# 5. HYDROLOGIC MODEL

## 5.1. Introduction

A hydrologic model is a tool for estimating the amount of runoff that flows from a catchment for a given amount of rainfall, and the timing of this runoff flow. Stream gauges (which measure water level in a stream) are a way of directly measuring this information, but they are expensive to setup and maintain. They also require a long record (several decades) to be of most use for flood estimation. The majority of small creeks in NSW are not gauged, and there are no long-term stream gauges in the Greendale Creek catchment. In such cases, using a computer-based hydrologic model is the best practice method for determining how much flow may occur from rainfall information (which is more widely available from rain gauges). This type of hydrologic model is referred to as a runoff-routing model.

A range of runoff-routing hydrologic models are available as described in ARR2019 (Reference 1). These models allow the rainfall to vary in both space and time over the catchment and will calculate the runoff generated by each sub-catchment. The generated flow hydrographs then serve as inputs at the boundaries of the hydraulic model, which provides details about flood levels and velocities.

A WBNM hydrologic runoff-routing model was used to determine flows for the entire Greendale Creek catchment to the outlet at the ocean. The WBNM model has a relatively simple but well supported method, where the routing behaviour of the catchment is primarily assumed to be correlated with the catchment area. If flow data is available at a stream gauge, then the WBNM model can be calibrated to this data through adjustment of various model parameters including the stream lag factor, storage lag factor, and/or rainfall losses. When flow data is not available (as is the case here), typical practice is to jointly verify the hydrologic and hydraulic models by comparing the model results to observed water level information.

The hydrological model for the entire Greendale Creek catchment (Figure 10), including the coastal overland flow areas draining directly to the ocean to the north and south, was created and used to calculate the flows for inclusion in the TUFLOW hydraulic model. The hydraulic model is discussed in Section 6.

## 5.2. Sub-catchment delineation

The total catchment area covered by the WBNM model of the entire Greendale Creek catchment is approximately 4.7 $km^2$ consisting of 755 sub-catchments (Figure 10) with an average sub-catchment size of 0.6 hectares. This relatively fine-resolution sub-catchment delineation ensures that where significant overland flow paths exist in the catchment, they are accounted for and incorporated into the TUFLOW hydraulic model.

## 5.3. Impervious Surface Area

Runoff from connected impervious surfaces (such as roads, gutters, roofs or concrete surfaces) occurs significantly faster than from pervious surfaces. This can result in a faster concentration of flow within the downstream area of the catchment as well as increased peak flow in some situations. This is accounted for in the model through an estimate of the proportion of both impervious and pervious surfaces.

The pervious and impervious area of each sub-catchment was estimated by assessing the proportion of the sub-catchment area covered by different surface types (from aerial photography) and then applying the impervious percentage of each surface type as indicated in Table 5.

Table 5: ARR2019 Effective Impervious Area Estimation

| Landuse Type | Pervious Area (%) | Indirectly Connected Impervious Area (%) | Effective Impervious Area (%) |
|---|---|---|---|
| Natural Vegetated Area | 100 | 0 | 0 |
| Grass/ Field | 80 | 0 | 20 |
| Medium Density Residential | 0 | 30 | 70 |
| Industrial/ Commercial/ High Density Residential | 0 | 10 | 90 |
| Lagoon | 10 | 0 | 90 |

## 5.4. Rainfall Losses and WBNM Lag Parameters

Methods for modelling the proportion of rainfall that is "lost" to infiltration are outlined in ARR2019 (Reference 1). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues. The initial/continuing loss method was adopted for this study.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed and vegetated areas are comprised of an initial loss and a continuing loss.

WBNM requires a catchment lag parameter and a stream lag factor to be selected which describes the average travel time for runoff from the catchment surface. The lag parameter is applied to pervious surfaces and adjusted to apply to impervious surfaces by multiplication by an impervious lag factor. The WBNM parameters selected are summarised in Table 6.

