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1 Introduction

Northrop Consulting Engineers have been engaged to undertake a hydrological and hydraulic investigation at the Kingshill Urban Release Area, North Raymond Terrace. The purpose of this correspondence is to summarise the extent of modelling, modelling methodology, results and design implications from a hydraulic perspective.

Kingshill Urban Release Area is located adjacent to Grahamstown Dam which is the Hunter Valley's largest drinking water supply. Hunter Water has previously advised that the eastern catchment that drains from the proposed development into Grahamstown Dam will need to be diverted should development occur. A number of possible routes have been investigated, including running along the eastern side parallel to the Pacific Highway, which has been considered as part of this analysis.

Included herein is;

- a description of the locality and subject catchment,
- a summary of design constraints and previous work with respect to the channel,
- an outline of hydrological modelling undertaken to determine the peak flows reaching the highway,
- the results of hydraulic modelling undertaken to determine the existing and developed flood behaviour, and;
- a discussion around the impact of the proposal as well as design and ongoing maintenance implications.

2 The Subject Site

2.1 Locality Description

The Kingshill Urban Release Area is located approximately ten minutes north of Raymond Terrace. It is bordered on the east by the Pacific Highway, on the north by Six Mile Road, west by Newline Road and south by Irrawang Swamp.

Grahamstown Dam is located to the east, with a portion of the site currently draining to the dam. To the south east of the site, a spillway from the dam releases water to the Irrawang Swamp. A secondary disused spillway is located to the north of the current spillway. Irrawang Swamp drains to the Williams River, just upstream of the confluence point with the Hunter River.

Kings Hill is located within the subject site with a summit elevation of approximately 140m AHD. To the north is Seaham Hill with a summit of approximately 180m AHD.

The major features in the vicinity are shown in Figure A1.

2.2 Subject Catchment

The contributing catchment from Kings Hill Urban Release Area is known as the eastern catchment and is approximately 1.8km² in size. It is largely undeveloped with the lower portions currently used for agricultural purposes.

Vegetation is mixed with the upper reaches characterised by densely wooded vegetation and the lower portion covered with pasture grasses. Soil types also vary with highly erosive soils in the upper reaches and dense clay in lower lying areas.

Topography is steep with grades in excess of 25 percent on the western portion of the catchment and levels up to 100m AHD. In the east grades are more accessible and are in the range of one to ten percent. Levels in the lower reaches are in the order of 13m AHD and act as storage volume for the Grahamstown Dam.

The Pacific Highway acts as a major hydraulic control prior to the runoff discharging into the Grahamstown Dam. A number of piped outlets convey water from west to east. On the eastern side of the highway, the land is low lying with an access road running along the length.

The subject catchment, including elevations and piped outlet locations is shown in Figure A2.

2.3 Development Proposal

Several hundred residential lots are proposed within the subject catchment. As mentioned earlier, Hunter Water requires water to be collected and conveyed around the dam. In order to satisfy this design requirement, a channel is proposed along the length of the site on the eastern side of the highway to the existing disused spillway to the south. From here the diverted water will enter the Irrawang Swamp.

Several new basins and swales are proposed for conveyance and water quality treatment within the development footprint. These have not been considered as part of this study due to the fact that they are designed primarily for the more frequent rainfall events, not the extreme cases considered herein.

Modifications have been considered to the outlet pipes, with cut-off swales and detention basins considered to attenuate the runoff sufficiently so as to cause no significant impact to adjacent properties or the highway.

As part of the *Kings Hill Urban Release Area Water Management Strategy Guidelines* produced by BMT WBM, hydrology and hydraulics for the upstream portion of the site were considered along with options for the diversion channel. An XP-RAPTS model was developed for the hydrology and an unsteady TUFLOW analysis was undertaken for the hydraulics.

This study has been used for reference and comparison throughout the course of these investigations.

4 Methodology

The study was undertaken through a process of initial negotiation and briefing, data collection, site investigation, client meetings, numerical modelling, validation and review.

An initial brief was undertaken with officers from Port Stephens Council and Hunter Water Corporation. Both these organisations will have ongoing maintenance requirements along the length of the channel and requirements were discussed regarding vegetation control, seepage monitoring and access arrangement. The existing 1% AEP critical event was modelled with tailwater from the Grahamstown Dam and Irrawang Swamp. For the developed case, the 1%AEP was modelled with the tailwater from Irrawang Swamp (the channel makes the Grahamstown Dam hydraulically isolated from the development) in order to assess the no significant impact criteria. The 0.2% AEP (1 in 500yr ARI) critical event was run as the capacity criteria for the channel.

