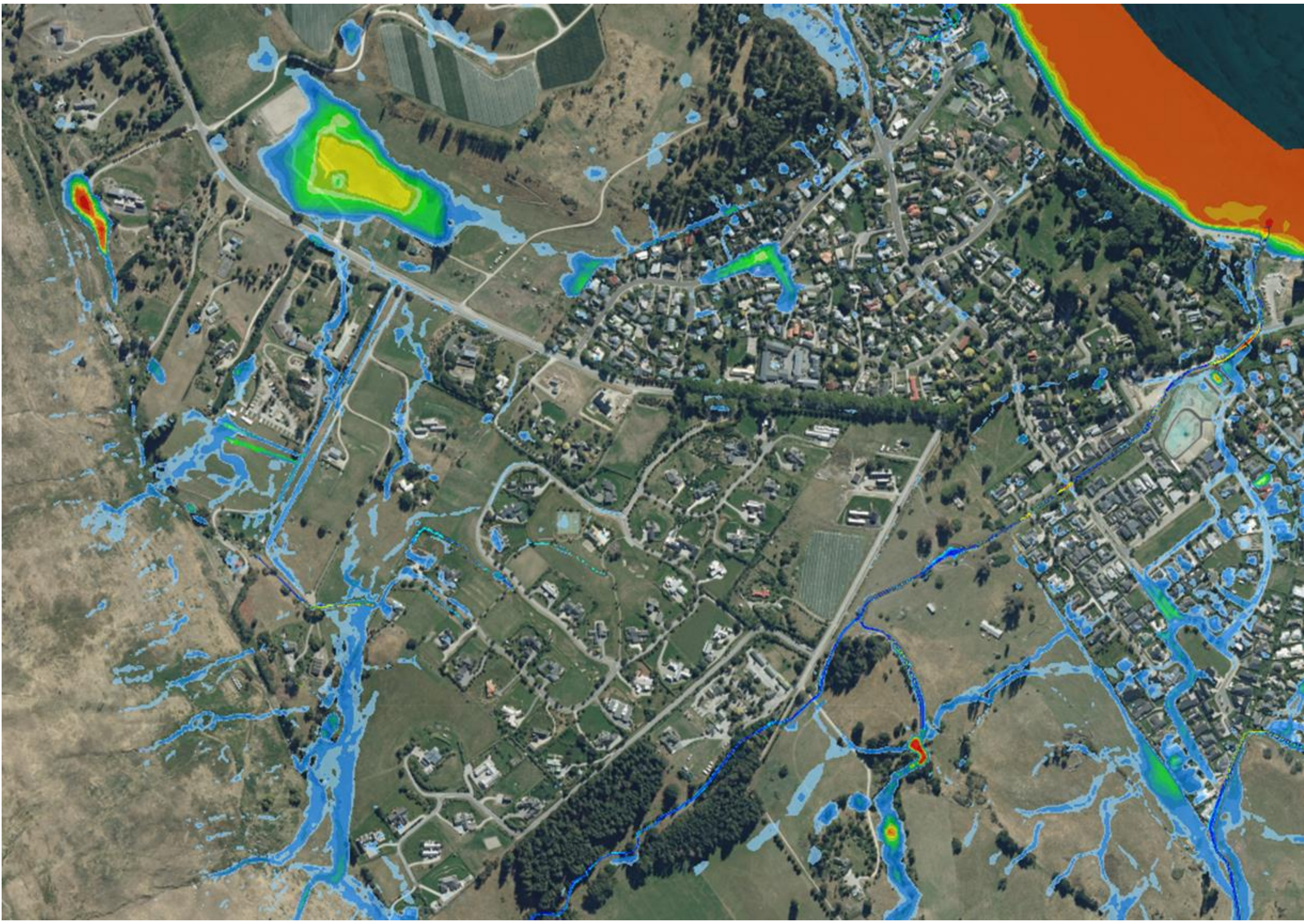
North Wanaka Model Update and Flood Extent Mapping

Report

25th November 2021

Prepared for Queenstown-Lakes District Council



The expert in **WATER ENVIRONMENTS**

North Wanaka Model Update and Flood Extent Mapping

This report summarizes update of the North Wanaka Flood model used to assess rainfall induced flooding in the catchment for the 100 year future climate and Maximum Probable Development scenario.

Report

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1 Introduction

The following memo outlines the steps taken to implement agreed peer review recommended updates in the North Wanaka flood model built by WSP in 2020.

The objective of the updates and refinements is to increase the confidence in the model predictions and to carry out mapping of 100 year flood extent and assessment of flood hazard. The extent of the update was restricted by time and budgetary constraints. The constraints and lack of measured flood data resulted in the limitations listed below.

2 Modelling and Flood Mapping Limitations

The scope of the model update was to reduce main uncertainties in the model, based on the existing available data, so that the initial flood extents and hazards can be mapped with sufficient confidence.

A mixture of model improvements has been completed. Most significantly, they related to the runoff calculation from rural and hill catchments and inclusion of additional existing assets and land features into the model. The inclusion of soakage components was deemed significant in parts of the catchment with no primary drainage network. The adjustments to the 2D model were carried where necessary to account for the changes in the catchment after the LiDAR was captured.

The limitations of the current model and flood maps include:

1. The model is quantitively calibrated by WSP to a 2018 rainfall event, based on a single gauged flow in Bullock Creek. Further qualitative validation was carried out based on flooding observations for the Bill's Way and Aubrey Rd parts of the catchment. The accuracy of the model predictions for 100yr climate change design rainfall is not quantifiable as there is no observed flooding data for extreme events.
2. The model update was not comprehensive and the level of detail in the model is not spatially consistent. The focus areas for the model refinement were Anderson Rd, Kelly's Flat and Bills Way, which showed significant flooding issues in the previous modelling completed by WSP.
3. The hydrology calculation, especially for the Rain on Grid method, assumes loss parameters based on literature and other modelling in the region with soils with similar drainage characteristics. Sensitivity testing confirmed that the flooding in the areas relying on soakage and storage is strongly impacted by the runoff from the natural and hill catchments. There is a high level of uncertainty whether the assumed parameters validated for 2018 rainfall event are valid for the 100yr Climate Change flood inducing rainfall.
4. The overland flow is governed by the 2D model based on the LiDAR 2018 interpolation. The LiDAR on which the mesh has been developed may not have accurately picked up some important features that may obstruct the overland flowpaths. The discrepancy between LiDAR and actual topography was evident in predicting overland flow in the Foxglove and Equestrian Pond areas. Spot survey is recommended to confirm elevations of high and low points.

5. Most of the assets added in this update do not have complete information, especially open drains and soakpits. Missing data was estimated based on engineering judgement and markups from the QLDC team following several site visits.
6. Model updates relating to new developments were guided by the consent conditions; these should be reviewed in detail and confirmed that their representation is correct and appropriate.
7. Buildings and significant fences or other barriers to the overland flow are not present in the model. These can have a potential impact on localised flooding.

3 Background

The model used as a base for this work was developed by WSP and provided to DHI on 27th May 2021. The model was validated to 2018 storm event flows at one location in Bullock Creek, where a gauge captured the peak flow of the event. Additionally, historical flood incident reports were used to confirm the flood-prone areas, mainly along the lake.

Bullock Creek catchment is relatively small and primarily established urban area. As such, it does not represent most of the North Wanaka, which is covered in larger lifestyle properties or new developments where various stormwater management strategies are implemented.

As the WSP report states, the areas further from the lake shore, such as upper Aubrey Rd, Kirimoko, Heights, Foxglove and Elderberry, have been under intensive development. As the model was built based on the 2019 LiDAR, ground levels of new developments may not be accurately represented in the model.

Following the completion of the draft flood maps in July 2021, the level of uncertainty in flood modelling was assessed as relatively high, and the model did not validate well to the anecdotal, qualitative evidence from the staff and local residents for the 2018 storm event. In particular, the model did not match observations in two areas: Bills Way in the western part of the catchment and Aubrey Rd, Anderson Rd, Kelly's flat and Rata Street in the east part of the catchment.

Information gathered from several local residents have revealed the following:

Bills Way:

- There was no significant flooding at Bills Way during the 2018 storm event
- There was no significant flooding over the lifestyle properties area during the 2018 storm.
- After any significant rain event, springs appear at the base of the southern hills

Aubrey Rd and Kelly's flat:

- There was no significant flooding at the Mt Roy Terrace during the 2018 storm event
- The development at the corner of Aubrey and Anderson roads does not flood
- There was some flooding observed on the Anderson Rd reserve, even in smaller events

The recommendation was made in the peer review to further validate the model to the 2018 storm event (in addition to the Bullock Creek flow validation) and to undertake sensitivity testing on the hydrological parameters so that any uncertainty can be assessed and potentially quantified.

Based on the above information gathered from locals and several site visits by QLDC staff, model refinements and updates were carried out to validate the model qualitatively.

4 Scope Of Model Updates

Findings and recommendations from the model peer review, analysis of the model setup and initial flood results for the 2018 event identified the following areas as main sources of uncertainty:

- The volume of runoff from natural undeveloped sub-catchments (southern and northern hills)
- Overland flowpaths at the base of the southern hills
- Changes caused by land development not captured by 2018 LiDAR
- Stormwater management measures implemented by the individual property owners in low density or rural areas (e.g. soakage pits)
- Soakage rates and stormwater management measures for recent larger developments such as Heights Avenue and Kirimoko.
- The ability of the existing pipes and inlets to capture and convey the runoff into the DN900 Mt Aspiring pipe
- Storage capacity of the pond on Equestrian land, Mt Aspiring Rd

Existence of man-made barriers with the potential to prevent flooding at Bills Way

The modelling included changing hydrological and hydraulic parameters until satisfactory validation was achieved. The main purpose of the updated model is the production of flood maps fit for publishing.

A comprehensive model improvement and refinement recommended by the peer review was not part of the scope at this stage, and further model improvements may be scoped and carried out at a later stage.

5 Hydrology Update

One of the most significant sources of uncertainty in the current model is the runoff computation and routing, especially in rural and semi-rural areas. The original modelling approach was to delineate the catchments and calculate runoff on a sub-catchment scale. The computed runoff is then loaded into a nearby pipe, a single point along the stream or a single point on the 2D surface. For the 2D, the loading point was placed along the most likely major flow path identified from the LiDAR. While this is a common approach to flood assessment, it does rely on relatively small sub-catchments to provide a suitable resolution for predicted flood extents, which is not the case for the large rural or hill catchments.

It was agreed to change the hydrology approach to apply the most appropriate method based on the drainage infrastructure and the land use. Accordingly, the model was updated as follows:

Urban sub-catchments, where the primary drainage (pipes, swales) exists, remain unchanged in the original model. The kinematic wave ("Model B"), suitable for modelling runoff for small urban catchments, is used to calculate the runoff from the sub-catchments. The runoff is then connected to the pipe network.

Large rural sub-catchments with no direct connection to the pipe network were removed from the model, and Rain on Grid (direct application of the rainfall to the 2D mesh) was applied instead.

For the large hilly catchments in the western part of the model and outside the 2D model coverage, the approach remains to model hydrology separately and distribute the computed hydrographs over a number of loading points along the edge of the 2D model.

5.1 Design Rainfall

QLDC has revised the design storm profile for Wanaka, and a new nested 24-hour storm was used in this modelling. The 10-minute rainfall depth, adjusted for climate change to 2100 (RCP8.5 (2100)) is shown in Figure 5-1.

