD hydraulic model was built based on the LiDAR topography with major culverts and large open channel drains within Kalynda Chase and Rangewood developments included using the 1D MIKE 11 elements.

- **Deeragun Flood Study (AECOM July 2012)**

The *Deeragun Flood Study (DFS)* assessed base case and urbanised scenarios flooding for the Deeragun area based on previously developed and calibrated models as part of the *City Wide Flood Constraints Project*. Hydrology models for the Black River, Bohle River 2, Bohle River 3, Saunders Creek and Stony Creek catchments were updated using TCC's LiDAR topography flown in 2009. A MIKE FLOOD hydraulic model was built based on the LiDAR topography with major culverts and large open channel drains within existing developments included in the model using the 1D MIKE 11 and MIKE URBAN elements. This hydraulic model was calibrated to the February 2008 storm event.

- **Lower Bohle Flood Study (AECOM October 2012)**

The Lower Bohle Flood Study (LBFS) assessed base case and urbanised scenarios flooding for the Lower Bohle area building on a number of previous flood assessment carried out in the vicinity as part of the City Wide Flood Constraints Project. A MIKE FLOOD hydraulic model was built based on TCC's LiDAR topography flown in 2009 with major culverts and large open channel drains within existing developments included in the model using the 1D MIKE 11 and MIKE URBAN elements. This hydraulic model is being superseded by a new version incorporating hydrographic survey of the downstream reaches of the Bohle River and 2012 LiDAR data.

- **Ross River Flood Study Report (TCC 2013)**

The *Ross River Flood Study Report (RRFSR)* covers the entire Ross River catchment, both upstream and downstream of the dam. The hydraulic model developed provides a broad-scale representation of flows within the lower Ross River and also informs dam outflow management.