Table 6: Adopted WBNM Parameters for Calibration

| WBNM Parameter | Value |
|---|---|
| Initial Loss (Pervious surface) | 19.6 mm – 28 mm |
| Continuing Loss (Pervious surface) | 1.5 mm/hr – 2.5 mm/hr |
| Lag Parameter (C) | 1.29 |
| Stream Lag Factor | 1.0 |
| Impervious Lag Factor | 0.1 |

The parameter values applied are generally consistent with the recommended values in the WBNM manual and are the recommended values for ungauged urban catchments (Reference 8). Initial and continuing loss values for rural pervious areas were obtained from the ARR2019 Datahub and modified to account for the various urban land-use types.

# 6. HYDRAULIC MODEL

## 6.1. Introduction

Hydraulic modelling is the simulation of how flow moves across the terrain. A hydraulic model can estimate the flood levels, depths, velocities and extents across the floodplain. It can also provide information about how the flooding changes over time. The hydraulic model can simulate floodwater both within the creek banks, and when it breaks out and flows overland, including flows through structures (such as bridges and culverts), over roads and around buildings.

2D hydraulic modelling is currently the best practice standard for urban flood modelling (Reference 9). It requires high resolution information about the topography, which is available for this study from the LiDAR aerial survey. Various 2D software packages are available (SOBEK, TUFLOW, RMA-2). The TUFLOW package was adopted as it meets requirements for best practice, and is currently the most widely used model of this type in Australia for riverine flood modelling.

The TUFLOW modelling package includes a finite difference or finite volume numerical model for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes.

The TUFLOW model version used in this study was 2018-03-AE-iSP (using the finite volume HPC solver), and further details regarding TUFLOW software can be found in the User Manual (Reference 10).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Mannings ‘n’ roughness value assigned to each grid cell. The size of the grid is determined as a balance between the model result definition required and the computer processing time needed to run the simulations. The greater the definition (i.e. the smaller the grid size) the greater the processing time needed to run the simulation.

## 6.2. Model Extent and Grid Resolution

The study implemented a TUFLOW model with a cell size of 2 m by 2 m. This resolution provides an appropriate balance between providing sufficient detail for roads and overland flow paths and workable computational run-times.

The TUFLOW hydraulic model encompasses the entire Greendale Creek catchment, including Curl Curl Lagoon, and the overland flow areas to the north and south draining directly to the ocean.

Typically, developed areas require a grid resolution of no more than 2 m to capture the various overland flow mechanisms characteristic of a built-up environment. In 2017, a new TUFLOW version was released with High-Performance Computing (HPC) Graphical Processor Unit (GPU) model support. The new HPC GPU models are significantly faster than the traditional Central Processing Unit (CPU). As such, the HPC Engine with GPU was used for this study, although the HPC models can be run over a longer timeframe using CPU. This enabled a grid size of 2 m to be adopted for the entire model area while producing practical run times.

## 6.3. Model Topography

The model terrain grid was established from the data discussed in Section 3.2 to Section 3.5. The LiDAR data was generally found to provide an appropriately detailed representation of the catchment topography in most areas however the LiDAR survey is unable to penetrate the water surface. Bathymetric survey of Greendale Creek and Curl Curl Lagoon was used to define the waterways downstream of the Harbord Road gross pollutant trap (GPT). The entrance to Curl Curl Lagoon was defined as a Z shape with variable geometry as discussed in Section 6.6.12 and Section 8.8. Bridges, weirs and the Harbord Road GPT were modelled as 2D elements while culverts were modelled as 1D structures linked to the 2D domain as discussed in Section 6.6.

## 6.4. Boundary Conditions

### 6.4.1. Inflow Boundaries

Local runoff hydrographs were extracted from the WBNM model (see Section 5) and applied to the receiving area of the sub-catchments within the 2D domain of the hydraulic model. These inflow locations correspond with gutters, stormwater inlet pits, drainage reserves or open watercourses features which have typically been constructed to receive intra-lot drainage and sheet runoff flows from upstream catchment areas.

### 6.4.2. Downstream Boundaries

For the November 2018 calibration event a static tailwater level of 0.78 mAHD was adopted as the downstream ocean boundary. Since the berm was known to be substantially elevated above ocean levels (initial water levels greater than 2 m AHD for this event), the adoption of a low static tailwater was considered appropriate as the tidal conditions would not have affected peak flood levels in Curl Curl Lagoon or Greendale Creek.

