IN THE MATTER OF	the Resource Management Act 1991
AND	
IN THE MATTER OF	applications for resource consents and notices of requirement in relation to the Ōtaki to North of Levin Project
BY	**WAKA KOTAHI NZ TRANSPORT AGENCY**
	Applicant

ŌTAKI TO NORTH OF LEVIN HIGHWAY PROJECT

TECHNICAL ASSESSMENT F: HYDROLOGY AND FLOODING

BUDDLE FINDLAY

Barristers and Solicitors
Wellington

Solicitor Acting: **David Allen / Thaddeus Ryan**
Email: david.allen@buddlefindlay.com / thaddeus.ryan@buddlefindlay.com
Tel 64 4 462 0423 Fax 64 4 499 4141 PO Box 2694 DX SP20201 Wellington 6011

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Introduction

1. This technical report assesses the actual and potential hydrology and flooding effects of the Ōtaki to North of Levin Highway Project (the "**Ō2NL Project**"). The report supports the notices of requirement for designations (**"NoRs"**) and application for resource consents for the Ō2NL Project.

2. The Ō2NL Project involves the construction, operation, use, maintenance and improvement of approximately 24km of new four-lane median divided state highway (two lanes in each direction) and a shared use path ("**SUP**") between Taylors Road, Ōtaki (and the Peka Peka to Ōtaki expressway ("**PP2Ō**")) and State Highway 1 ("**SH1**") north of Levin.

3. The existing topographic and hydrological environment of the proposed designations is dominated by the Tararua Range. High rainfall in the steep mountains gives rise to rapidly responding rivers, streams and overland flow paths that drain predominantly westwards toward the sea. The orientation of existing SH1 and the proposed designations near the base of the foothills means that the highways cross many of these watercourses. Existing SH1 is subject to flood risk and erosion issues, which will become worse over time because of the predicted effects of climate change.

4. Despite the large scale of the proposed designations that interact with all these watercourses, the effects of the Ō2NL Project on hydrology and flooding will be less than minor. The method I have followed to come to this conclusion is outlined below.

Methodology

5. This assessment has been informed through development of hydrological and computational hydraulic models that represent the baseline condition, and an indicative Ō2NL Project 'concept' design within the proposed designations.

6. The design and assessment rely significantly on the modelled 1:100 Annual Exceedance Probability ("**AEP**") rainfall event, including the potential effects of climate change, over an asset design life extending to 2130. Climate change forecasts are approached on a moderately-conservate basis, which is considered appropriate given the long design life and high cost to upgrade culverts or bridges during the Project's operational life if a less conservative

scenario was considered. Predicted impacts of climate change on flood-generating storms are considered part of the baseline case when assessing potential effects. This is because climate change will take place whether the Ō2NL Project is present or not.

7. Rainfall adjustment factors for future climate are based on the High Intensity Rainfall Design System ("**HIRDS**") version 4 report for a medium-high Representative Concentration Pathway ("**RCP**") 6.0 emissions scenario. HIRDS v4 RCP scenarios are derived from the Intergovernmental Panel on Climate Change ("**IPCC**") Fifth Assessment (2014).

8. The selection of hydrological and hydraulic modelling software, the model boundary conditions including climate change, and level of detail applied, are consistent with industry best practice for assessing effects of a project of this scale and nature.

9. The baseline modelling report was provided to Iwi Project Partners (Muaūpoko Tribal Authority ("**Muaūpoko**") and Ngāti Raukawa ki te Tonga ("**Ngāti Raukawa**")), Manawatū-Whanganui Regional Council ("**Horizons**"), Horowhenua District Council ("**HDC**"), Kāpiti Coast District Council ("**KCDC**") and Greater Wellington Regional Council ("**GWRC**"). Discussions with Horizons and their expert reviewer (both of whom are also acting on behalf of GWRC) suggested agreement in principle that this approach is reasonable when assessing the actual and potential effects of the Ō2NL Project.