2.0 Hydrology Assessment

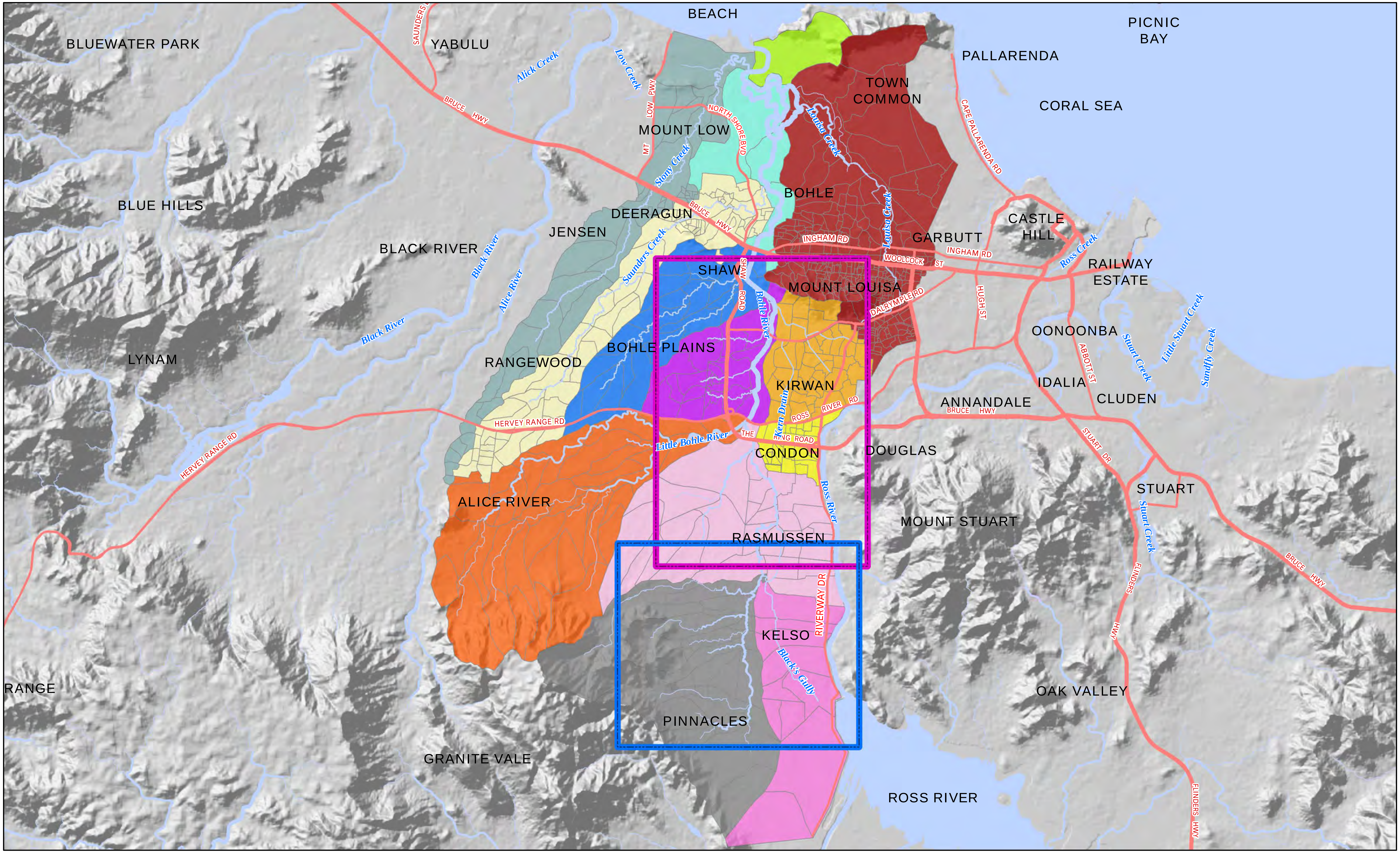
2.1 Overview

The hydrology for the Upper and Middle Bohle Flood Study was obtained from the previously completed BPFPR (*BPFPR, 2010*), Upper Bohle Plains Flood Study (*UPBFS, 2011*), Deeragun Flood Study (*DFS, 2012*) and Lower Bohle Flood Study (*Lower Bohle Flood Study, 2012*). Fraction impervious changes were made to various existing XP-RAFTS models to account for significant development in the area. No re-delineation of catchments was undertaken as part of this study.

The location and extent of model catchments in relation to the study area is shown in Figure 2-1 with detailed catchment maps being found in Appendix C. For this study the loss factors were adopted based on TCC guidelines *Preparation of Flood Studies and Reports - Guidelines* (*TCC, 2010*). For the pervious areas within the model the initial loss of 25 mm and continuing loss 2.5 mm/h were used whereas, for the impervious areas within the model the initial loss of 0 mm and continuing loss of 1 mm/h were adopted.

Two methods were used to represent rainfall runoff within the hydraulic models used for this study. There were:

- Rain-on-Grid which was used across the more urban and relatively flat catchments; and
- The rainfall runoff hydrological modelling approach (XP-Rafts) which was generally applied across rural as well as steep sub-catchments.



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Watercourse	Black's Gully	Bohle River 3	Kirwan	Middle Bohle River	Upper Bohle River
Upper Bohle Model Extent (This study)	Bohle River 1	Bohle River 4	Little Bohle River	Saunders Creek	
Middle Bohle Model Extent (This study)	Bohle River 2	Condon	Louisa Creek	Stony Creek	

UPPER & MIDDLE BOHLE FLOOD STUDY
Location and Extents of Model Catchments

Figure 2-1

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2.2 Design Rainfall

Intensity Frequency Duration (IFD) input parameters specific for the study area were determined from Volume 2 of the Australian Rainfall and Runoff report (AR&R, 1987). The values are summarised in Table 2-1. Standard techniques from AR&R were used to determine rainfall intensities for the durations assessed and for ARI's up to the 100-yr event. For the rainfall event greater than 100-yr ARI but less than 1000-yr ARI, extrapolation of AR&R has been undertaken and verified against CRC-FORGE rainfall estimation methods. The values obtained are summarised in Table 2-2. The design rainfall intensities developed correlate with those established in the BPFPR 2010.

Table 2-1 IFD Input Parameters

Parameter	Value
2 year ARI, 1 hour duration (mm/h)	54.8
2 year ARI, 12 hour duration (mm/h)	12.77
2 year ARI, 72 hour duration (mm/h)	4.46
50 year ARI, 1 hour duration (mm/h)	107.82
50 year ARI, 12 hour duration (mm/h)	27.95
50 year ARI, 72 hour duration (mm/h)	9.9
G	0.05
F2	3.93
F50	17.03
Zone	3

Table 2-2 Design Rainfall Intensities in mm/h

Duration (hours)	Average Recurrence Interval (year)							
	2	5	10	20	50	100	200	500
1	55	71	80	92	109	122	135	152
2	36.6	47.9	55	64	75	84	94	106
3	28.9	38	43.5	51	60	68	75	86
4.5	22.7	30.1	34.6	40.5	48.3	54	61	69
6	19.1	25.5	29.4	34.5	41.3	46.6	52	60
9	15.1	20.2	23.4	27.5	33.1	37.4	41.9	48
12	12.72	17.18	19.93	23.49	28.28	32.03	35.92	41.29
18	10.17	13.76	15.97	18.83	22.69	25.7	28.84	33.16
24	8.66	11.72	13.62	16.06	19.36	21.94	24.62	28.32
36	6.86	9.3	10.81	12.75	15.38	17.44	19.58	22.53
48	5.77	7.83	9.1	10.74	12.97	14.71	16.52	19.02
72	4.44	6.04	7.02	8.3	10.02	11.37	12.77	14.71

2.3 Extreme Rainfall Events

The Generalised Short Duration Method (GSDM) and the Generalised Tropical Storm Method (GTSM) were used to estimate the Probable Maximum Precipitation (PMP) for this study. The rainfall intensity for the extreme (2000-yr ARI and PMP) events assessed are summarised in Table 2-3 and the corresponding areal reduction factors are found in Table 2-4.

The critical durations assessed for the extreme rainfall events (2000-yr ARI and PMP) were 1, 4.5 and 6 h for the Upper Bohle model and 2, 12 and. 72 h for the Middle Bohle model. The *Ross River Flood Study Report (RRFSR 2013)* identifies 72 h as the duration where a break out occurs from the Ross River main channel into the Bohle River catchment and therefore this duration was selected for the assessment of the Middle Bohle section. The other critical durations were determined following review of the critical duration assessment for the 100-yr ARI event.