Data collection was undertaken in order to better understand the catchment and issues surrounding the existing flood behaviour of the subject site and its surrounds. A range of data was available including topographic information from LIDAR and detailed survey, aerial photography and previous studies. A number of site investigations were carried out throughout the study area to ground truth the topographic data provided, and review the catchment characteristics.

From all the data sources and site visits described above, numerical modelling of both hydrological and hydraulic processes was undertaken. Firstly, the traditional hydrological modelling was undertaken in order to ascertain the critical duration storm event. XP-RAFTS was used for this purpose. RAFTS was also used to undertake preliminary hydraulic modelling investigating a range of geometric designs. Once design was settled on, this was passed to Hyder (the civil designers) with geometry, water depth and grades. A 12D TIN was created and this was input into XP-STORM to undertake the two-dimensional analysis using rainfall on grid hydrology.

Periodic meetings were held with various stakeholders to present the findings of preliminary modelling, as well as refine and guide the channel design.

5.1 Traditional Hydrology using a RAFTS model

Table 1 - Pervious catchment parameters

Table 2 - Impervious catchment parameters

Design rainfall has been estimated using the IFD parameters for Beresfield and the Australian Rainfall and Runoff temporal patterns. A number of durations ranging from 25 minutes to 72 hours were simulated for the 1% AEP and 0.2% AEP design storms. Catchments are shown attached in Figure B1.

Using the critical rainfall pattern adopted for the RAFTS model, runoff was generated directly on the hydraulic grid surface. The benefit of this method is that catchment extents and concentrated flow behaviour do not need to be defined prior to running the model. One of the benefits of this type of modelling was representing the lateral flow along the Pacific Highway and interaction in spill levels both along and over the highway.

The extent of the direct rainfall polygon is shown in Figure B2.

A hydraulic model was built using the XP-STORM computer software package. This package uses the TUFLOW hydrodynamic modelling engine. A description of some of the modelling parameters is included below.

Terrain data was obtained from a range of data including LIDAR and several difference detailed surveys. These were combined in XP-STORM to form a single existing TIN. In areas not representing the expected ground conditions well, elevation objects were used to alter the surface as required.

Due to the selection of direct rainfall on grid, the hydraulic grid extends to the catchment boundary. On the downstream side, the grid extends roughly to the border of the Grahamstown Dam, and Irrawang Swamp.

Cell size is determined as a function of accuracy and model run time. For the upstream reaches of the catchment where the hydraulic representation is not as critical a four metre grid was chosen. Around the highway and for the proposed channel, a finer one metre grid was nested in the larger grid to more accurately represent the hydraulic behaviour.

Head boundaries and rainfall polygons form the boundary conditions for the model. In the existing scenario these include the Grahamstown Dam, Irrawang Swamp and a catchment ridgeline boundary. In the post developed condition, this includes the Irrawang Swamp and catchment ridgeline only. Table 3 shows these levels below.

Location	Elevation
Grahamstown Dam 1% AEP	13.60m AHD
Irrawang Swamp 1% AEP	4.59m AHD
Catchment ridgeline	0m AHD (free discharge)

A figure showing the location of all these boundary conditions is included in Figure C1.

Manning's roughness represents the resistance to flow across the surface. Values of Manning's roughness vary over the two dimensional grid depending on surface type and land use. These have been adopted from a literature review and site inspection and are shown below in Table 4.

Table 4- Manning's n roughness parameters

Surface Type	Manning's n
Roads	0.015
High Grass with Scattered Brush	0.060
Water bodies	0.030
Sparse trees	0.080
Dense trees	0.100
Developed	Varies by depth 0.030-0.200
Channel	0.050

The spatial distributions in the pre-developed and post-developed scenario are included in Figures C2 and C3.

6.5 Loss Model

In order to maintain consistency with the traditional hydrological model, an initial and continuing loss model was incorporated in the land use polygons. For impervious areas an initial loss of 1mm was adopted with no continuing loss. For pervious areas, the initial loss was 15mm, with a continuing loss of 2.5mm/hr.

6.6 1D Elements

One dimensional elements have been used to represent the pipes and culverts identified at the outlet to the subject catchment. These include the outlet spillway and associated channel, pipes under the Pacific Highway and Hunter Water Corporation access road.

The size and invert level of these features have been adopted from detailed survey, and their location is shown in the Figure C4.

6.7 Model Run Duration and Time Step

The duration of the model runs were longer than that of the storm event in order to represent the falling limb of the hydrograph. The time step for the model was dependent on the grid size. For the four metre grid a two second time step was adopted, with half a second for the nested one metre grid.

6.8 Blockage

Blockage has been considered on all culverts, with 50 percent applied. Due to the likely impact on the flow reaching the channel, a sensitivity case of no blockage has also been investigated.