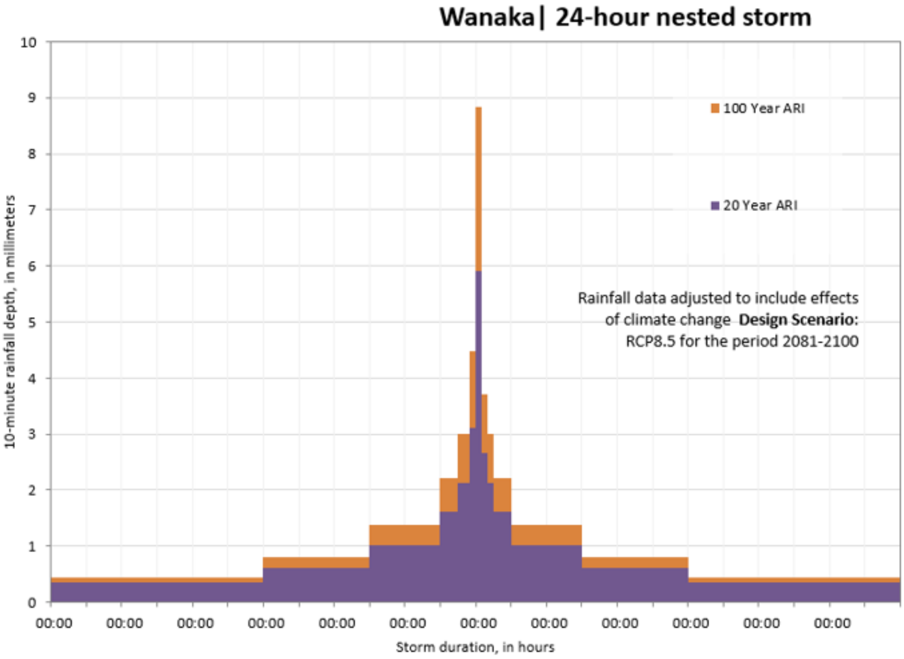

Figure 5-1 New design storm depths and profile revised by BECA

5.2 Updates to Urban sub-catchments

The urban sub-catchments that contained significant portions of green areas, such as for Kelly's Flat, Anderson Rd and Bill's Way, were split to improve the representation of rainfall losses and loading into the pipe network.

A selection of sub-catchments to be moved from the Model B hydrology to the Rain on Grid (RoG) methodology included all those not connected to the pipe network. The selection was further reviewed and refined based on the modeller's judgment about where the RoG approach could reduce some of the flow path uncertainty. These were mainly large undeveloped, rural or low density sub-catchments. In the final model setup, approximately 55% of the Wanaka Catchment was covered by the RoG.

Figure 5-2 shows the sub-catchments remaining in the updated model.

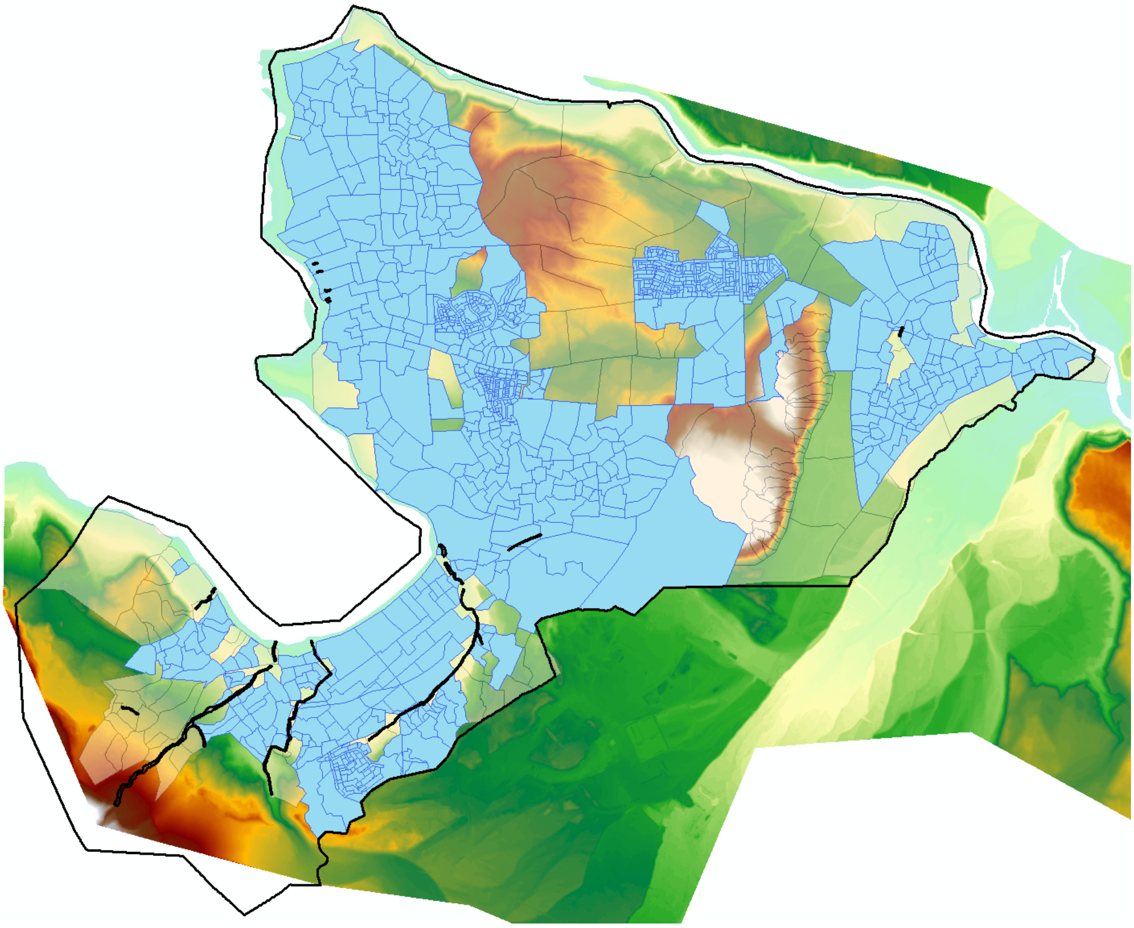

Figure 5-2 Urban sub-catchments that remain connected to the assets (blue); sub-catchments removed from the model (semi-transparent), mesh outline (black line)

The Model B parameters were updated to match the initial abstraction and continuous infiltration applied in the RoG method.

5.3 Rain on Grid methodology and coverage

RoG methodology can be applied in several ways in MIKE by DHI software. The method used for this modelling is to apply the **total rainfall** and use the "storage and leakage" approach.

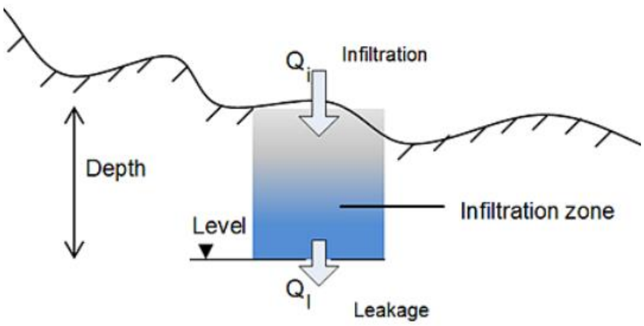

Figure 5-3 Constant infiltration with the capacity approach

The method applied to account for rainfall losses in the model comprises the use of infiltration with the capacity concept available in MIKE 21. The approach allows for representing constant but spatially variable initial and continuing losses. Two parameters based on the land use were used, the **storage depth** and **leakage**, to calculate the runoff, which is then routed overland.

The default storage depth and the leakage used in the model are based on the soil drainage and land use and guided by the previous modelling. Available information on soil types for the Wanaka catchment (S-Map, Landcare) show soils mostly moderately to well drained, so it was assumed that a simplified approach would be suitable for determining flood extents. Additionally, the actual infiltration depends on the soil moisture, known to vary significantly between seasons. Two representative sets of parameters were used, one for the impervious areas and one for the rest of the catchment, which is considered to be "well drained" soil. Higher infiltration rates were implemented in selected locations, as described in the model validation section.

Table 1 Values for leakage and storage depths adopted in the model are highlighted

Drainage type	Drainage rate (leakage) mm/hr	Initial abstraction (storage depth) mm
Impervious	0	1
Very poor	0.5	
Poor	1.5	
Imperfect	3	
Well drained	7	5
Very well drained	20	

The leakage was applied across the whole 2D domain. For the urban MPD catchments, the leakage rate and spatial variation have been calculated based on the pervious area percentage values already assigned in the model.

Localized adjustments were made to the infiltration during the model validation in the southwest part of the catchment. The final leakage rates and spatial variation are presented in Figure 5-4.

The spatially uniform time-varying 2D rainfall grid was prepared for all simulated events. The rainfall is applied over the model domain, but only to the catchment areas not covered by the urban sub-catchments. The 2D rainfall input for design events was developed based on the new design profiles prepared by BECA.

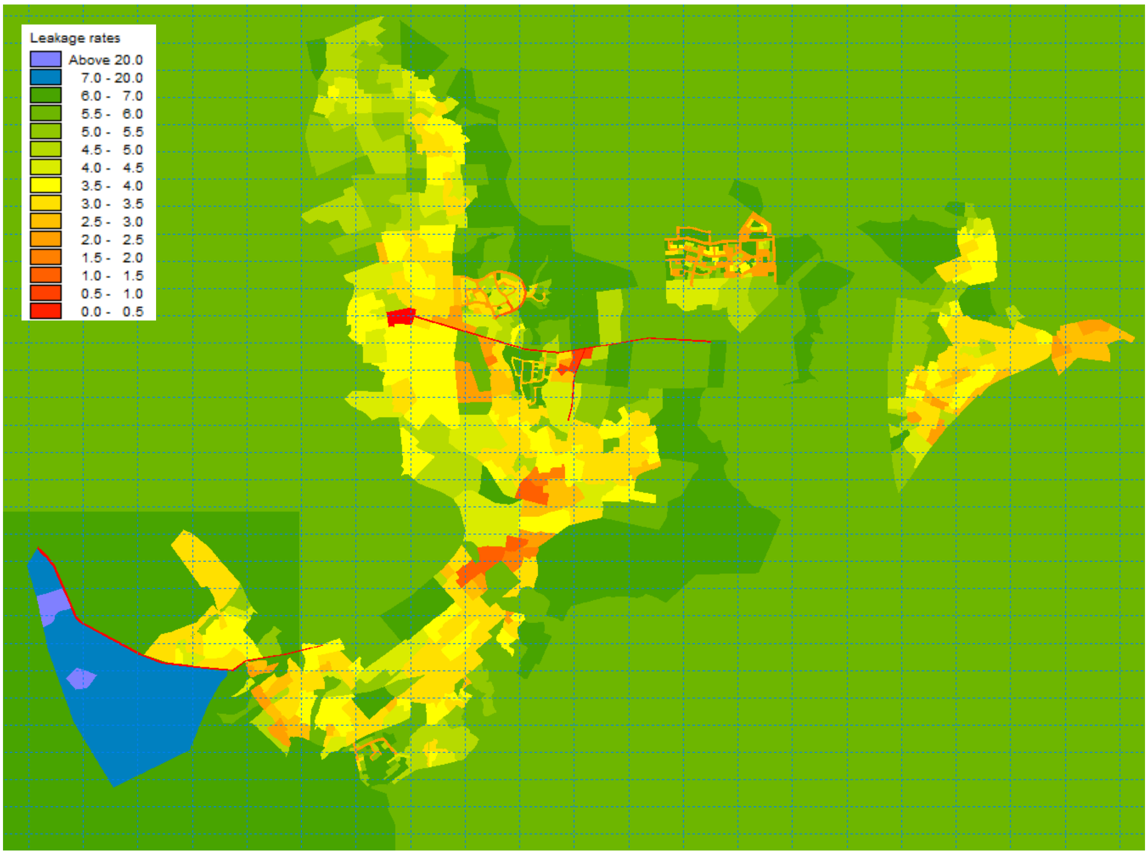

Figure 5-4 Leakage map of the Wanaka catchment

5.4 Hill catchments runoff

The runoff from the southwestern hill catchments is a major, if not the primary source of flooding in the Mt Aspiring Rd area. It was therefore essential to gain some insight on its impact on flooding in order to increase the confidence in the model predictions. Sensitivity testing was carried out during the validation to establish a reasonable set of parameters that would match the flooding observed on the ground.