The sensitivity of peak flood levels to tailwater conditions is discussed in Section 10.

## 6.5. Surface Roughness

Roughness, represented by the Mannings ‘n’ coefficient, is a key parameter in hydraulic modelling. As part of the calibration process roughness values are adjusted within ranges defined in the literature so that the model better matches observed peak flood levels at a variety of locations. Chow (Reference 11) provides some information with regards to the setting of the of the roughness values for hydraulic calculations. Mannings ‘n’ values are also discussed in

Project 15 of ARR2019 – *Two Dimensional Modelling in Urban and Rural Floodplains* (Reference 12).

The Mannings 'n' values adopted for the study area are shown in Table 7. These values have been adopted based on site inspection, past experience in similar floodplain environments, consideration of the above references, and the model calibration process. The spatial variation in Mannings 'n' within the model boundary is shown in Figure 11.

Table 7: Mannings 'n' values adopted in TUFLOW

| Surface | Mannings 'n' |
|---|---|
| Grass | 0.04 |
| Light Vegetation | 0.06 |
| Medium Vegetation | 0.07 |
| Thicker Vegetation | 0.09 |
| Creek | 0.05 |
| Paved Area | 0.02 |
| Lagoon | 0.03 |
| Urban Properties | 0.065 |
| Industrial | 0.20 |

## 6.6. Hydraulic Structures

### 6.6.1. Buildings

Buildings and other significant features likely to obstruct flow were incorporated into the model based on building footprints defined from aerial photography. These types of features were modelled as impermeable obstructions to flow and thus were assumed to have no flood storage capacity. Building delineation was validated in key overland flow areas by site inspection and using aerial and street level photographs.

### 6.6.2. Fencing and Obstructions

Smaller localised obstructions (such as fences) can be represented in TUFLOW in several ways including as impermeable obstructions, a percentage blockage or as an energy loss. The obstructions may also be approximated generally by increasing Mannings roughness for certain land use areas (such as residential) to represent the typical type of fencing used in such areas.

Individual fences in the catchment were not explicitly modelled, as they are difficult to identify and relatively impermanent (since people can change their fences without Council approval). Fences in urbanised areas were therefore accounted for by applying a slightly higher Mannings roughness for the residential land-use type to simulate the obstruction to flow.

The exception to the above was a concrete wall in the Kilns development, which was clearly part of an overland flow management design (see Photo 12).

### 6.6.3. Bridges and Culverts

Key hydraulic structures were included in the hydraulic model, at the locations indicated in Figure 12. Griffin Road Bridge, pedestrian crossing and Harbord Road GPT were modelled in the 2D domain to maintain continuity in the model and because the 2 m resolution was generally sufficient to resolve the waterway area accurately. Griffin Road Bridge (Photo 5) is a large relatively clear spanning structure with a large waterway area. Reference 2 stated that the structure does not cause significant afflux during large flood events.

Photo 5: Griffin Road bridge (looking upstream)

Culverts and stormwater pipes that have geometry smaller than the 2D grid were modelled as 1D computational elements.

The modelling parameter values for the hydraulic structures were based on the geometrical properties of the structures obtained from survey data and site inspections, using the guidance provided in the TUFLOW manual (Reference 10).

### 6.6.4. Surface and Sub-Surface Drainage Network

The stormwater drainage network was modelled in TUFLOW as a 1D network dynamically linked to the 2D overland flow domain. This stormwater network includes conduits such as pipes / box culverts, and stormwater pits including inlet pits and junction manholes. The schematisation of the stormwater network was undertaken using the pit and pipe GIS layers supplied by Northern Beaches Council. Figure 3 shows the location of pits and pipes included as 1D elements in the hydraulic model.

Only pipes with a minimum dimension of 300 mm or greater were included in the model. Smaller pipes than this are unlikely to have a significant influence on flood behaviour during major overland flow events.