PMP rainfall calculations were completed with catchments grouped as follows;

- Blacks Gully, Upper Bohle River and Middle Bohle River
- Little Bohle River
- Kirwan and Condon
- Bohle River 1, Bohle River 2 Bohle River 3 and Bohle River 4 as well as Saunders and Stony Creek
- Louisa Creek

The sub-catchments were grouped to represent major tributaries within the catchment being assessed and to identify the one combination likely to generate the greatest rainfall for the PMP event across the wider catchment. This approach was based on the generally accepted premise that it is highly unlikely that PMP would fall across more than one of the main tributaries (all sun-catchment grouped) at the same time.

Table 2-3 Extreme Rainfall Events Intensity (mm/h)

Duration (hours)	Blacks Gully, Upper Bohle and Middle Bohle River		Little Bohle River		Kirwan and Condon		Bohle River 1, 2 and 3, Saunders and Stony Creek		Louisa Creek	
	2000-yr ARI	PMP	2000-yr ARI	PMP	2000-yr ARI	PMP	2000-yr ARI	PMP	2000-yr ARI	PMP
1	172	360	195	370	198	410	194	350	188	380
2	133	235	135	255	137	280	134	245	128	250
3	103	183	112	197	114	217	112	193	105	190
4.5	77	142.5	86	156	87	170.5	86	152.5	87	149
6	69	118	75	128	76	140	75	127	72	123
9	55	96	61	102	61	107	60	98	59	96
12	46	85	52	88	53	91	52	84	50	83
18	38.5	74	42.4	75	42.4	75	42	70	40.9	69
24	34	68	36.5	69	36.4	67	36.2	63	35.4	63
36	28	56	29.2	56	29.1	55	28.9	52	28.5	51
48	24.3	49	24.8	49.1	24.7	47.8	24.5	45.3	24.3	44.9
72	19.7	41.1	19.4	41.1	19.3	40.1	19.2	38	19.1	37.6

Table 2-4 Extreme Rainfall Events Areal Reduction Factors

Duration (hours)	Blacks Gully, Upper Bohle and Middle Bohle River	Little Bohle River	Kirwan and Condon	Bohle River 1, 2 and 3, Saunders and Stony Creek	Louisa Creek
	Areal Reduction Factor	Areal Reduction Factor	Areal Reduction Factor	Areal Reduction Factor	Areal Reduction Factor
1	0.86	0.91	0.95	0.86	0.91
2	0.91	0.94	0.97	0.91	0.94
3	0.94	0.96	0.98	0.94	0.96
4.5	0.95	0.97	0.99	0.95	0.97
6	0.95	0.97	0.99	0.95	0.97
9	0.96	0.97	0.99	0.96	0.97
12	0.96	0.98	0.99	0.96	0.98
18	0.97	0.98	0.99	0.97	0.98
24	0.97	0.98	0.99	0.97	0.98
36	0.93	0.93	0.93	0.93	0.93
48	0.94	0.94	0.94	0.94	0.94
72	0.95	0.95	0.95	0.95	0.95