The modelling approach, accounting for runoff from the hills, is to model the hydrological response and load the computed runoff hydrographs into the flood model as boundary conditions, distributed over an appropriate number of loading points.

A time-area method (Model A) was set up in MIKE FLOOD, and runoff was computed using a set of parameters suitable for the alpine hydrology. More details on the hydrological modelling of the hills are presented in Appendix A.

The hills were delineated into 7 sub-catchments. Catchment 4 was loaded directly into Stoney Creek and all other catchments to the 2D model, distributed across a number of points along the base of the hill, as shown in Figure 5-5 below.

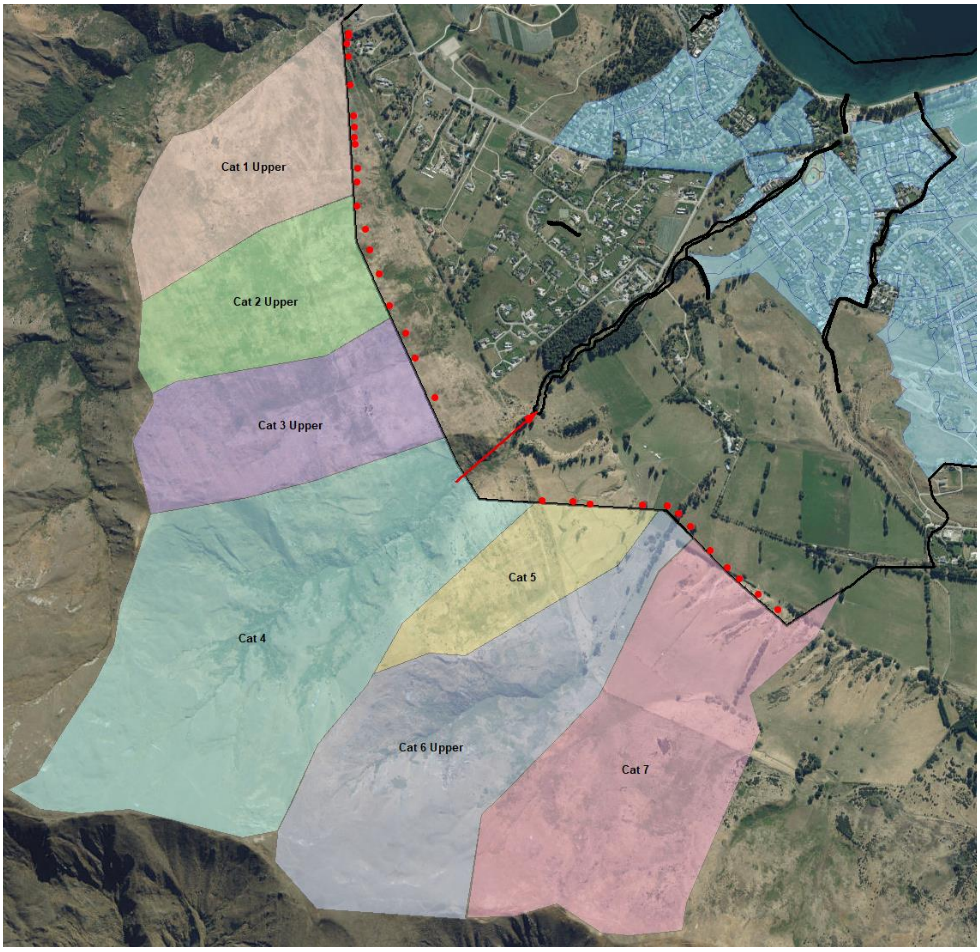

Figure 5-5 Hill catchments hydrographs are loaded as inflow into the coupled model

6 Hydraulic Model Update

Updates to the flood model were carried out through a number of iterations, based on new asset information, images, inspections and review of the stormwater management documentation for new developments. Several site visits by QLDC staff were also carried out to clarify uncertainties regarding the missing assets, visual assessment of flow paths impacted by open drains, bunds and fences. Markups and photographs documenting the site visit findings are presented in Appendix B.

6.1 River network update

The 1D river network model was upgraded from MIKE 11 to MIKE HYDRO RIVER and the new, more efficient MIKE1D computational engine was used. The main components of the 1D river model are the three streams: Bullock Creek, Stoney Creek and Middle Creek.

As noted earlier, intensive land development has been taking place in West Wanaka, and various stormwater management measures are implemented around properties, often including landscaping with bunds, swales and cut drains intercepting natural overland flowpaths. Based on the aerial images and site visits markups, several cut-drains were included in the 1D model in the Foxglove area. Figure 6-1 shows the location of the cut-drains.

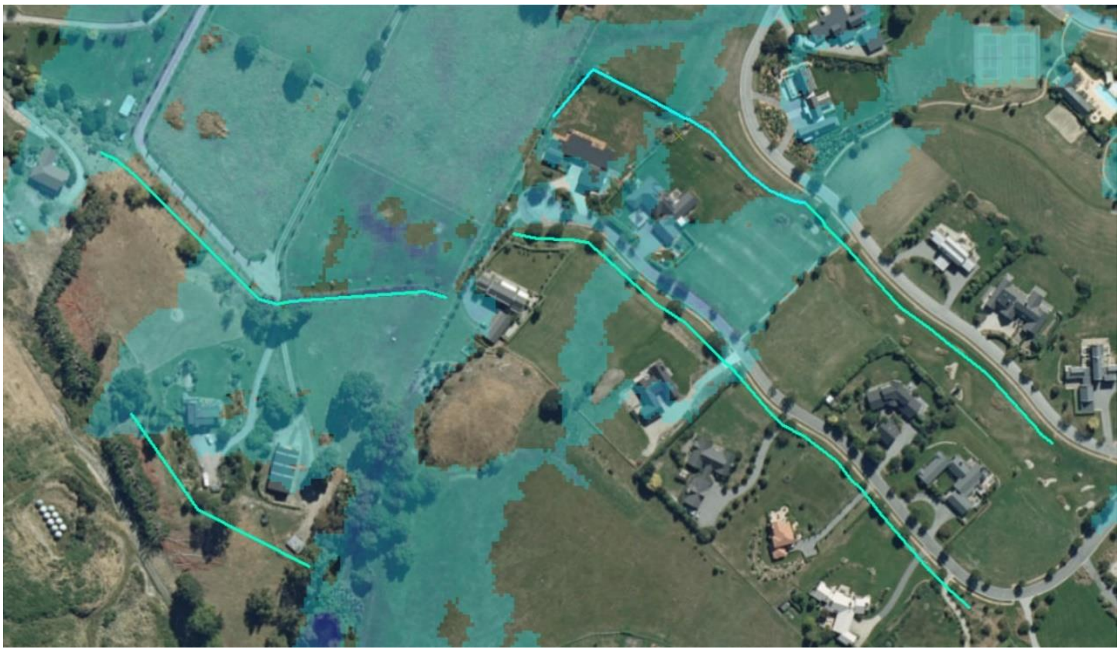

Figure 6-1 Cut drains in the Foxglove area in the west Wanaka

The cross-sections for the new channels were digitised from the LiDAR and manually adjusted to enable the drainage, based on the observations from the QLDC staff site visit.

6.2 Urban network update

Update of the urban component of the model mainly focused on incorporating additional inletting and conveyance assets in areas where spare capacity is observed in pipes or where the assets directly impact the overland flow. The updates included:

- Adding pipes and mud tanks in the Foxglove area
- Adding inlets in Kelly's flat and Rata St
- Updating the inlet capacity in Kelly's flat, Foxglove, Elderberry and Bill's Way areas

In addition, public and private soakage devices were added along the Aubrey Rd, Anderson Rd, housing developments and lifestyle properties to account for stormwater management measures. Where the information on the actual setups and infiltration rates was not available, values were estimated based on the QLDC Code of Practice. The devices are modelled performing as designed and no allowance was made for the potential lack of maintenance.

6.3 2D Model update

Update of the 2D model component was focused on the western part of the model. The peer-review recommended considering remeshing the 2D model to ensure features important for the overland flow are represented in an optimal way. However, this update was not critical and due to time and budget constraints, the existing mesh resolution was used and adjusted locally where required. The mesh elements in the areas of interest are, while not optimal, sufficiently small to represent the overland flows in the catchment.

Based on the site visit markups and photographs, the updates carried out in the 2D model are:

West Wanaka *and Bills Way:*

- Added fences at the back of the properties in Bills Way (represented as 500mm high infrastructure element)
- Added east and west bund around the Equestrian land with crest levels at 324.4 m RL and 323.0 m RL, respectively
- Added low bund around the cut-drain at Foxglove to divert the overland flow towards east
- Added 2D culverts under the Reservoir Rd and under the Mt Aspiring Rd filling the Equestrian land.

Anderson Rd and Aubrey Rd:

- 300mm bunds are added on both sides of the Mt Roy Terrace
- 300mm bund was added between the road and the housing at 154 Anderson Rd
- The MPD land use was updated with new developments, one proposed for the site at the corner of Anderson Rd and Aubrey Rd and the other currently being built adjacent to the campground at 211 Mt Aspiring Rd. The simplified representation of the proposed 20-year stormwater management was implemented in the model.

In addition to updates to the model to improve the representation of the catchment necessary to achieve better model validation, a number of technical updates were carried out to reduce instabilities in the model. The updates are recorded in Appendix B.

7 Model Verification – 2018 Flood Event

The updates to the model, as described above, were mainly informed by the need to validate the model and reduce the level of uncertainties through sensitivity testing.

The 2018 rain was a double peak event with a modest peak rainfall depth of 11.4 mm/hr for the first peak and 10.6 mm/hr for the second peak 8 hours later. The total accumulated rainfall over the 36 hours was 96.8 mm. The event was estimated to be below 10 year ARI for 1 h duration and between 20 year and 50 year ARI for 12 hour event duration.

As there were no recorded measurements outside a single flow gauge in Bullock Creek, the validation focused on the local observations, markups and assessments based on the site visits. The validation was an iterative process, and each round of model improvements and parameter adjustments was informed by the analysis of the previous iteration.

Adjustments made during the model calibration included:

- Model setup updates, as described in section 4
- Adjustment to infiltration rates across the catchment
- Adjustment to soakage rates for public soakage devices
- Adjustment to hydrological parameters for the hill catchments

Sensitivity testing was carried out for the runoff from the natural catchments and hill catchments. The testing confirmed that, in addition to the peak runoff, the focus areas of

Aubrey Rd and Bills Way are susceptible to the total amount of runoff due to relying on soakage and storage of excess runoff. Details on the sensitivity testing are given in Appendix A.