### 6.6.5. Inlet Pits

For the modelling of inlet pits the “R” pit channel type was utilised, which requires a width and height dimension for the inlet in the vertical plane. The width dimension represents the effective inlet length exposed to the flow, and the vertical dimension reflects the depth of flow where the inlet becomes submerged, and the flow regime transitions from the weir equation to the orifice equation. For lintel inlets, the width was based on the length of the opening which was generally available in surveyed pits database provided by Northern Beaches Council. In cases where the lintel length of inlet pits was erroneous or unavailable, a length of opening of 1.2 m was assumed. Details of the 1D solution scheme for the pit and pipe network are provided in the TUFLOW user manual (Reference 10).

### 6.6.6. Road Kerbs and Gutters

LiDAR typically does not have sufficient resolution to adequately define the kerb and gutter system within roadways. The density of the aerial survey points is in the order of one per square metre, and the kerb/gutter feature is of a smaller scale than this, so the LiDAR does not pick up a continuous line of low points defining the drainage line along the edge of the kerb. Reference 12 provides the following guidance:

> *“Stamping a preferred flow path into a model grid/mesh (at the location of the physical kerb/gutter system) may produce more realistic model results, particularly with respect to smaller flood events that are of similar magnitude to the design capacity of the kerb and gutter. Stamping of the kerb/gutter alignment begins by digitising the kerb and gutter interval in a GIS environment. This interval is then used to select the model grid/mesh elements that it overlays in such a way that a connected flow path is selected (i.e. element linkage is orthogonal). These selected elements may then be lowered relative to the remaining grid/mesh.”*

The road gutter network plays a key role for overland flow in the urbanised parts of the study area. In order to model the system effectively, the gutters were stamped into the mesh using the method described above. The method used was to digitise breaklines along the gutter lines, and reduce the ground levels along those model cells by 0.1 m, creating a continuous flow path in the model.

### 6.6.7. Harbord Road GPT

A GPT is located at the outlet of the two large culverts under Harbord Road. The geometry of this was incorporated into the model based on the cross-section data in the plans provided by Northern Beaches Council. The trash rack was modelled as an obstruction to flow with a high percentage blockage (100%) and a large form loss to account for the substantial amounts of debris which are likely to become lodged in this structure. Photographs of the GPT were obtained during the site visit and these are shown in Photo 6 and Photo 7.

Photo 6: GPT (looking upstream at Harbord Road culverts)

Photo 7: GPT trash rack (looking downstream)

### 6.6.8. Footbridge and Rock Weir

Two pedestrian bridges cross Greendale Creek between Harbord Road and Griffin Road. The bridges are clear spanning with a large waterway area. A rock weir was constructed downstream of the eastern pedestrian footbridge circa 2000 as part of the Greendale Creek Rehabilitation Project for water quality control purposes.

Dimensions of the eastern footbridge over Greendale Creek were obtained during the site visit. Photographs of the rock weir and western footbridge were obtained during the site visit and these are shown in Photo 8 and Photo 9, respectively.

Photo 8: Rock Weir (looking downstream from western pedestrian footbridge)

Photo 9: Western pedestrian footbridge (looking upstream)

### 6.6.9. The Kilns

The steep channels downstream of Governor Philip Lookout descend to 'The Kilns' development. A semi-natural channel to the west of the site directs flows from north to south, before meandering eastwards. Flows from the channel then enter into a culvert passing under several low lying properties on Consul Road. A concrete lined channel to the east of the site directs flow to a large grated inlet pit, with the piped stormwater system joining the semi-natural channel to the south-west of the site. The concrete wall for the eastern channel was included in the model as a raised 2D element which presents an impermeable barrier to flow.

Photographs of the hydraulic structures of interest around The Kilns were obtained during the site visit and these are shown in Photo 10, Photo 11, Photo 12 and Photo 13.