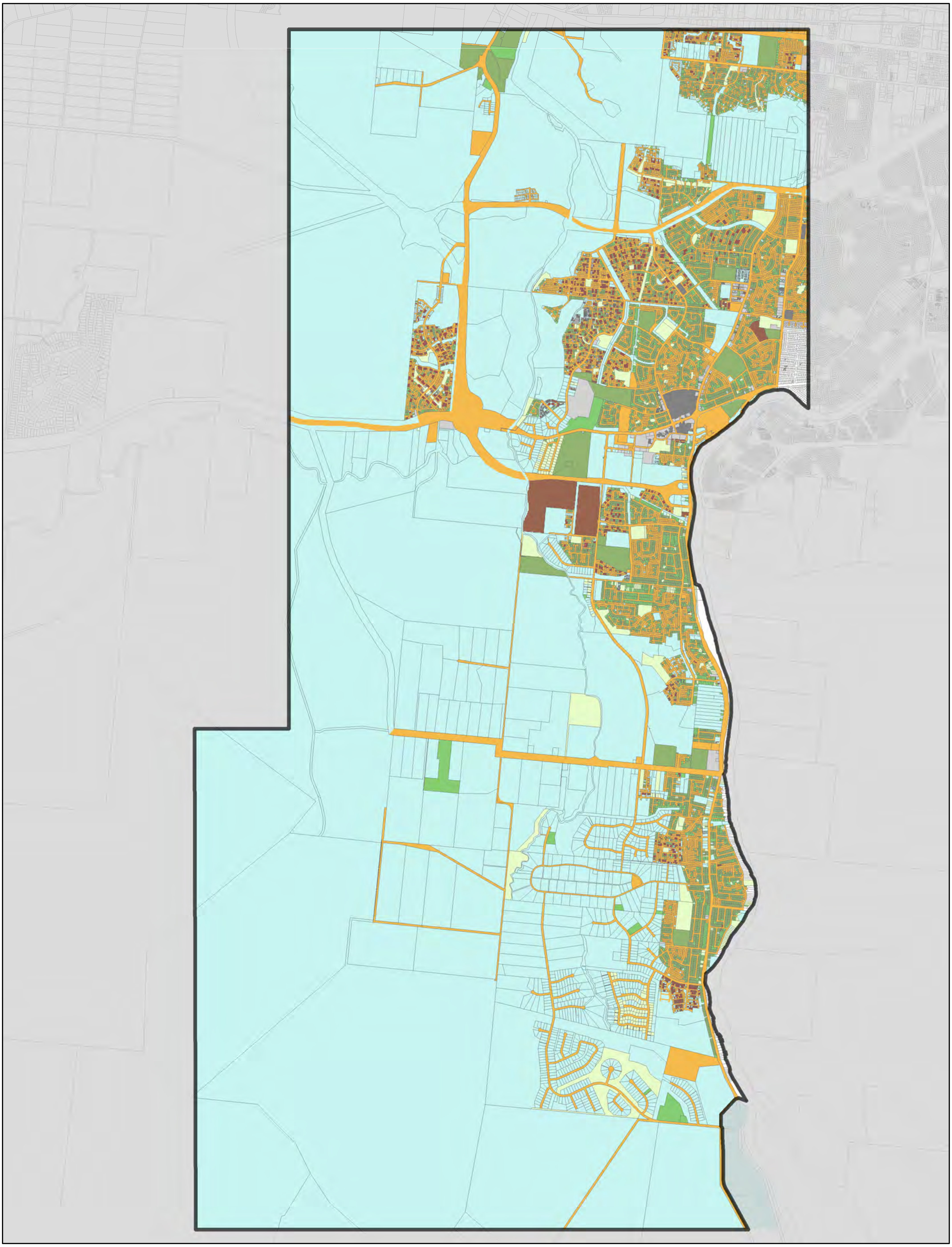
2.4 Rain-on-Grid Method – Local Runoff

Rain-on-Grid is a method for applying rainfall to a hydraulic model. It involves applying the rainfall directly on the two-dimensional grid which supplements the rainfall/runoff hydrologic modelling approach using software like XP-RAFTS, RORB, etc. This method is particularly advantageous in ungauged urban areas such as those within the Upper & Middle Bohle model extents. For this reason rain-on-grid was applied within the model grid to simulate the local runoff generated. It must be noted, however, that this method is not recommended for steep areas and therefore the extent of application across the hydraulic models has been limited to relatively flat areas.

Two-dimensional rainfall excess time series for each ARI and duration were created to represent the local net precipitation for the study area. This rainfall excess is calculated by applying initial and continuing losses to the design rainfall for two extreme scenarios (i.e. pervious and impervious). As outlined in AR&R Volume 1 initial and continuing loss values represent infiltration and storage of runoff in surface depressions. Initial and continuous loss values of 25 mm / 2.5 mm/h and 0 mm / 1 mm/h were applied to the pervious and impervious areas respectively for both the Upper & Middle Bohle models.

For design events between the 2-yr ARI and 500-yr ARI, temporal patterns were applied based on AR&R, volume 2. For events greater than the 500-yr ARI with storm durations of less than 6 h, the GSDM temporal pattern was applied. For longer duration rare events (i.e. greater than 500-yr ARI), duration specific temporal patterns were used based on the Generalised Tropical Storm Method.

An imperviousness map for the base case scenario was created using TCC's property boundary dataset and high resolution aerial imagery (see Figure 2-2). The property boundary dataset contains suitable descriptors that allow the separation between vacant land, vacant land intended for residential use, residential dwelling, parks, commercial and industrial land, etc. To determine the imperviousness percentage an average house size to land parcel ratio was used. For all other parcels, an imperviousness fraction was applied based on typical values for the type of land in the area.



UPPER & MIDDLE BOHLE FLOOD STUDY
Imperviousness Map

Impervious Fraction (%)

- 0 - 10% Impervious
- 10 - 20% Impervious
- 20 - 30% Impervious
- 30 - 40% Impervious
- 40 - 50% Impervious
- 50 - 60% Impervious
- 60 - 70% Impervious
- 70 - 80% Impervious
- 80 - 90% Impervious
- 90 - 100% Impervious

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Figure 2-2

3.0 Hydraulic Modelling

3.1 Overview

MIKE FLOOD was used as the platform to construct two hydraulic models for Upper & Middle Bohle. The model extents for Upper & Middle Bohle in relation to previous studies are shown in Figure 3-1.

3.2 MIKE FLOOD Hydraulic Model

MIKE FLOOD is a numerical hydraulic model developed by the Danish Hydraulic Institute (DHI). The model dynamically couples the one-dimensional MIKE URBAN pipe hydraulics and one-dimensional MIKE 11 elements (culverts, bridges and open channels) hydraulics with the two-dimensional surface water hydraulic model MIKE 21. Outputs from MIKE FLOOD include GIS compatible maps of flood extents, water depth, water level, flow and velocities.