7.1 Model verification discussion – Aubrey Rd

It was agreed that, due to overall level of uncertainty in the model, lack of the measured data and the time and budget constraints for the modelling, the MPD model with climate change adjusted rainfall will be used for the validation against the historical event.

For the validation, it was assumed that the event did not cause flooding issues in Rata St and Kings Drive areas as there were no flood incidents recorded. This is not surprising due to the nature of the event and given that the primary drainage system was able to convey the excess peak runoff for the connected areas. The model validates well for Kelly's Flat location as the model predicted no flooding.

The area up the Anderson Rd, however, relies solely on soakage and storage. The area has no drainage, and all the surplus runoff, not infiltrated in the contributing sub-catchments, pools in the natural basins along Aubrey Rd and Anderson Rd. In addition, the area receives runoff from large natural catchments with a high level of uncertainty in the runoff calculation.

There were no records of flooding observed in the Anderson Rd area during the 2018 rain event, either on the roads or over properties. As the original model was showing significant flooding around Anderson Rd, it was necessary to refine the model by adding public and private soakpits present from the QLDC asset register and assumed private soakage for the lifestyle properties.

Sensitivity testing was carried out for pervious surface infiltration rates and soakage infiltration rates. The sensitivity testing shows that flooding in the area is highly impacted by the amount of runoff coming from the hilly natural catchments. Without actual infiltration or runoff measurements, a continuous infiltration rate of 7 mm/hr was adopted, representative of well-drained soils and matching the infiltration used for the RoG areas of the catchment.

Figure 7-1 shows the reduced flood extent for the validation event with the final adopted parameters and model updates. To further reduce uncertainty in this area, infiltration needs to be measured across the catchment and assumed private soakage confirmed with property owners.

Figure 7-1 Validation event 2018 - flooding in Aubrey Rd area with assumed 7 mm/... infiltration for pervious areas and soakpits infiltration of 200 mm/hr

7.2 Model verification discussion – Bills Way and Mt Aspiring Rd

Similar to the Aubrey Rd area, there were no reported flooding incidents for the Bills Way area or around Mt Aspiring Rd area for the 2018 rainfall event. Furthermore, talking to locals did not reveal significant flooding concerns apart from an increase in the runoff from the direction of Reservoir Rd in recent years.

The area receives most of the runoff from the hills and has a major natural pond situated on Equestrian land. It is also an area of recent land development, mainly low density lifestyle blocks.

The initial modelling shows significant flooding of the Bills Way area, which does not validate to the qualitative observations.

Sensitivity testing was carried out for the hill catchment hydrology, which was identified as the most significant source of uncertainty impacting on flooding in the area. The presence of springs after rainfall suggests that the catchment response to the rain may be highly affected by unaccounted storage, seepage and extended travel time through fissures and the ground in general. In addition, recent measured infiltration rates cited in resource consents applications for subdivisions show very high infiltration rates. Based on the several site visits, the model was refined and updated until a reasonable qualitative validation was achieved to 2018 event.

Figure 7-2 Validation to 2018 event

8 Flooding From Rainfall - 1% AEP, Year 2100 Climate, RCP 8.5 Median Scenario

The finalised validated model was used to determine flood extents resulting from a 1% AEP climate 2100 (RPC8.5) design rainfall event and a Mean Monthly Maximum Lake level of 276.27 m RL. The following figures show the flood extents for the whole catchment, including Aubrey Rd and Bill's Way.

Flood Hazard assessment relates to flooding impacts on life and properties. The most common parameters considered in this assessment is the flooding depth and the velocity of the flow. The flood hazard matrix used for Wanaka is based on the most recent Australian Rainfall-Runoff guide, as shown in Figure 8-1 and

Table 2 below.

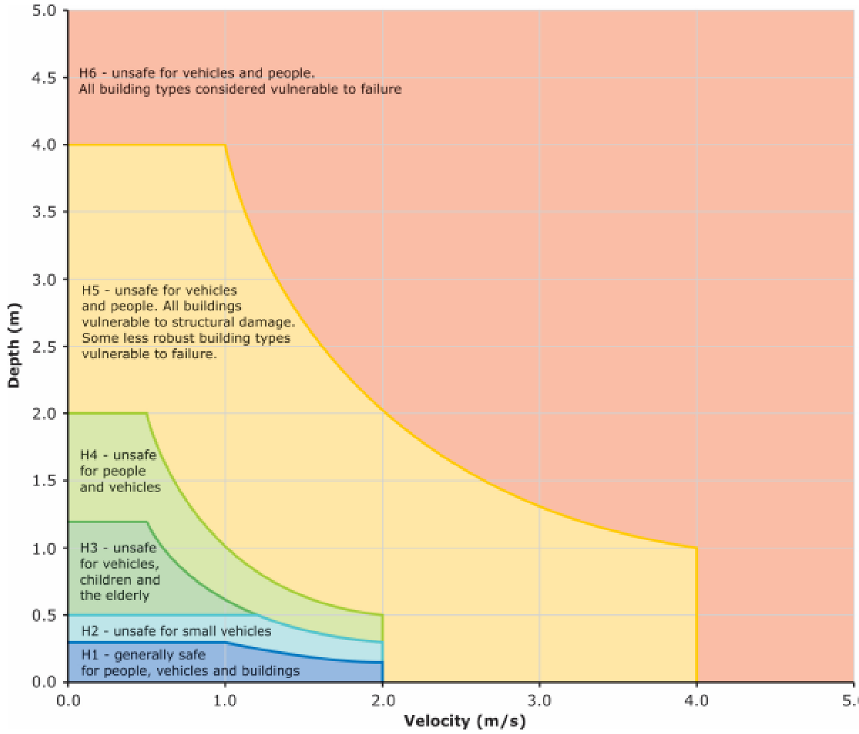

Figure 8-1Combined Flood Hazard Curves (Smith et al., 2014)

Table 2 Flood Hazard matrix

Depth [m]	0.001	0.2	0.3	0.4	0.8	1	1.2	2
Speed [m/s]								
0.001	1	1	2	2	3	4	4	4
0.7	1	1	2	2	3	4	4	4
1.4	1	1	2	3	4	4	4	4
2	4	4	4	4	4	4	4	4

Figure 8-2 1% AEP CC flood extent showing water depths above 5cm

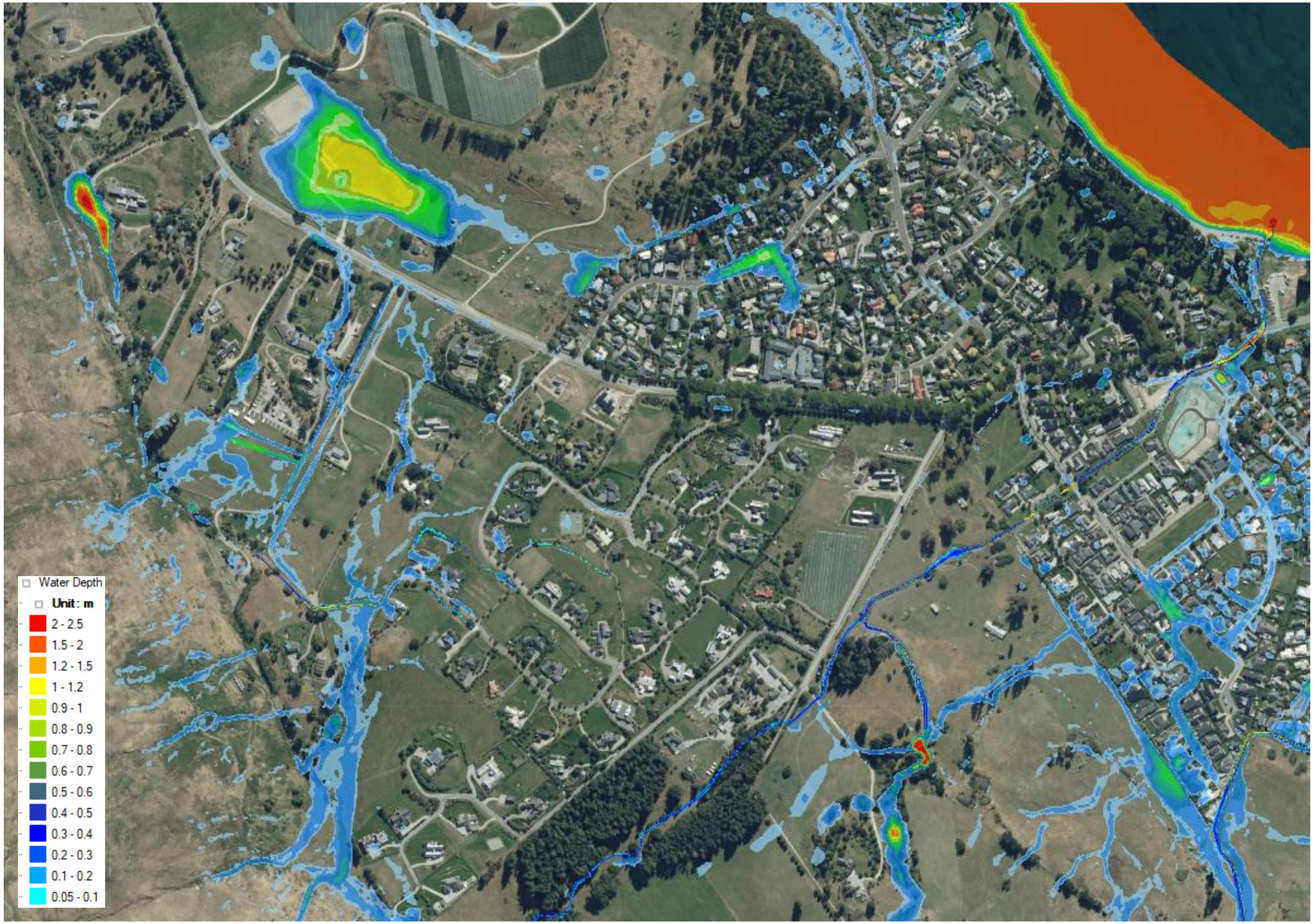

Figure 8-3 1% AEP CC flood extent showing water depths above 5cm - Mt Aspiring Rd and Bills Way area