Photo 10: Typical semi-natural channel section at the Kilns (looking downstream)

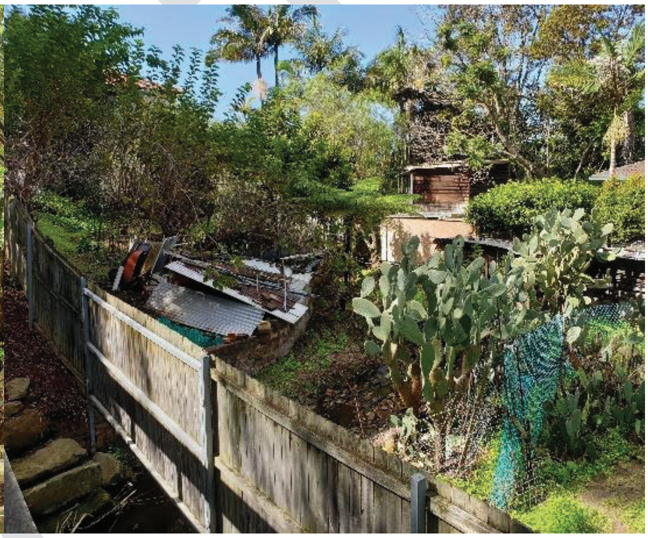

Photo 11: The Kilns channel through property (looking downstream)

Photo 12: Western stormwater channel at The Kilns (looking downstream)

Photo 13: Inlet grate (The Kilns, western channel)

### 6.6.10. Brookvale Oval

The pit/pipe database provided by Northern Beaches Council contains stormwater drainage infrastructure information within Brookvale Oval. Three 375 mm pipes which connect to the Council's stormwater network service Brookvale Oval and these were included in the hydraulic model.

Photographs of Brookvale Oval were obtained during the site visit and these are shown in Photo 14 and Photo 15.

Photo 14: Brookvale Oval (eastern bund looking north)

Photo 15: Brookvale Oval (eastern bund looking south)

### 6.6.11. St Augustine's School


Photo 16: St Augustine's College flow path

The recent re-development of St Augustine's School at Brookvale involved modifications to the building footprints and ground levels around the school. The building footprints were incorporated in the model based on the most recent available aerial photography. Updated ground levels were incorporated based on plans provided by Northern Beaches Council. During the site visit it was noted that a planter wall had been constructed in the drainage easement passing between the new primary school and new senior science buildings which is likely to present a significant obstruction to overland flows through the site. This was modelled as a flow constriction with a large blockage factor (70%) applied.

The flow path through St Augustine's School was inspected during the site visit and photographs are shown in Photo 16.

### 6.6.12. Curl Curl Lagoon Entrance

Lagoon breakout is a complex process which involves constant changes to the geometry of the breakout channel during the lagoon opening. Closure of the channel rapidly occurs as a result of sand movement into the breakout channel via coastal processes including tide and wind action. A detailed description of these lagoon breakout and closure mechanisms is presented in Appendix A from Reference 2.

The entrance to Curl Curl Lagoon was inspected during the site visit and a photograph is shown in Photo 17.

Photo 17: Curl Curl Lagoon entrance

The changing geometry of the sand berm during the calibration event (November 2018) on Curl Curl beach was modelled using a variable Z shape with parameters as detailed in Section 8.8.

# 7. MODEL CALIBRATION

## 7.1. Approach

Typically, in urban catchments with short gauge records calibration information is lacking. The following limitations prevent a comprehensive calibration of the hydrologic and hydraulic models for this study:

- There is only a limited amount of historical flood information available for the study area. For example, there is only a single water level gauge in Curl Curl Lagoon and a single flow gauge at Harbord Road, Brookvale. Both of these gauges have a short record and the Harbord Road gauge failed to capture data for the November 2018 calibration event.
- Rainfall records and particularly pluviometer records for past floods within the catchment are limited. Rain gauges are sparsely distributed and may not accurately capture the spatial and temporal distribution of rainfall during the storm event; and
- Changes to the catchment over time due to urban development may result in significant changes to land uses and drainage structures.

These limitations are typical of the majority of urban catchments and the calibration exercise undertaken here constitutes recommended practice as outlined in Reference 12.