3.2.1 MIKE 11

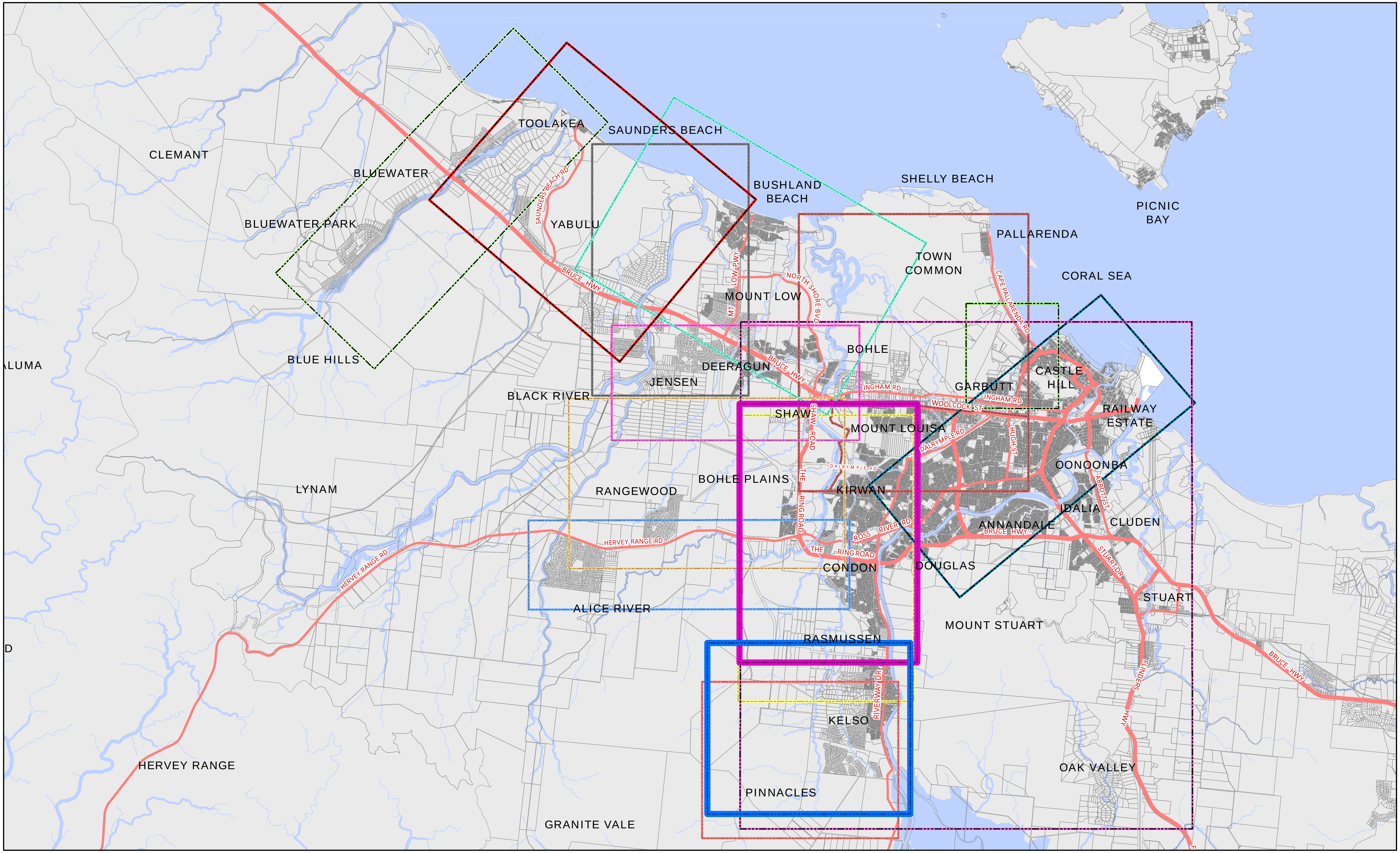
MIKE 11 is a software package used for one-dimensional simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. The model is typically used to assess one-dimensional flows through structures such as bridges and culverts. It also enables simulation of complex river systems where one-dimensional flow predominates.

3.2.2 MIKE 21

MIKE 21 is a software package used for two-dimensional simulation of flow distribution based on water and ground levels at each time step of a model run. The two-dimensional model provides a more accurate determination of the extent, magnitude and direction of the flood flows than MIKE 11, without the need to pre-determine the flow path.

3.2.3 MIKE URBAN

MIKE URBAN is a software package used for one-dimensional simulation of sanitary or storm drain sewers as well as water distribution systems that couples with MIKE 11 and MIKE 21. This software package can be used to analyse a range of parameters including water quality, rainfall runoff and infiltration.



UPPER & MIDDLE BOHLE FLOOD STUDY
Model Extents in relation to previous studies

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0 0.5 1 2 Kilometres

Coordinate System: GDA 1994 MGA Zone 55

Base Data:
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- Main Roads
- Watercourse
- Upper Bohle Model Extent (This study)
- Middle Bohle Model Extent (This study)
- Louisa Creek Model Extent (2014)
- Bluewater Creek Model Extent (2013)
- Althaus/Deep Creek Model Extent (2013)
- Ross River Model Extent (2010)
- Ross Creek Model Extent (2013)
- Captains Creek Model Extent (2014)
- Lower Bohle Model Extent (2014)
- Black River Model Extent (2013)
- Deeragun Model Extent (2012)
- Little Bohle River Model Extent (2011)
- BPFPR (Lower Bohle) Model Extent (2010)
- Upper Bohle Plains Model Extent (2011)
- BPFPR (Upper Bohle) Model Extent (2010)

Figure 3-1

3.3 Model Development

The Upper & Middle Bohle hydraulic models were constructed using as-built or as designed plans of new developments, details of road culverts and information from existing MIKE FLOOD hydraulic models. The previous Upper & Lower Bohle River *(BPFPR)*, Upper Bohle Plains and Little Bohle River models overlap the study area as shown in Figure 3-1. These models provided relevant information for the construction of the new Upper & Middle Bohle models.