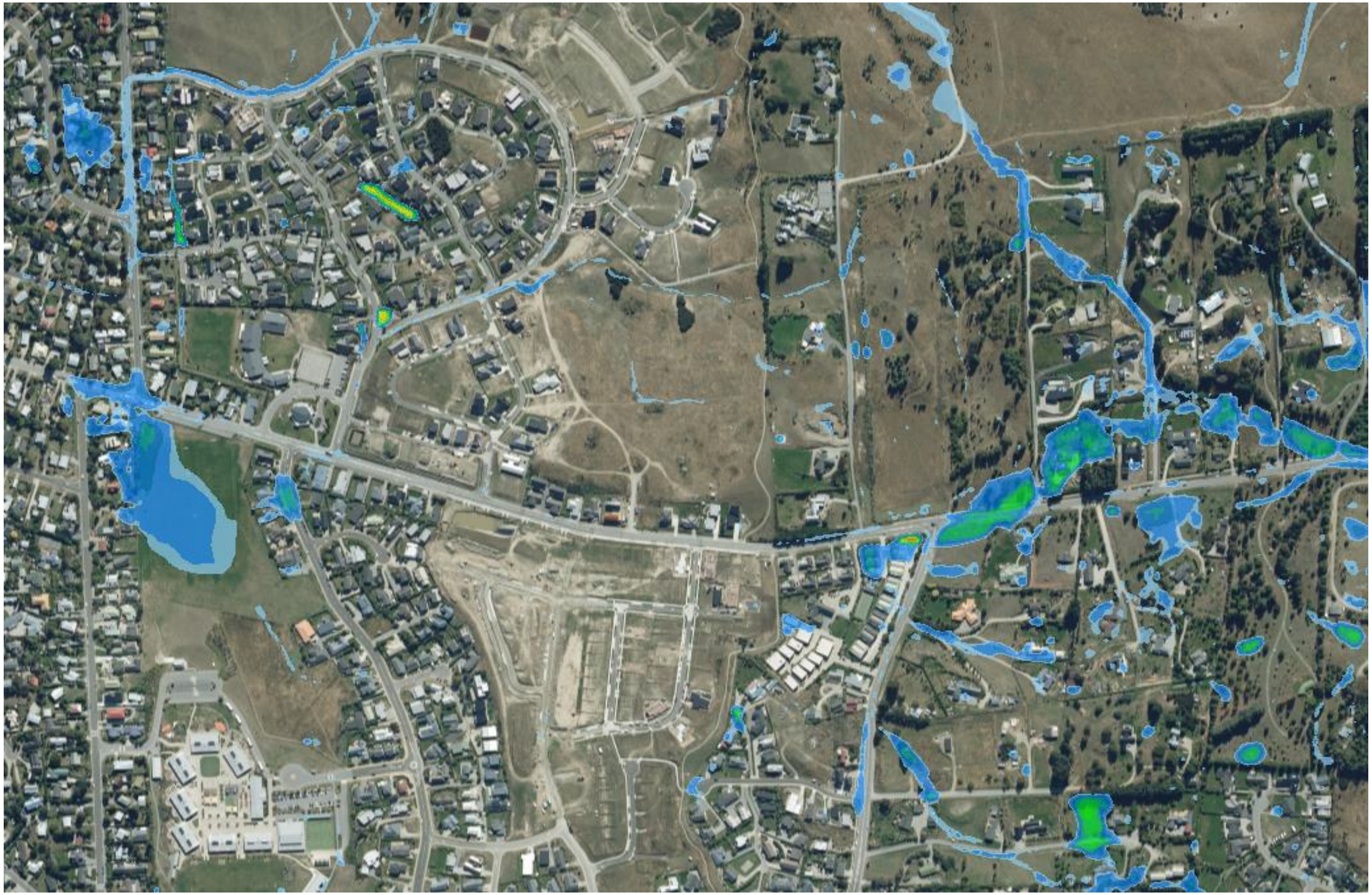

Figure 8-4 1% AEP CC flood extent showing water depths above 5cm – Aubrey Rd area

9 Recommendations for further flood mapping improvements

The recommendations for improving the confidence in flood mapping are as follows:

1. A detailed hydrological study focusing on small alpine catchments should be carried out as the runoff from the hill catchments still contains significant uncertainty. The study should establish what data is available, preferably from New Zealand, and what approaches are most suitable for our alpine and sub-alpine regions.
2. Establish a flow gauge that would be more representative of low density urban and rural catchments, possibly in Stoney Creek.
3. Complete sensitivity testing to establish the impact on flooding from all significant sources of uncertainty. The tests should be designed to include several scenarios to capture the full flooding outcomes in the catchment, combining different runoff yields from hills and infiltration rates in the lower parts of the catchment.
4. Include buildings into the 2D model to achieve more realistic flooding extents in urbanised areas.
5. Improve the model mesh to properly represent important linear features such as open drains, swales, and roads. Mesh optimisation, including the removal of very small elements, will also increase the model stability and reduce the simulation time, which is important when the model is used for iterative scenario testing.
6. In addition to flooding caused by extreme rainfall, carry out flood extent mapping for floods caused by high lake levels and storm surge.

10 References

/1/ WSP (2020). *DRAFT_V1.4_Model Build Report - submitted 14 Dec 2020.pdf*;

/2/ WSP (2021). *Updates to North Wanaka model following Peer review - memo*

/3/ DHI (2021). *North Wanaka MF model peer review report*

/4/ NZSoil. *Soils Of NZ By Region* soilrec (nzsoils.org.nz)

/5/ Landcare Research (2020). *Land use database v5.0*. https://lris.scinfo.org.nz/layer/104400-lcdb-v50- land-cover-database-version-50-mainland-new-zealand/

/6/ Landcare Research (2020). *Land use database v5.0*. https://lris.scinfo.org.nz/layer/48079-fsl-new-zealand-soil-classification/

/7/ NIWA. *NIWA River Flood Statistics* New Zealand River Flood Statistics. (arcgis.com)

/8/ Christchurch City Council. *Rainfall and runoff calculation guide* https://www.ccc.govt.nz/assets/Documents/Environment/Water/waterways-guide/21.RainfallAndRunoff.pdf

Appendix A Details of hydrology setup and sensitivity testing

Appendix A.1 Overview and purpose

This brief note summarises the rainfall-runoff modelling work carried out as part of the Wanaka model update project.

The rainfall-runoff model was developed to represent the rainfall-runoff processes occurring on the alpine hill catchments to the south of the study area that drain into the study area. The subsequent model was used to generate design ARI rainfall inflows to the hydraulic flood hazard model used in this study.

Appendix A.2 Available information

The available, site-specific information available was limited to a DEM and aerial photography of the site. These are the main points:

- The was no hydrometric data (rainfall, recorded levels, recorded flows, observed overland flows in storm events). Several literature sources and hydrological databases were sourced to provide some referencing data.
- Some anecdotal information regarding runoff from the hill catchments became available following the presentation of flood modelling results and subsequent discussion with residents.

There is some literature information available on the nature of the alpine hill catchments on the eastern side of the Southern Alps. This information was only superficially reviewed (due to limited available project scope).

Appendix A.3 Model schematisation

Given that there was no site-specific hydrometric information it was decided to keep the rainfall-runoff modelling at a simple level of complexity and use the model to predict the potential range of flow responses from the hill catchments. The model utilised was the Time-Area model (ref.: https://manuals.mikepoweredbydhi.help//2021/Water_Resources/MIKE_1D_reference.pdf, section 7).

In the Time-Area rainfall-runoff method, the amount of runoff is controlled by the initial loss, the size of the contributing area and by a continuous hydrological loss. The shape of the runoff hydrograph is controlled by the time of concentration and the time-area curve.

Appendix A.4 Model set-up

The DEM was processed to obtain the total catchment areas, length, slope and shape. The Bransby-Williams time of concentration formulae (ref.: *Ministry of Works and Development 1975. The Metric Version of Technical Memorandum No. 61. Planning and Technical Services Group, Water and Soil Division, Ministry of Works and Development, Wellington*) which is:

$Tc=14\cdot L\cdot A^{0.1}\cdot S^{-0.2}$$Tc=14\cdot L\cdot A0.1\cdot S-0.2$

where Tc = time of concentration [min]; L = catchment length [km]; A = catchment areas [km^2]; and S = catchment slope [-].

Table A.1 presents the catchment characteristics and Time of concentration estimate.

Table A.1 Catchment characteristics and Time of Concentration estimate

Catchment ID	Area (km2)	Length (km)	Slope (-)	Tc (min) Bransby-Williams	Catchment Shape	Time-Area curve ID
Cat_1_Upper	0.471	1.123	420	18	rectangular	TACurve1
Cat_2_Upper	0.430	1.063	405	17	rectangular	TACurve1
Cat_4	1.502	1.16	820	21	converging	TACurve3
Cat_5	0.292	1.041	415	15	converging	TACurve3
Cat_6_Upper	0.970	2.177	780	37	converging	TACurve3
Cat_7	1.020	1.611	560	28	rectangular	TACurve1
Catch_3_Upper	0.522	1.16	500	18	rectangular	TACurve1

The initial losses were set to 0mm. The continuous loss was assessed for values: 25%, 50%, 75%.

Appendix A.5 Model validation and scenario simulations

The rainfall-runoff model was simulated for the storm even in February 2018 and the design ARI (with climate change) rainfall events: 10 year, 20 year and a 100 year. The model results are presented in Tables A.2 through to A.5.

The model results (hydrographs of flow) were evaluated against known likely flows coming off the hill catchment (QLDC) and against some information gathered from a brief review of the literature and the NIWA Rational Method HIRDS V4 database of rainfall-runoff for similar catchments. Table A.6 gives the stations used and associated area normalised peak flow (m^3/s / km^2).

Table A.2 RR model results for Feb 2018 event, 60% continuing loss

Catchment ID	Maximum [m^3/s]	Accumulated flow [m^3]	Area (km^2)	Area normalised Qp (m^3/s / km^2)
Catch_3_Upper	1.101	30,289	0.5215	2.1
Cat_1_Upper	0.995	27,380	0.4714	2.1
Cat_2_Upper	0.910	24,970	0.4299	2.1
Cat_4	3.221	87,260	1.5024	2.1
Cat_5	0.636	16,946	0.2918	2.2
Cat_6_Upper	1.980	56,366	0.9705	2.0
Cat_7	2.115	59,296	1.0209	2.1
Total		302,511		

Table A.3 RR model results for 100 yr ARI (with CC) event, 60% continuing loss

Catchment ID	Maximum [m³/s]	Accumulated flow [m³]	Area (km²)	Area normalised Qp (m³/s / km²)
Catch_3_Upper	4.271	45,983	0.5215	8.2
Cat_1_Upper	3.860	41,566	0.4714	8.2
Cat_2_Upper	3.594	37,913	0.4299	8.4
Cat_4	13.33	132,2970	1.5024	8.9
Cat_5	2.880	25,722	0.2918	9.9
Cat_6_Upper	6.945	85,175	0.9705	7.2
Cat_7	7.045	89,891	1.0209	6.9
Total		458,549		

Table A.4 RR model results for 20 yr ARI (with CC) event, 60% continuing loss

Catchment ID	Maximum [m³/s]	Accumulated flow [m³]	Area (km²)	Area normalised Qp (m³/s / km²)
Catch_3_Upper	2.911	34,102	0.5215	5.6
Cat_1_Upper	2.632	30,826	0.4714	5.6
Cat_2_Upper	2.446	28,118	0.4299	5.7
Cat_4	8.998	98,100	1.5024	6.0
Cat_5	1.935	19,075	0.2918	6.6
Cat_6_Upper	4.736	63,148	0.9705	4.9
Cat_7	4.842	66,658	1.0209	4.7
Total		340,030		

Table A.5 RR model results for 10 yr ARI (with CC) event, 60% continuing loss

Catchment ID	Maximum [m³/s]	Accumulated flow [m³]	Area (km²)	Area normalised Qp (m³/s / km²)
Catch_3_Upper	2.406	29,485	0.5215	4.6
Cat_1_Upper	2.175	26,653	0.4714	4.6
Cat_2_Upper	2.021	24,311	0.4299	4.7
Cat_4	7.459	84,809	1.5024	5.0
Cat_5	1.598	16,491	0.2918	5.5
Cat_6_Upper	3.946	54,585	0.9705	4.1
Cat_7	4.035	57,629	1.0209	4.0
Total		293,966		

Table A.6 NIWA rational method HIRDS V3 reach data for area normalised peak flows

Reach ID	Area normalised peak flow (m3/s / km2)		
	10 year ARI	20 year ARI	100 year ARI
14014572	3.9	4.7	6.8
14013358, cat_4	1.7	2.0	2.9
14014572	3.9	4.7	6.8
14014463	4.0	4.9	7.1
14014232	2.8	3.3	4.9
14014781	5.9	7.1	10.4

Following the inspection of the rainfall-runoff results, it was decided to adopt a continuous loss of 60%. The rainfall-runoff model was used to create the historical and design rainfall-runoff hydrographs for use in the hydrodynamic flood hazard model.