## 7.2. Hydraulic Model Calibration

The November 2018 event was a significant flood event in the Greendale Creek catchment which produced overland flooding and caused breakout of the entrance to Curl Curl Lagoon. A recorded water level hydrograph was available from Curl Curl gauge at Griffin Road Bridge (213426). However no additional data were available for this event upstream of the lagoon influence and no quantitative peak flood level marks were able to be obtained from the community consultation responses for this event. Flooding observations collected from the community consultation process were therefore used to validate modelled flow behaviour to ensure that overland flow paths and areas of ponded water were captured in the modelled flood event.

At the time the model calibration was undertaken, the stream gauge data for this event was not yet quality controlled by the gauge operator (MHL), indicating that it represents raw data from the instrument with only preliminary quality checks performed. WMAwater assessed that the data was of sufficient reliability for the purposes of the calibration exercise.

Mannings ‘n’ roughness values in the TUFLOW hydraulic model were set based on past experience and recommended values from the literature. The sensitivity of peak flood levels to Mannings ‘n’ roughness values is discussed in Section 10.4.

As noted in Reference 2 information on the entrance conditions of Curl Curl Lagoon is limited. The berm height varies substantially over time and hence lagoon flood levels for a given event will be highly dependent on entrance conditions. The modelled entrance characteristics were based on the adopted geometry in Reference 2 and the recorded lagoon water level data and the adopted model parameters are shown in Table 8. The adopted design berm height in Reference 2 was 2.2 mAHD and hence the initial berm elevation at the lagoon entrance is considered reasonable.

Table 8: Adopted Parameters of Curl Curl Lagoon Entrance

| Parameter | Value |
|---|---|
| Width | 70 m |
| Final Elevation | 0.35 m AHD |
| Trigger Value | 2.5 m AHD |
| Initial Berm Elevation | ~2.3 m AHD<br>(based on LiDAR/ Lagoon survey data) |
| Period | 0.1 hr |

Lagoon water level data for the November 2018 event indicates that at the onset of the storm burst the initial lagoon water level was approximately 2.0 mAHD. Several preliminary model runs were completed to determine the appropriate geometry, trigger value and period to achieve a reasonable match to both the shape of the modelled rising limb and peak flood levels.

Joint calibration of the hydrologic and hydraulic models was undertaken by comparing the modelled flood levels with the stage hydrograph recorded on the downstream side of Griffin Road Bridge. A comparison of the modelled and recorded peak flood levels at Curl Curl gauge is shown in Table 9.

Table 9: Comparison of Modelled and Recorded Flood Levels

| ID | Location | Recorded Level (mAHD) | Modelled Level (mAHD) | Difference (Modelled minus Recorded) (m) |
|---|---|---|---|---|
| 213426 | Curl Curl Lagoon at Griffin Road bridge | 2.54 | 2.51 | -0.03 |

The model was found to produce a reasonable match to the observed historical peak flood levels within approximately ±0.05 m of the recorded level. This error is considered reasonable due to the uncertainty in observed rainfall and model parameters, and measurement error of the gauge. The model is unable to perfectly match the recession limb due to the complex and event-specific opening characteristics of the lagoon entrance. This portion of the event is not important for the peak flood behaviour which is the focus of this study.

Mapping of peak flood levels and depths for the November 2018 calibration event are shown in Figure C1. Figure C2 shows a reasonable match for both the shape of the rising limb and the recorded peak flood height.

Sensitivity testing was undertaken to determine the effect of the assumptions made to the modelled entrance conditions.

The selection of appropriate entrance conditions for design flood estimation should be based on the joint probability of catchment rainfall, lagoon entrance conditions (particularly berm height) and initial lagoon water levels. The parameters adopted for design modelling are discussed in Section 8.

## 7.3. Validation

Descriptions of flood affectation provided by community consultation respondents and Council's customer complaints database were of some utility in validating key overland flow paths and the ponding of floodwaters at sag points. Residents did not specifically identify flooding as occurring during the November 2018 event however most respondents were able to identify where the flooding had occurred on the property around that time, or during previous events. Several respondents indicated that frequent flooding occurs in a specific location. The locations identified by this process were taken to represent areas where historic flooding may have occurred.