10. An indicative Ō2NL Project concept design has been applied in the model to evaluate a with-scheme situation and potential effects. The hydraulic modelling indicates that the Ō2NL Project will have less than minor effects on hydrology and flooding, as discussed below.

    (a) The potential effects of the Ō2NL Project were assessed from the difference in water surface elevation between the with-scheme model and the baseline model. Any changes in flood level (for 1:100 AEP with climate change RCP 6.0 to 2130) that are greater than 0.05m were identified and the potential effect of this increase in water level assessed against potentially impacted receptors. This detection threshold is informed by the topographic, morphological, and land-use context of the Ō2NL Project, as well as the hydraulic model computational accuracy. This does not imply that an impact above 0.05m will be unacceptable to a particular receptor but is used for maps and discussion of potential effects. The Flood Protection Department of GWRC use an informal guideline of 0.1m for rural areas and 0.05m for urban areas,[1] when assessing significance of flood effects, and as such I consider it an appropriate threshold for testing the Ō2NL Project.

11. My assessment also considered flood events of different magnitudes and frequencies, and changes in velocity as an indicator for increased scour potential.

Assessment of effects

12. **Upstream** changes in peak water levels greater than 0.05m relative to baseline (for 1:100 AEP with climate change RCP 6.0 to 2130) have been mapped and evaluated, with the following findings:

    (a) Increases in flood levels upstream of bridges and culverts are generally contained within the proposed designation boundaries. Modelled increases dissipate to less than 0.1m within 50m upstream of the proposed designation boundaries (70m in the case of the Ohau River) and are commensurate with the landscape and land-use context and the extreme nature of the design event. The short durations of increased water levels are considered unlikely to have a material effect on sediment deposition or crop recovery.

    (b) No buildings outside the proposed designations are impacted by the modelled increase in flood levels for the 1:100 AEP with climate change RCP 6.0 to 2130.

    (c) In more frequent flood events such as the 1:10 AEP current climate, the peak flood level changes are contained within the proposed designations, except for backwater effects on the Ohau River that dissipate to less than 0.1m within approximately 50m of the proposed designation.

    (d) Therefore, given the rural context, the extreme nature of the design event (1:100 AEP with climate change RCP 6.0 to 2130), and the short duration and small footprint of impacts, I consider these effects less than minor.

[1] Conversation with James Flanagan, Senior Engineer, Flood Protection, GWRC.

13. **Within the proposed designations,** the design philosophy for bridges and culverts allows for effective passage of water and sediment underneath the Ō2NL Project.

    (a) Localised increases in velocity within the proposed designations are small and will be managed with scour protection.

    (b) Flows redistribute laterally to confirm to their original floodplain pattern within a very short distance downstream of the structures, and generally within the proposed designations.

    (c) Fish passage is provided, except for some culverts on ephemeral flow paths where no fish are present, and no viable habitat exists upstream.

    (d) Stormwater from the highway will be managed within the proposed designations, including treatment and attenuation of any discharge. Scour protection will be provided where necessary, and any effects on hydrology and flooding will be less than minor.

14. **Downstream** of the bridges and culverts:

    (a) Flows redistribute laterally to confirm to their original floodplain pattern (<0.05m relative to baseline) within the proposed designations or approximately 100m downstream (115m in the case of the Ohau River for the 1:100 AEP design event with climate change).

    (b) In the 1:10 AEP event, the only locations to show modelled increased levels downstream of the proposed designations are the Ohau River, Waikawa Stream tributary and Manakau Stream. These are all because of small changes in lateral distribution that totally redistribute upon returning to the main channel a short distance downstream.

    (c) There are no cumulative effects passed further downstream, and no existing buildings with discernible increases in flood risk.

Conclusion

15. Based on my detailed assessment, my professional opinion is any adverse effects of the Ō2NL Project on hydrology and flooding in the area will be less than minor.