3.3.1 Model Geometry

3.3.1.1 Upper Bohle

A 10 m by 10 m Cartesian grid was developed to represent the topography of the Upper Bohle hydraulic model surface. The grid was based on topographic data supplied by TCC using 2012 LiDAR data. The model consists of approximately 675,000 cells with each cell representing the average elevation over each cell area (10 m x 10 m). To ensure adequate representation and continuity, stream inverts for the major watercourses within the study extents were stamped into the MIKE 21 grid using levels obtained from the previous Upper and Lower Bohle River Flood Planning Report *(BPFPR)* which were based on topographical survey data.

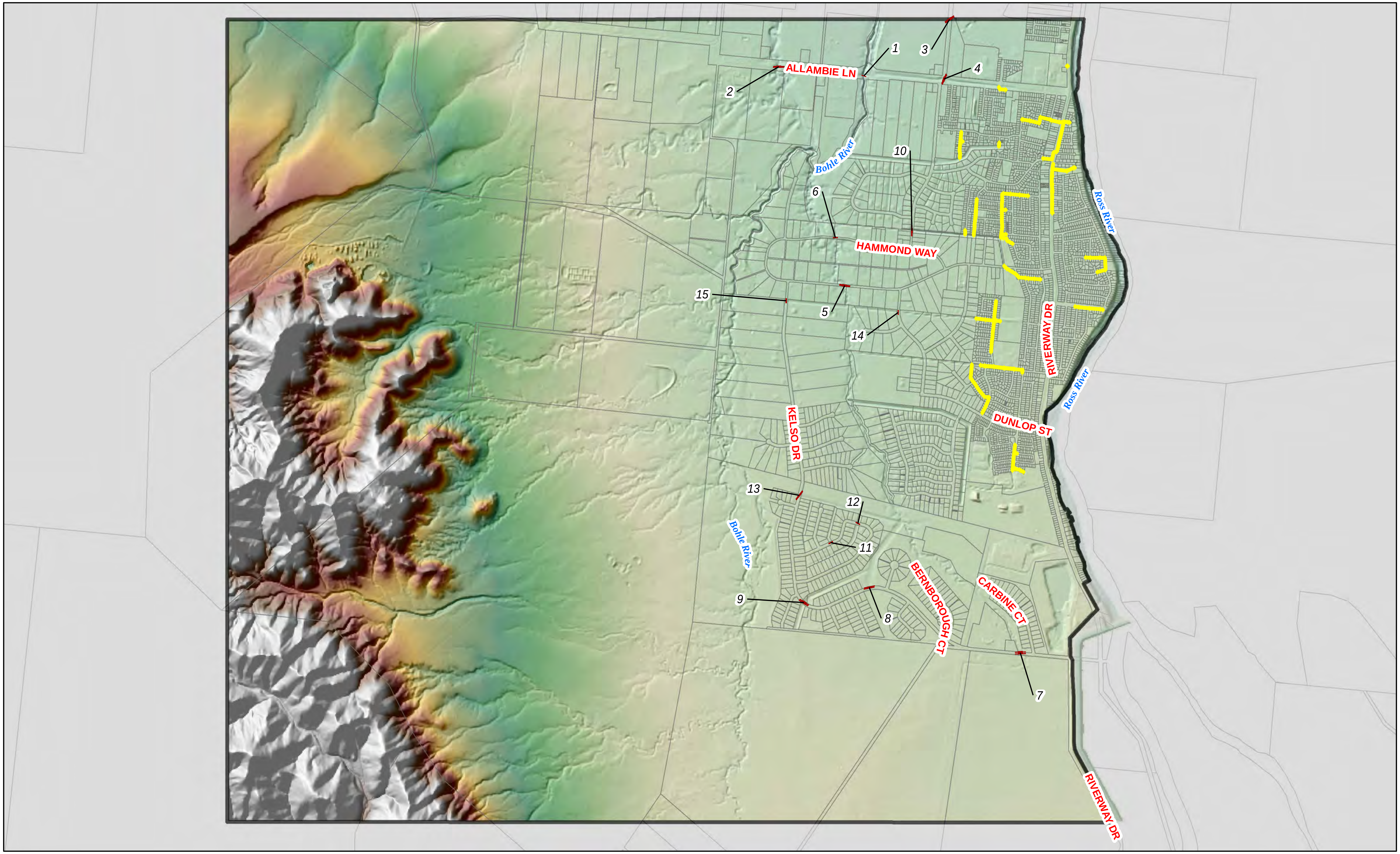
Road crown levels of Riverway Drive, Beck Drive, Allambie Lane, Hammond Way, Kelso Drive, Oldenburg Place, Connemara Course, Dunlop Street, Bernborough Court and Carbine Court were incorporated into the MIKE 21 grid as they act as major flood control mechanisms within the study area.

Hydraulic structures within the study area were represented using either the 1D MIKE 11 or MIKE URBAN elements that were coupled into the 2D MIKE 21 grid. All major culverts along all roadways were represented in the MIKE 11 model and major underground drainage was generally represented using the MIKE URBAN model as shown in Figure 3-2. Note that only structures with a cross-sectional area equivalent or in excess of that of a 900 mm diameter pipe were included in the model. Details of the structures modelled using MIKE 11 are summarised in Table 3-1.