The results shown in Figure C3 to Figure C6 presents a comparison of the data collected from Northern Beaches Council's customer complaints database, flooding investigations and community consultation responses against modelled flood behaviour for the November 2018 event, recognising that not all the observed flooding corresponded to this event. A comparison of each description of flooding against the modelled flood behaviour for the November 2018 event is shown in Table 10.

Table 10: Validation of Modelling from Community Responses and Customer Complaints

| ID | Description of Flooding | Calibration Match |
|---|---|---|
| W_002 | Back yard flood affected | Reasonable |
| W_008 | Garage or shed flood affected | Good |
| W_020 | Front yard and back yard flood affected, above 100 yr flood zone | Good |
| W_024 | Back yard and pool area flood affected | Good |
| W_028 | Flood affected | Reasonable |
| W_044 | Main building - below floor level flood affected | Poor[(1)] |
| W_054 | Main building above floor level flood affected | Poor[(2)] |
| O_109 | Front yard flood affected | Reasonable |
| W_009 | Back yard flood affected | Good |
| W_011 | Back yard flood affected | Good |
| W_016 | Flood affected | Reasonable |
| W_033 | Back yard and garage flood affected | Poor[(3)] |
| W_043 | Back yard flood affected | Poor[(4)] |
| W_053 | Main building below floor level and garage flood affected | Reasonable |
| O_088 | Garage or shed flood affected | Reasonable |
| O_113 | Main building below floor level flood affected | Good |
| O_105 | Back yard flood affected | Good |
| W_015 | Front yard flood affected flooding was experienced in August 1970 | No address provided |
| W_046 | Main building - below floor level flood affected, 3 times in last 40 years | Good |
| W_052 | Front and back yard and garage flood affected in one off event 30 years ago | Good |

| ID | Description of Flooding | Calibration Match |
|---|---|---|
| W_068 | Back yard flood affected | Good |
| W_072 | Garage or shed flood affected. No address provided. | n/a |
| W_074 | Garage or shed flood affected before kerb and guttering | Reasonable |
| W_007 | Main building - below floor level flood affected | Poor(5) |
| W_017 | Back yard flood affected | Good |
| W_018 | Back yard, garage and main building - below floor level flood affected | Poor(6) |
| W_021 | Front yard and garage flood affected | Good |
| W_026 | Back yard flood affected | Good |
| W_027 | Front and back yard and garage flood affected | Good |
| W_048 | Front yard flood affected | Good |
| O_082 | Business access road flood affected | Good |
| O_095 | Front yard frequently flood affected | Good |
| O_104 | Back yard flood affected | Good |
| DF2011/0034 | Landslip to the south of building, blocking creek and water flowing onto property | N/A |
| DF2011/0325 | Land slide at the back of property. About a metre high and blocking the creek | N/A |
| DF2011/0336 | Tradelink premises flooded | Reasonable |
| DF2012/0266 | Flooding is coming into the back of 16 Chard Rd Brookvale from 77-79 Winbourne Rd Brookvale. Water is pooling up from 77 Winbourne Rd and flooding into the factory building of 16 Chard Rd | Poor(7) |
| DF2013/0647 | Blocked stormwater drain outside property. Capacity problem, could not take the flow of water | N/A |
| DF2014/0152 | Stormwater floods down Beacon Hill Road into Elizabeth Place, and into Early Learning Centre buildings and playground | Reasonable |
| DF2015/0024 | Claims neighbour's stormwater is directed into property | N/A |
| DF2016/0575 | Fast flowing flood water eroded the creek bank, collapse of bank towards Council footpath. Small cracks appeared on road and side of footpath | Reasonable |
| DF2018/1482 | Pit lid blown off by water frequently. Pushed up and half open, a hazard for pedestrians and reversing cars | N/A |
| DF2018/0524 | Water overflowing out of storm water asset | N/A |
| DF2018/0608 | Major flooding problems, 10cm flooded at garage whilst using sandbags | Poor(8) |
| DF2019/0358 | Path out the front of property floods, cracked and subsided slightly towards the street causing water to pool | N/A |
| DF2018/0452 | Water flow when there is heavy rain | Reasonable |
| DF2011/0110 | Water from Weldon Oval along fence line | Reasonable |
| DF2012/0098 | Large flooding in the street area of Manuela Place | Reasonable |
| DF2012/0503 | Overland flows occur through site | Reasonable |
| DF2015/0423 | Large deep pool of water forms and does not drain away | Reasonable |
| DF2017/0247 | Water eroded soil now exposing concrete | N/A |
| DF2017/0259 | Water runs through like a river under property, might be due to a broken council stormwater pipe | Reasonable |
| DF2014/0513 | Street flooded, cars having to turn back | Reasonable(9) |
| DF2015/0242 | N/A | N/A |
| DF2015/0352 | Flash flooding across garden, footpath and the entire road | Reasonable(9) |
| DF2016/0031 | Water coming into property from the main road | Reasonable |
| DF2016/0402 | Front of property flooded, creating a sinkhole | Reasonable |