6.9 Post Developed Basins and Swales

In order to convey runoff to the outlet points and attenuate runoff sufficiently to utilise the existing infrastructure, swale and basins have been proposed along the highway. These are represented as elevation objects in XP-STORM which modify the existing TIN. The size of these swales and basins do not encroach on the development area and it is anticipated they will be able to be integrated into the landscape and urban design concept.

7 Results

7.1 Critical Storm Durations and Peak Flows

From the RAFTS model, it was determined that the two hour storm was critical for both the 1% AEP and 0.2% AEP events. The peak flows as determined from the various methods are shown below in Table 5.

Table 5 - Peak flows entering the hydraulic model

Outlet	XP-RAFTS	XP-STORM Culverts
	m ³ /s	m ³ /s
A	0.62	0.55
B	1.44	1.70
C	5.68	3.67
D	6.96	7.64
E	6.48	1.36
F	4.72	8.39

From the above, it is shown that the two methods produce results which are distributed differently. Representing flow behaviour longitudinally along the highway, as well as more accurately representing the existing detention effects and spill levels of the highway embankment is one of the benefits of using the direct rainfall on grid approach. Despite the differences with XP-RAFTS it is noted that the sum of the peaks is within ten percent which is considered a good correlation. Furthermore, the peak obtained from the rainfall on grid method is larger than the XP-RAFTS simulation which reflects a conservative approach.

7.2 Existing Design Flood Behaviour

The existing 1%AEP event was considered as a baseline for comparison with the post developed scenario. Figures showing the existing flood behaviour are included in Figures D1-D4.

7.2.1 1% AEP – Zero Blockage Scenario

In the critical 1%AEP event, flow is concentrated along the watercourses traversing the site prior to intersecting with the highway.

Water is generally contained to the west of the highway with a few notable exceptions. Ponding extends onto the northbound carriageway in the vicinity of Outlet C; whilst at Outlet E, flow completely inundates the northbound travel lanes. Due to the low lying nature of the site around Outlet F, the peak water level from the Grahamstown Dam extends back into the site.

7.2.2 1% AEP – 50 Percent Blocked Scenario

The behaviour for the blocked scenario is similar to that of the unblocked case, apart from the greater ponding extent and depth around the piped outlets. Inundation of the northbound lane extends from Outlet E to Outlet C for this blockage condition.

7.3 Post Development Flood Behaviour

Post developed flood behaviour is significantly different on the eastern side of the highway due to the channel diversion. On the western side, the concentration of flows is faster due to the reduction on catchment roughness. Flow is also diverted to the basins around the outlets via a system of swales. The northbound carriageway is flood affected around outlets C and E in both the 1% and 0.2% AEP events.

Channel water surface elevations are shown in Table 6 below.

Table 6 - Post developed water levels in the channel

Chainage	Outlet	1% AEP 0% Blockage	0.2%AEP 0% Blockage	Channel Invert	Bund Height
24	A	17.61	17.62	17.38	17.78
200		16.96	17.02	16.72	17.80
400	B	16.29	16.38	15.92	17.30
670	C	15.53	15.62	14.87	16.05
885	D	15.30	15.37	14.06	16.45
1200		14.47	14.57	13.33	15.90
1489	E	13.86	14.05	12.66	15.65
1889	F	13.26	13.51	11.71	14.70
2200		12.67	12.92	11.14	14.60
3000		11.47	11.99	9.65	13.50
3107	HWC U/S	11.45	11.97	9.45	13.40
3142	HWC D/S	11.24	11.69	9.38	13.00
3485		11.21	11.69	8.73	13.00

The results are illustrated in Figures E1-E6.

7.4 Comparison of Scenarios

Due to the proposed development, the water elevation in the natural watercourses is elevated. Around the outlet basins, a reduction in water level is calculated. Generally speaking, water elevation is reduced around the highway – in particular, no increases are calculated on the travel lanes. Increases are calculated around the new access track on the eastern side of the highway reflecting the increased surface elevation. Furthermore, an increase is calculated to the south of outlet F of in excess of 200mm. It is noted in this case that the freeboard to the highway is still in excess of one metre.

A comparison at outlet points is shown below in Table 7. The differences are illustrated in Figures F1 and F2 attached.