Appendix A.6 Revision to the model

The rainfall-runoff model result hydrographs were used as inflow boundary conditions for the hydraulic flood model. The resulting flood inundation and spread were discussed with residents and the QLDC staff.

The residents advised that they had not experienced as severe flooding as predicted by the model for the 2018 storm event. However, the residents did comment that they observed 'springs' flowing from the hillsides long after any significant rainfall. This could indicate that the catchment rainfall-runoff is more representative of a considerable surface infiltration and then sub-surface flow to these 'springs'.

To represent that phenomenon in the simple time-area rainfall-runoff model, we have increased the time of concentration parameter by a factor of 10 (the Tc parameter controls the attenuation and translation of the hydrograph without altering the overall runoff volume). Note that this is not modelling the actual subsurface flow phenomenon but is attenuating and translating the runoff hydrograph to respond somewhat like what may be created by subsurface flow. There is insufficient soil and hydrometric information available to create a model representing the possible subsurface flow phenomenon.

Additionally, the continuing loss was reduced further as the model was still producing too much runoff to match the observations from the residents. The value of 40% was selected for the initial flood assessment and mapping.

The revised RR model was used as input BC again in the HD model, and the results of inundation in the town are more aligned with what was observed by residents.

It should be noted that the historical events relating to anecdotal 'spring flows' pointed out by the residents are likely to correlate to lower ARI events that actually occurred in recent history. It is very likely that the rainfall-runoff process for a higher ARI rainfall (100 year) could be quite different from that modelled here; therefore, uncertainty about potential flooding caused by the extreme events is still relatively high.

Even with the significant lack of hydrological data available on the catchments, the modelling can give some upper and lower bounds to potential runoff from the hill catchments under various rainfall forcing that should be useful in stormwater management for stormwater management the area. If further reduction in uncertainty is required, then the proposed items (water level recorder in the pond behind 247 Mt Aspiring Rd and flow site in Stoney Creek) to gain some quantitative information on the catchment should be implemented.

Appendix A.7 Infiltration sensitivity testing for rural catchments – hydrology

The urban sub-catchment hydrology is calculated in MIKE URBAN using ModelB. In this model, each sub-catchment is proportioned to Impervious and Pervious surfaces, each with a set of parameters to determine initial and continuous rainfall loss.

Several parameter sets are present in the model used as a base (WSP), and all values are reasonable. It is not expected that differences in parameters will have a significant impact in urbanised areas. However, in sub-catchments with large pervious areas, significant differences could be expected observed.

The RoG part of the Wanaka master flood model uses the following infiltration parameters:

Drainage type	Class	Drainage rate mm/hr	Initial abstraction = depth mm
Impervious	0	0	1
Very Poor	1	0.5	
Poor	2	1.5	
Imperfect	3	3	
Well	4	7	5
Very well	5	20	

Figure 10-1 A simple soil drainage classification and the rainfall loss parameters. The highlighted are used for the Rain On Grid part of the model

The objective is to apply similar parameters for the areas that use catchment-based hydrology calculation. As the two calculation methods, the ROG and ModelB, are different, some sensitivity testing was carried out to determine the best fitting set of parameters.

Table 3 Hydrology Sensitivity testing

Hydrology sensitivity testing for 2018 validation												
Validation event 2018		Initial Abstraction mm	1		Initial Abstraction mm	5		Initial Abstraction mm	2		Initial Abstraction mm	2
		Infiltration Rate Max mm/h	36		Infiltration Rate Max mm/h	36		Infiltration Rate Max mm/h	36		Infiltration Rate Max mm/h	12
		Infiltration Rate Min mm/h	3.6		Infiltration Rate Min mm/h	7		Infiltration Rate Min mm/h	5		Infiltration Rate Min mm/h	5
	Test O3			Test O4			Test O4b			Test O4d		
Catchment ID	Maximum [m^3/s]	Time of maximum	Accumulated flow [m^3]	Maximum [m^3/s]	Time of maximum	Accumulated flow [m^3]	Maximum [m^3/s]	Time of maximum	Accumulated flow [m^3]	Maximum [m^3/s]	Time of maximum	Accumulated flow [m^3]
Catchment_139a	0.142	1/02/2018 3:40	3,416.70	0.069	1/02/2018 3:00	1,947.60	0.103	1/02/2018 3:40	2,649.80	0.103	1/02/2018 3:40	2,647.50
Catchment_139b	0.104	1/02/2018 3:40	2,337.50	0.037	1/02/2018 3:00	1,023.20	0.069	1/02/2018 11:40	1,651.50	0.070	1/02/2018 11:40	1,649.50
Catchment_142aa	0.042	1/02/2018 11:40	1,000.70	0.018	1/02/2018 3:00	510.3	0.029	1/02/2018 11:40	736.3	0.029	1/02/2018 11:40	735.4
Catchment_142ab	0.051	1/02/2018 11:40	1,145.70	0.011	1/02/2018 3:40	305.8	0.029	1/02/2018 11:40	673.6	0.029	1/02/2018 11:40	671.8
Catchment_142b	0.101	1/02/2018 11:40	1,975.20	0.012	1/02/2018 3:50	294.3	0.058	1/02/2018 11:40	1,102.50	0.058	1/02/2018 11:40	1,099.80
Catchment_513	0.203	1/02/2018 11:40	4,586.90	0.006	1/02/2018 5:40	89.8	0.089	1/02/2018 11:40	1,909.10	0.089	1/02/2018 11:40	1,898.60
Catchment_7aa	0.030	1/02/2018 3:40	909.2	0.029	1/02/2018 3:40	875.3	0.030	1/02/2018 3:40	892.2	0.030	1/02/2018 3:40	892.2
Catchment_7ab	0.020	1/02/2018 3:00	530.4	0.019	1/02/2018 3:00	510	0.019	1/02/2018 3:00	521	0.019	1/02/2018 3:00	520.9
Catchment_7ac	0.032	1/02/2018 3:40	801.1	0.024	1/02/2018 3:00	653	0.029	1/02/2018 3:40	732	0.029	1/02/2018 3:40	731.8
Catchment_7ad	0.013	1/02/2018 3:40	358.2	0.011	1/02/2018 3:00	312.5	0.012	1/02/2018 3:40	336.1	0.012	1/02/2018 3:40	336
Catchment_7ae	0.014	1/02/2018 3:00	366.7	0.012	1/02/2018 3:00	337.3	0.013	1/02/2018 3:40	353.1	0.013	1/02/2018 3:40	353.1
Catchment_7ba	0.017	1/02/2018 3:00	470.6	0.016	1/02/2018 3:00	452.3	0.017	1/02/2018 3:00	461.9	0.017	1/02/2018 3:00	461.9
Catchment_7bb	0.011	1/02/2018 3:40	227.9	0.005	1/02/2018 3:40	128.8	0.008	1/02/2018 3:40	180.8	0.008	1/02/2018 3:40	180.7
Catchment_7bc	0.023	1/02/2018 11:40	593.7	0.012	1/02/2018 3:10	343	0.016	1/02/2018 11:40	453.5	0.016	1/02/2018 11:40	452.9
Catchment_7ca	0.066	1/02/2018 11:40	1,563.00	0.024	1/02/2018 3:00	693.3	0.042	1/02/2018 11:40	1,079.70	0.042	1/02/2018 11:40	1,077.80
Catchment_7d	0.099	1/02/2018 11:40	2,076.20	0.020	1/02/2018 3:40	544.9	0.059	1/02/2018 11:40	1,264.90	0.059	1/02/2018 11:40	1,262.30
Total			22,359.80			9,021.40			14,998.10			14,972.10

The results from the hydrology testing were analysed, and it was decided to run the full hydrodynamic simulation for the 2018 validation event to verify the model.

For the 2018 event simulation, the full dynamic results were analysed, and the Option 4 was selected as the most representative of the observed flooding in the Aubrey Rd / Anderson Rd area.

The adopted hydrological parameters for the Horton's infiltration are given below. This parameter set was used for all urban sub-catchments.

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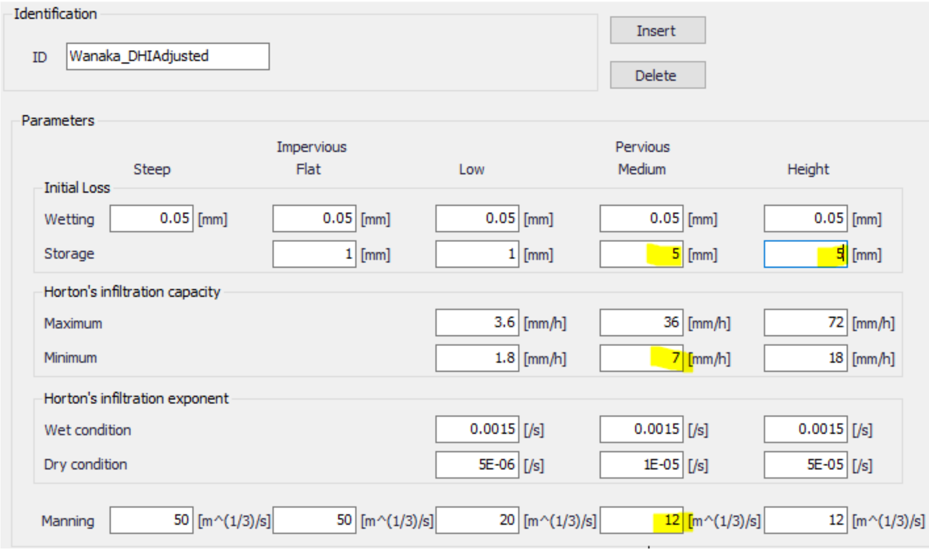


Identification

ID: Wanaka_DHIAdjusted

Insert | Delete

Parameters

	Impervious Steep	Impervious Flat	Pervious Low	Pervious Medium	Pervious Height
Initial Loss					
Wetting	0.05 [mm]	0.05 [mm]	0.05 [mm]	0.05 [mm]	0.05 [mm]
Storage		1 [mm]	1 [mm]	5 [mm]	5 [mm]
Horton's infiltration capacity					
Maximum			3.6 [mm/h]	36 [mm/h]	72 [mm/h]
Minimum			1.8 [mm/h]	7 [mm/h]	18 [mm/h]
Horton's infiltration exponent					
Wet condition			0.0015 [/s]	0.0015 [/s]	0.0015 [/s]
Dry condition			5E-06 [/s]	1E-05 [/s]	5E-05 [/s]
Manning	50 [m^(1/3)/s]	50 [m^(1/3)/s]	20 [m^(1/3)/s]	12 [m^(1/3)/s]	12 [m^(1/3)/s]

Figure 10-2 Wanaka_DHIAdjusted ModelB validated parameters, changes from the previously used modelling are highlighted

Appendix B Technical details on other model updates

Appendix B.1 Model stabilisation outside the model update areas

Model updates often have an impact outside the areas that are changed in the model. This is most often due to subtle changes in the simulation that push already unstable parts over the stability threshold and crash the simulation.