Table 3-1 Details of culverts modelled using MIKE11 in the Upper Bohle Model

Reference Number	Culvert Reference	Configuration	Invert level (m AHD)		Length (m)
			Upstream	Downstream	
1	AllambieLn_BohleRvr	5/3300x2400RCBC	14.04	13.93	7.32
2	AllambieLn_SpringCreek	1/750RCP	16.46	16.46	12.20
3	BeckDr_6	2/1200x600RCBC	18.93	18.87	20.58
4	BeckDr_7	3/1800x1500RCBC	18.68	18.66	18.00
5	BlacksGully	3/3600x3600RCBC	18.41	18.33	10.20
6	BlacksGully_Culv	3/3600x3600RCBC	17.84	17.76	9.80
7	BlacksGully_Culvert1	5/23800x1800RCBC	26.09	26.08	10.00
8	KelsoDr_Easement1	6/2005x800RCBC	26.33	26.27	10.00
9	KelsoDr_Easement2	5/1500RCP	26.76	26.65	10.00
10	ShetlandPl_Drain	3/3030x2140RCBC	19.78	19.74	11.40
11	OctagonalCrs_DrainA	4/675RCP	25.24	25.20	14.64
12	OctagonalCrs_DrainB	3/375RCP	25.24	25.20	14.64
13	KelsoDr_DrainA	2/1200x600RCBC	26.27	26.21	13.20
14	OldenburgPl_Drain	2/1200x600RCBC	21.96	21.90	13.42
15	KelsoDr_DrainB	2/1200x600RCBC	21.79	21.71	11.60

Note:
RCBC = Reinforced Concrete Box Culvert;
RCP = Reinforced Concrete Pipe.



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Coordinate System: GDA 1994 MGA Zone 55

Base Data:
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MIKE URBAN Structures	MIKE 11 Structures

UPPER & MIDDLE BOHLE FLOOD STUDY
Upper Bohle: Model Geometry

Figure 3-2

3.3.1.2 Middle Bohle

A 10 m by 10 m Cartesian grid was developed to represent the topography of the Middle Bohle hydraulic model surface. The grid was based on data supplied by TCC and developed using a combination of 2009 and 2012 LiDAR as well as as-built information for post-2009 developments in the area. The model consists of approximately 770,000 cells with each cell representing the average elevation over each cell area (10 m x 10 m). To ensure adequate representation, stream inverts for the major watercourses within the study extents were stamped into the MIKE 21 grid using levels obtained from the previous Upper and Lower Bohle River Flood Planning Report *(BPFPR)* which were based on topographical survey data.

Road crown levels of the Townsville Ring Road, Shaw Road, Dalrymple Road, Hervey Range Road, Kalynda Parade, Thuringowa Drive, Bamford Lane, Ross River Road, Riverway Drive, Beck Drive and Allambie Lane were incorporated into the MIKE 21 grid as they act as major flood control mechanisms within the study area.

Hydraulic structures within the study area were represented using either the 1D MIKE 11 or MIKE URBAN elements that were coupled into the 2D MIKE 21 grid. All major bridges and culverts along all roadways were represented in the MIKE 11 component. Whereas major underground drainage was generally represented using the MIKE URBAN element as shown in Figure 3-3. Note that only structures with a cross-sectional area equivalent or in excess of that of a 900 mm diameter pipe were included in the model. Details of the structures modelled using MIKE 11 are summarised in Table 3-2 and Table 3-3.

Table 3-2 Details of culverts modelled using MIKE11 in the Middle Bohle Model

Reference Number	Culvert Reference	Configuration	Invert level (m AHD)		Length (m)
			Upstream	Downstream	
1	AllambieLn_BohleRvr	5/3300x2400RCBC	14.04	13.93	7.32
2	AllambieLn_SpringCreek	1/750RCP	16.46	16.46	12.20
3	BeckDr_1	4/2100x1500RCBC	13.99	13.93	10.30
4	BeckDr_2	2/2400x1800RCBC	15.10	15.01	12.00
5	BeckDr_3	2/2400x1800RCBC	14.81	14.70	14.40
6	BeckDr_4	3/3000x1800RCBC	15.56	15.41	15.60
7	BeckDr_5	3/2700x1800RCBC	18.54	18.53	10.80
8	BeckDr_5b	2/1200x600RCBC	18.42	18.32	10.80
9	BeckDr_6	2/1200x600RCBC	18.93	18.87	20.58
10	BeckDr_7	3/1800x1500RCBC	18.68	18.66	18.00
11	BeckRd_GouldianDrain	3/300x1800RCBC	14.00	13.90	22.80
12	BeckRd_VickersDrain	3/1800x1800RCBC	14.50	14.34	32.01
13	Bohle_Dalrymple	6/1200x900RCBC	4.78	4.72	20.00
14	BurndaSt_DrainA	3/3300x2000RCBC	8.82	8.80	20.00
15	CarlyleGardens_SmithDrain	3/2700x1500RCBC	14.30	14.29	9.60
16	DalrympleRd_DrainA	3/3300x3000RCBC	7.84	7.84	20.00
17	DalrympleRd_KernDrain	5/3600x3600RCBC	7.00	6.91	24.00
18	DalrympleRd_LouisaCk_1	2/1200RCP	8.03	7.90	22.50
19	DalrympleRd_LouisaCk_2	1/3300x1800RCBC	7.54	7.45	39.00
20	DalrympleRd_TableDrain	3/1200x1200RCBC	9.37	9.27	37.16
21	DalrympleRdBox_DrainB	2/3300x3000RCBC	7.01	7.01	20.00
22	DalrympleRdPipe_DrainB	1/1650RCP	8.01	8.01	20.00
23	FranklinDr_LibertyDrain	3/1200x900RCBC	19.98	19.81	21.60
24	GolfLinksDr_KernDrain	5/3600x3600RCBC	7.45	7.40	50.00
25	GrahamAv_LibertyDrain	5/1200x900RCBC	12.40	12.29	20.40
26	GreenwoodDr_DrainB	3/3300x2700RCBC	7.32	7.32	19.00
27	HerveyRangeRd_Cul2A_ch5535	2/1200x300RCBC	22.05	22.03	9.80