Table 7 - Comparison 1% AEP water elevations (m AHD)

	1% AEP 50% Blockage			1% AEP 0% Blockage		
Point	Pre	Post	Comparison	Pre	Post	Comparison
Outlet A U/S	21.44	21.29	0.15	21.28	21.17	0.11
Outlet A D/S	18.47	18.47	0.00	18.47	18.02	0.45
Outlet B U/S	20.18	19.90	0.28	18.95	18.87	0.08
Outlet B D/S	17.78	16.69	1.09	17.59	16.70	0.89
Outlet C U/S	19.27	19.13	0.14	19.19	19.13	0.06
Outlet C D/S	16.47	15.91	0.56	16.55	16.06	0.49
Outlet D U/S	18.17	18.02	0.15	17.85	17.75	0.10
Outlet D D/S	16.04	15.81	0.23	16.18	15.37	0.81
Outlet E U/S	16.72	16.20	0.52	16.37	16.06	0.31
Outlet E D/S	15.08	14.42	0.66	15.12	14.01	1.11
Outlet F U/S	14.81	14.56	0.25	14.27	14.02	0.25
Outlet F D/S	13.60	12.98	0.62	13.60	13.28	0.32

8 Discussion

8.1 Significant Impact

The NSW Floodplain Development Manual references “no significant impact” as a means of assessing developments within flood prone land. For the purposes of this study we have assumed that significant impact means increasing the flood level on the highway or decreasing the freeboard in adjacent areas where it is already less than 500mm.

Other potential impacts relate to Grahamstown Dam and existing residential properties along Newline Road. With respect to the dam, a small reduction in storage volume is a consequence of the development proposal. Given the large overall volume, this is expected to have a negligible impact on the flood behaviour and dam operation. In terms of existing residences in Newline Road, we have relied on the information contained in the *Kings Hill Urban Release Area Water Management Strategy Guidelines* prepared by BMT WBM.

8.2 Upstream Development

Upstream development has been taken into account by reducing the catchment roughness to represent the quicker response of impervious areas. A low flow value of $n=0.03$ was chosen to represent the mixture of pervious and impervious surface coverings. The increased flow is evident from the increased flood level along the natural watercourses throughout the site. Swales and small basins have been included on the western side of the highway in order to convey and attenuate runoff to suit the current capacity of the existing culverts. As discussed earlier, these basins and swales are expected to be incorporated within the urban design and landscape concept in this area. As part of the traditional pit and pipe network of the perimeter road, some of these swales and/or basins may be rendered redundant.

We note that a number of additional water quality devices will be required in order to satisfy the guidelines which may include rainwater tanks, bio-retention basins and raingardens, and constructed ponds and wetlands. These devices will help to attenuate the peak flow and volume leaving the developed area, however have been left out of this modelling. Given the less likely events modelled, this assumption is considered appropriate, albeit slightly conservative.

8.3 Highway Culvert Modification

As part of the hydraulic design process, consideration was given to upgrading the culverts under the Pacific Highway. The purpose of this option was to assess whether the detention basins on the western side of the highway could be removed in order to facilitate more lots. In order to assess the potential of this option, the culverts were doubled at each outlet and an additional outlet was modelled between outlets E and F where a significant amount of runoff is intercepted by the highway.

It was determined that a significant decrease in water levels could be achieved on the western side of the highway from this approach; however increases were still calculated along the site frontage. This option was discounted due to the potential expense and minimal benefit on lot yield.

8.4 Sensitivity Analysis

A sensitivity analysis was undertaken on culvert blockage and channel roughness.

Council originally specified a roughness of $n=0.05$ which is representative of an excavated channel, not maintained with a “clean bottom, brush on the sides” (Chow, 1959). Consideration was given to an increased roughness of $n=0.065$ and $n=0.08$. This maximum value represents “dense weeds, high as flow depth” (Chow, 1959). This situation is considered unlikely due to

A blockage of 50% was considered over the outlet culverts. A sensitivity analysis was also undertaken for no blockage. Both events satisfied the no significant increase in flood impact test for the 1%AEP event, as defined above, and the conveyance was satisfied for the 0.2%AEP event.

The disused spillway to the south of the site has been used for the outlet of the channel. A bund has been modelled running east west at an elevation of 12m AHD to prevent water interacting with the current spillway. It may be desirable to have a smaller bund in this area with water continuing along parallel to the highway and spilling through the existing spillway. It is not expected to have an impact on the capacity of this infrastructure due to the differing times of concentration of the two catchments; however this scenario has not been considered as part of this modelling.

From a hydraulic perspective, the proposed channel has no significant impact on the adjacent highway, Grahamstown Dam, or downstream properties in a 1% AEP event. Furthermore, the capacity of the channel is sufficient to convey a peak 0.2% AEP event. The following recommendations are offered regarding the execution of the development;

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- The Pacific Highway is flood affected in the existing 1%AEP and 0.2%AEP scenarios;
- A portion of the site is inundated by the Grahamstown Dam at maximum storage level;
- No significant impact was calculated for the critical 1%AEP event as a result of the proposed development and channel design;
- The channel has sufficient capacity to convey the critical 0.2%AEP event;

Prepared by:

Angus Brien

Civil Engineer

Reviewed by:

Ben Clark

Principal

Appendix A – Figures