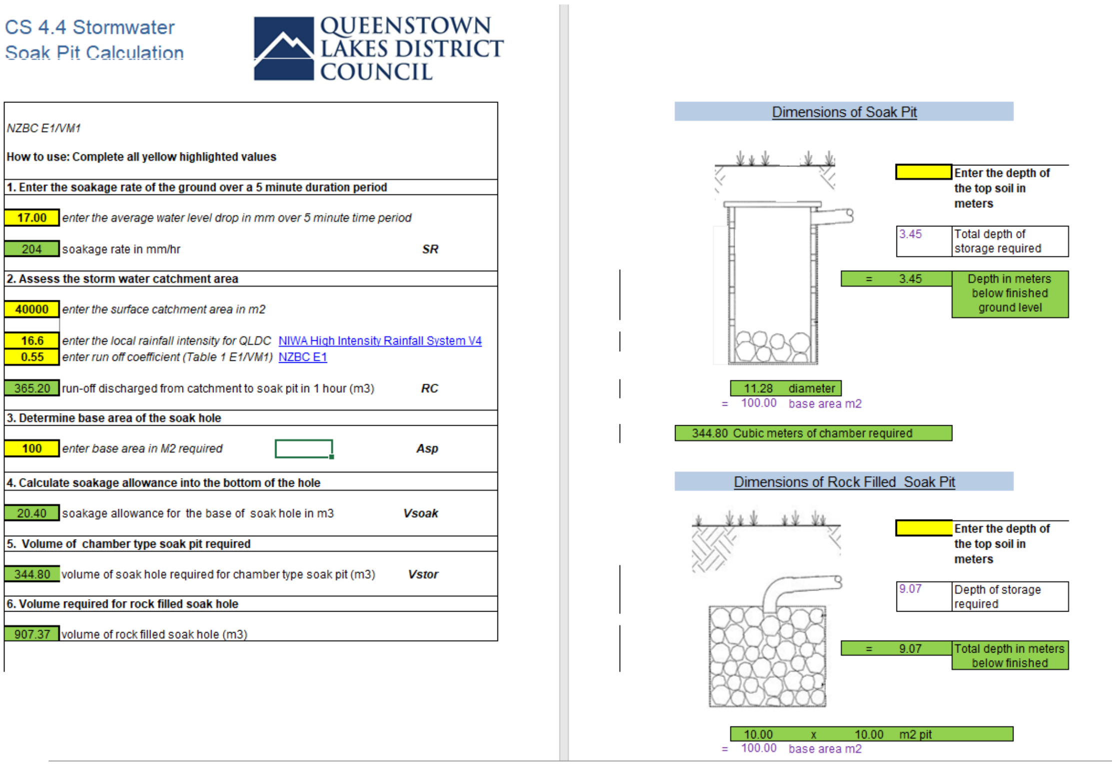
Some examples of model changes required to resolve simulation crashes are:

- Fixing the lateral linking along the Middle Creek
- Removing unstable outlets into the lower Stoney Creek and loading to the 2D along the bank
- Removing lateral linking over the culverts
- Smoothing the 2D mesh along the unstable lateral links
- Fixing instabilities in several outlets to the lake in the northern part of the catchment

Appendix B.2 Model updates – Aubrey Rd, Anderson Rd and Kelly's flat

A number of updates to the model were carried out:

1. Refinement of the catchments in Kelly's flat, and the school grounds, Anderson Rd and Aubrey Rd area and their reconnection to the pipes and the surface, as appropriate
1. Implementing stormwater management for the new developments in Kirimoko and Heights Avenue
2. Adding private soakage in the Aubrey Rd area. As there were no records available, the QLDC soak pit calculator was used to estimate the soakage, an example is shown below.



The soakage pits are represented by using a "soakaway" node in MIKE URBAN, which allows assigning the infiltration rates directly at the node, thus avoiding having to use the dummy outlet and regulation. The soakage was assumed as continuous. The **Figure 10-3** shows filling and emptying of soakpits.

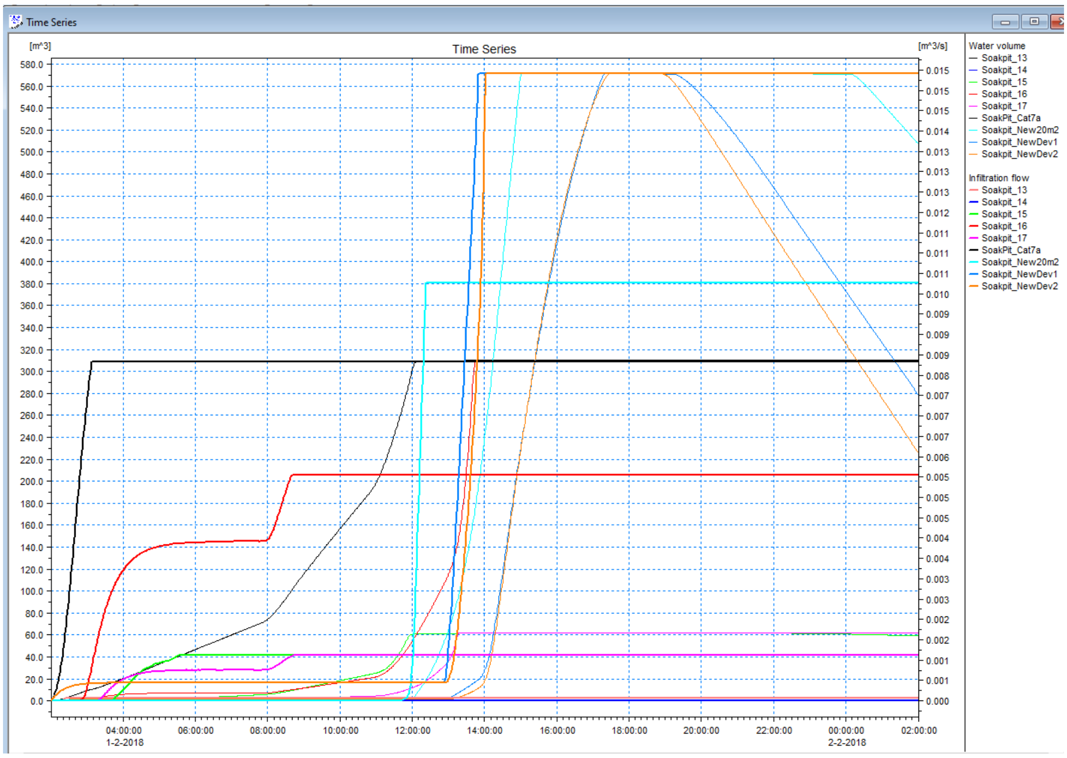


Figure 10-3 An example performance Figure 10-3of soakage pits in the model

Figure 10-4 Bottom of the Mt Roy Terrace with its "bunds" visible on each side. The soakage pits are located on each side of the road depression between two houses

3. A new development was added to the MPD model, corner of Anderson Rd with the proposed stormwater management consisting of a soakpit and an attenuation basin.

Appendix B.3 Model updates – Bills Way and Mt Aspiring Rd

Based on the several site visits, the following updates to the model were carried out in the Bills Way and Mt Aspiring Rd:

1. Addition of several cut drains and associated inlets, outlets and mud tanks in the Foxglove area. Some information was available in the QLDC assets, and some was estimated during the site visit, see **Figure 10-5**. Four drains are added to the 1D (MIKE 11) part of the model. The cross-sections were extracted from the LiDAR and adjusted where necessary to ensure the water flows in the marked direction. The mesh was blocked out at the drains locations to avoid double counting the water volume.

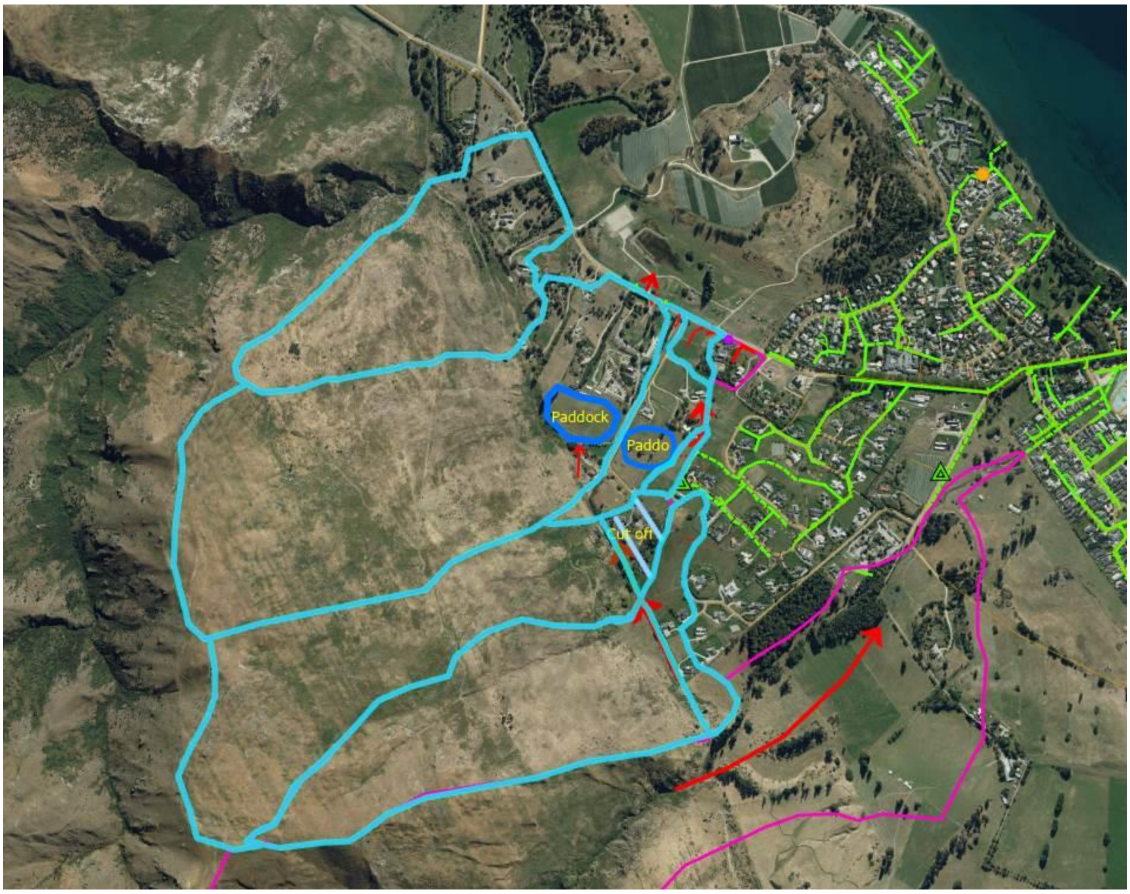


Figure 10-5 Site visit markup with cut-drains missing in the assets

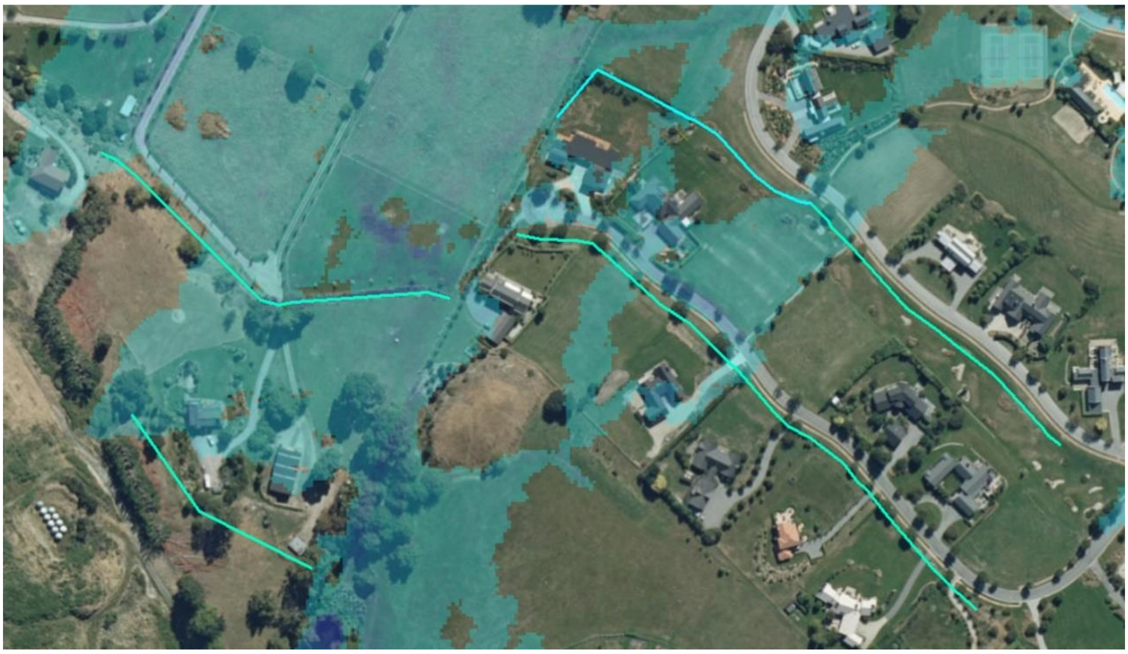


Figure 10-6 Four drains added to the model during the update

2. Refinement of the catchments between Bills Way and the Reservoir Rd. The catchments originally included mixed land use – high density urbanized along the Bills Way and large undeveloped hill

catchments to the north. The catchments were trimmed, and undeveloped portion represented in RoG. The lower catchments were left in urban hydrology setup using ModelB. The catchment parameters were updated, as were the catchment connections where appropriate, see **Figure 10-7**.