| ID | Description of Flooding | Calibration Match |
|---|---|---|
| DF2017/0071 | Road flooded, a car had to be towed out | Reasonable(9) |
| DF2017/0101 | Street flooded, issues at school pick up time as children need to walk on road | Reasonable(9) |
| DF2017/0105 | Water flooding from stormwater | Reasonable |

(1) Modelling shows property as unaffected and likely is a local drainage issue. Main building of business/ garage is located below street level so drainage from within the property may be limited.
(2) Modelling shows property as unaffected. Shopfront is located approximately 0.6 m above street level and flooding above the main floor level considered unlikely. However the lower ground level is below the street gutter level and it is plausible that runoff may have entered the below ground garage and the comment refers to the garage.
(3) Modelling shows property as unaffected in November 2018. It may be a local drainage issue in the backyard.
(4) Modelling does indicate flow close to the backyard although not quite within this property.
(5) Modelling shows property as unaffected. Topography rises steeply to the rear of the property and there may be local drainage issues with runoff from adjacent lots.
(6) Modelling shows property as unaffected. Property is located in a valley below street level. No Council owned pit/pipe stormwater drainage infrastructure is installed at this location. Due to the small catchment area this is likely to be a local drainage issue rather than overland flooding.
(7) Modelling shows property as unaffected and likely a local drainage issue related to runoff from the neighbouring industrial property.
(8) Modelling shows property as unaffected and likely a local drainage issue. Crest of driveway may be insufficient to prevent inflow from gutter at the front of property.
(9) Each of these comments relates to flooding over road at the sag point in front of Northern Beaches Secondary College, which is reflected in the modelling.

There is generally good agreement between the locations of flooding complaints and modelled flood behaviour for the November 2018 event, with the exception of some properties where local drainage issues occur, due to small catchment areas or inter-lot drainage from neighbouring properties, rather than overland flooding. Most of the flooding complaints, local flood investigations and community reports of flooding in the catchment relate to properties in overland flowpaths or ponded areas at sag points which are adequately captured in the model.

## 7.4. Summary

Due to the lack of streamflow data and limited availability of peak flood level data, only a limited calibration of the hydrologic and hydraulic models to recorded water levels was possible. Generally the model reproduces flood behaviour as described in Council's customer complaints database and community consultation responses (as discussed in Section 7.3). Recorded peak lagoon levels at Curl Curl Lagoon water level gauge are reasonably matched.

Overland flooding within the catchment is generally the result of short, localised rainfall bursts which may not have been accurately captured by surrounding pluviometers. No peak flood level data was available for calibration outside of the influence of Curl Curl lagoon flooding. The modelled flood behaviour was validated against Council's customer complaints database and community consultation responses. Most customer complaints and community consultation responses relate to overland flowpaths and areas of ponded water at sag points which are generally well reproduced in the model. Given these observations it is considered that the model has been reasonably calibrated to historical flooding in the catchment.

As with all flood studies, the accuracy of the modelling in reproducing recorded flood behaviour could be improved by the inclusion of additional high quality historical flood and rainfall data from future events. In particular historical peak flood level data for the upstream portion of Greendale Creek would allow for a more robust calibration of the model.

It is recommended that following future flood events a program of data collection should be implemented which includes the collection of accurately surveyed peak flood levels as soon as practical following large flood events.