Reference Number	Culvert Reference	Configuration	Invert level (m AHD)		Length (m)
			Upstream	Downstream	
28	HerveyRangeRd_Cul2B_ch6035	1/750x400RCBC	23.12	23.05	9.80
29	HerveyRangeRd_KernDrain	3/3600x1800RCBC	11.65	11.64	40.00
30	HerveyRangeRdPipe_KernDrain	1/1700RCP	11.65	11.64	40.00
31	KalyndaPrd_3MileCreek	Irregular Shaped Structure (3/6200x1800RCBC)*	13.69	13.64	22.52
32	KalyndaPrd_NthCreek	Irregular Shaped Structure (3/5800x1800RCBC)*	13.85	13.85	26.00
33	PinnacleQuarries_BohleRvr	1/2000RCP	14.56	14.47	10.00
34	RR_29A	2/1200x450RCBC	16.86	16.77	19.20
35	RR_30A	4/1200x600RCBC	17.07	16.97	13.20
36	RR_32A	1/1200x450RCBC	15.57	15.45	34.80
37	RR_33A	5/3000x1800RCBC	12.76	12.65	39.00
38	RR_34A	3/3600x3000RCBC	12.00	11.50	22.80
39	RR_34B	2/3600x3000RCBC	12.36	12.28	20.40
40	RR_35B	3/1200RCP	13.50	13.11	42.70
41	RR_37A	3/1200RCP	13.90	13.79	36.60
42	RR_37B	Irregular Shaped Structure	11.92	11.80	21.60
43	RR_44A	1/1500x600RCBC	14.56	14.49	18.00
44	RR_45A	1/1200x600RCBC	14.80	14.63	31.20
45	RR_46A	4/1050RCP	12.50	12.37	25.62
46	RR_47A	Irregular Shaped Structure	11.11	11.02	16.80
47	RR_47B	1/1200RCP	13.30	13.18	24.40
48	RR_47C	1/750RCP	14.00	13.84	31.72
49	RR_47D	4/1500RCP	14.38	14.30	19.52
50	RR_48A	4/1200RCP	14.10	14.00	20.74
51	RR_49A	5/3600x2400RCBC	10.42	10.31	22.80
52	RR_49C	7/1200x450RCBC	13.80	13.73	30.00
53	SandstoneDr_KernDrain	Irregular Shaped Structure (3/5950x3200RCBC)**	9.20	9.20	20.00
54	ShawRd_BohleTrib1	3/3600RCP	2.75	2.75	15.00
55	ShawRd_BohleTrib2	2/2550RCP	5.43	5.15	15.00
56	TompkinsRd	2/900RCP	5.67	5.20	15.00
57	VickersRd_VickersDrain	2/600RCP	14.00	13.95	19.40
58	PinnacleDr_AllambieTableDrain	3/900RCP	19.91	19.88	19.09
59	ChelseaDr_Driveway	2/1200x750RCBC	14.20	14.18	9.60
60	ChelseaDr_Road	2/1200x750RCBC	14.24	14.22	10.80
61	NineteenthAv_1	2/1200x300RCBC	14.14	14.11	9.93
62	NineteenthAv_2	2/1200x300RCBC	14.04	14.01	9.36
63	NineteenthAv_3	2/1200x300RCBC	14.00	13.89	8.76
64	NineteenthAv_4	3/1200x300RCBC	13.75	13.72	11.00

Reference Number	Culvert Reference	Configuration	Invert level (m AHD)		Length (m)
			Upstream	Downstream	
65	NineteenthAv_TableDrain	3/1200x225RCBC	13.94	13.89	22.56
66	BeckDr	1/3000x1200RCBC	15.38	15.24	20.00
67	EvergreenDr	1/4500x1500RCBC	9.81	9.76	8.00

Note:
RCBC = Reinforced Concrete Box Culvert;
RCP = Reinforced Concrete Pipe;
* These irregular shaped structures have, through analysis, been assumed to have an equivalent cross sectional area to the culvert dimensions shown above or modelled as an open cross-section using dimensions obtained from as-constructed drawings.

Table 3-3 Details of bridges modelled using MIKE11 in the Middle Bohle Model

Reference Number	Bridge Reference	Bridge Deck Level (Top) (m AHD)
68	BowhuntersDr_BohleRvr	14.20
69	Pedestrian_KernDrain	13.82
70	RR_BohleRvr	17.15
71	RR_LittleBohleRvr	17.28
N/A*	BruceHwy_BohleRvr_NBound	5.84
N/A*	BruceHwy_BohleRvr_SBound	9.17
N/A*	NorthCoastRailway_BohleRvr	8.05
77	HerveyRangeRd_BohleRvr	13.86

Note:
* These structures do not lie within the 2D model extents and therefore are not displayed on Figure 3-3 and subsequently have not been given a reference number.