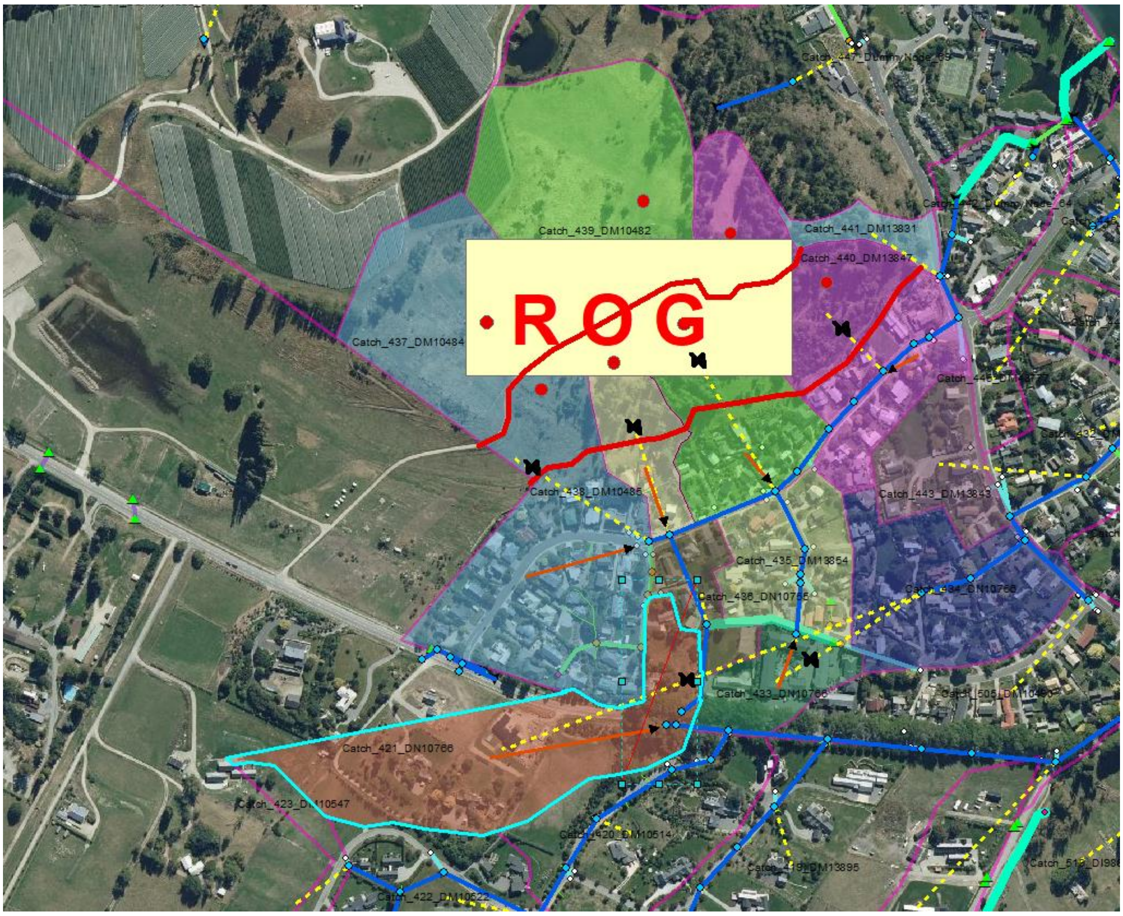


Figure 10-7 Splitting the catchments in the Bill's way area

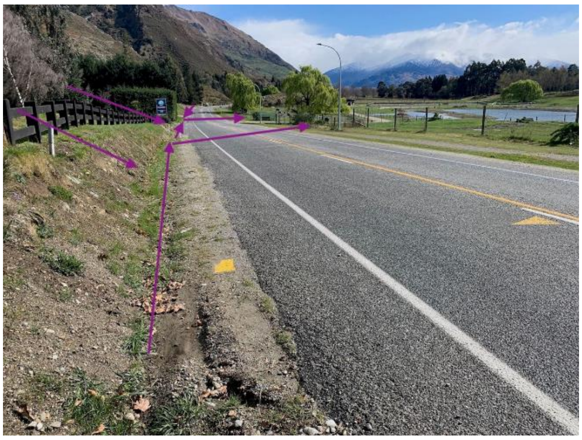
3. Fences at the back of the Bills Way properties were represented as infrastructure feature in M21, adding 600mm to each mesh element along the back of the properties. The bathymetry was smoothed in the vicinity of the fence to resolve instabilities caused by fast runoff from the hill hitting a solid boundary.
4. Soakpits between the Equestrian land and the Bills way was added as per the sketch in the Appendix C. The Soakpit was schematized with multiple inlets to cover the extent of the gravel capture bed.
5. Two bunds were added for the pond on the Equestrian land, both are estimated during the site visit. Talking to locals revealed that the pond does have water most of the time. As the LiDAR is flat in this area, it is assumed that it reflects the permanent water level in the pond. See **Figure 10-8** for details.
6. 2D culverts, DN300 and DN600 were added under the Mt Aspiring Rd and configured with information available in assets.
7. A culvert was added under the Reservoir Rd with assumed DN250 and location based on the photographs
8. Roughness was adjusted in the Waterfall Creek to slow down the overland flow and allow infiltration to work, as site visit identified large shallow ponding areas.

Figure 10-8 Pond elevation and bunds to the east and west

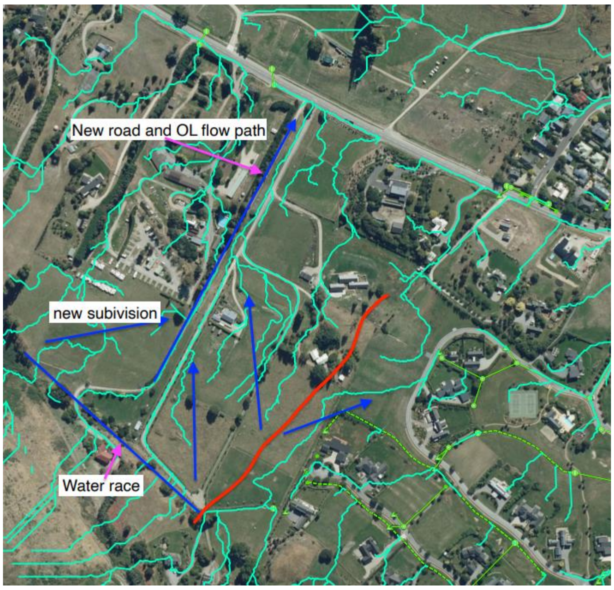
Appendix C Site visits markups and photographs

Several site visits were carried out through September and October by the QLDC staff, and they were all taken into account during the model update. Some of the captured photographs and marked up assessments of overland flowpaths and ponding areas are presented in these appendices

Appendix C.1 Site visit 4th October 2021 – Bills Way and Equestrian pond



Appendix C.2 Site visit 20th October 2021 - Equestrian Pond and southern hills



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Appendix C.3 Site visit 20th October 2021 – Aubrey Rd and Mt Roy Terrace

Appendix C.4 Site visit 26th October 2021 – southwest Wanaka hills and the new subdivision




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Appendix C.5 Site visit 4th November 2021 – overland flows and Equestrian pond

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From: Simon Brackstone <Simon.Brackstone@qldc.govt.nz>
Sent: Thursday, November 4, 2021 2:59 PM
To: Rajika Jayaratne <Rajika.Jayaratne@qldc.govt.nz>
Subject: Re: Wanaka - Fox Glove Overland Flow Path check

Hi Rajika,

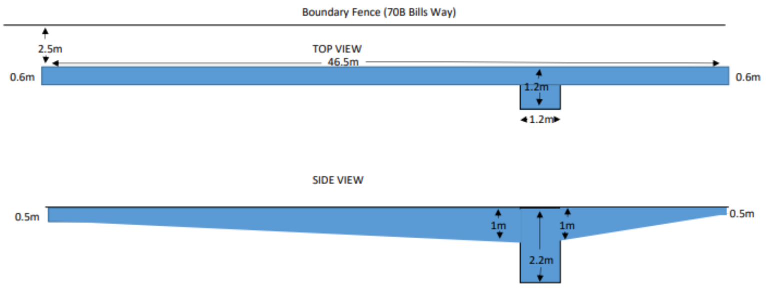
I confirm I attended site again yesterday and revisited the land parcels that we had previously visited. Attached is my mark up along with a few supporting photos of the pond at the equestrian centre.

A couple of points

- The equestrian center pond could take a lot more volume before it tips over towards bills way. Approx 1.5 meters by my eye calculation. And if needed a more robust bund could be formed along the existing tree line to further protect down stream , but this would have to be with the equestrian center/land owners approval. Not sure if Lidar picks up the land contours enough here to determin the potential depth of the pond.
- The flow path near fox grove and Elderbury cres tips top the East as we previously observed but my mark up clearly articulates that. So a significant portion of hill run off would be intercepted by the water race and flow towards foxglove heights and away to the east and does not go to the equestrian land. . There are a number of new houses built that the GIS maps don't show on the eastern end of the water race which would further direct hill catchment SW towards the east
- So the split in catchments is as per my previous mark up advise when I sent you the information about the new subdivision. New subdivision environs SW is managed as per the subdivision info I sent.
- Further west, the pond behind 247 is well formed within a valley and a significant amount of water would be held in this land depression
- I have marked up the high points along Mt aspiring road which would affect any flow paths , any SW outside of these high points would flow away from the equestrian center.
- 249 Mt Aspiring road does have some catchment that would flow towards the western side of the equestrian center, but some of it would be held there as the equestrian pond is bunded to the west, so effectively there is another potential catchment are that would hold water to the north west of the equestrian center.

Regards
Simon

WaterFall Equestrian Cut off Drain – East End (not to scale)



Flow Test Results

0.82L per second

Note: After 1 hour depth of water did not exceed 0.75m

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