16. Increase in heavy rainfall anticipated from climate change is predicted to exacerbate flooding along existing SH1. The proposed Ō2NL Project will

lower risk exposure and provide greater regional resilience benefits to emergency responders, operators, and users of the road network, compared to the existing SH1.

INTRODUCTION

17. My full name is Andrew Robert Craig. I am currently employed at Stantec as Practice Leader for Flood Risk Management.

18. For the Ō2NL Project I have led the following elements:

    (a) Baseline hydrology and hydraulic model.

    (b) Hydraulic design of bridges and culverts for passing existing watercourses underneath the Ō2NL Project.

    (c) With-scheme hydraulic modelling.

    (d) This assessment of effects on hydrology and flooding.

19. To fulfil these requirements, I have worked closely with a team of hydrologists, hydraulic modellers, and stormwater design engineers. I have been part of the group of 'design team leads' on the Ō2NL Project which has enabled my close collaboration with other discipline leads, in addition to working with other relevant assessment of environmental effects ("**AEE**") assessors.

20. Dr Jack McConchie of SLR, who is the author of Technical Assessment G – Hydrogeology and Groundwater, has provided feedback, including ultimately via a formal peer review memorandum. Dr McConchie's peer review is provided as Appendix F.3 to this assessment.

Qualifications and experience

21. I have the following qualifications and experience relevant to this assessment:

    (a) I hold a Bachelor of Science in Engineering (Civil Engineering) from the University of Cape Town, South Africa, 1994.

    (b) I am a Member of the Chartered Institution of Water and Environmental Management (MCIWEM) and a Chartered Water and Environmental Manager (C.WEM).

(c) Since obtaining my engineering degree, I have gained 28 years of relevant experience in hydrology and hydraulic modelling in South Africa, the United Kingdom and New Zealand. My work has covered: flooding from major rivers, estuaries, urban stormwater and coastal environments, in addition to conceptual design of flood alleviation works and climate change adaptation strategies.

22. I have had in-depth involvement in the development of the Ō2NL Project since January 2020. This has provided me with detailed knowledge of the available datasets (including their limitations), the physical environmental processes and their mathematical representation in hydrological and hydraulic models. It has also enabled me to contribute to Project design to avoid, remedy and mitigate adverse environmental effects.

23. During 2021 I led a separate study for Horizons to prepare a baseline hydrological and hydraulic model for the Ohau – Manakau drainage area using TUFLOW,[2] which provided a valuable check on the baseline modelling for the Ō2NL Project in the overlapping areas.

24. In addition to the above, in New Zealand, I have recently:

(a) Helped develop the Milford Opportunities Project Masterplan for Milford Sound Piopiotahi and the Journey (2021) by leading the Hazards and Visitor Risk workstream.[3]

(b) Led hydrological and hydraulic modelling for many sites along the Porangahau and Wimbledon roads in Hawkes Bay (2019-2021). This was directed at High Productivity Motor Vehicle structural strengthening and resilience improvements.[4]

25. In the United Kingdom I led the Flood Risk Assessment for Sizewell C Nuclear New Build project (estimated CAPEX >GBP18Bn), from 2017-2019. As project manager and technical director, I supervised modelling of extreme pluvial, fluvial and coastal flooding sources to inform embedded design, assessment of effects, mitigations, climate change adaptations, exceedance design and flood incident management for Development Consent and to support the Safety Case. As a Nationally Significant Infrastructure Project,

[2] TUFLOW is a suite of advanced 1D/2D/3D computer simulation software for flooding, urban drainage, coastal hydraulics, sediment transport, particle tracking and water quality.
[3] This strengthened my knowledge of New Zealand natural hazards including the role of earthquakes and floods on mobilising rock and debris injections into river channels.
[4] I have also advised and reviewed modelling in Napier, Hastings and Waipawa that has helped to improve my knowledge of New Zealand North Island catchment hydrological conditions.

the Development Consent application process had many similarities with the New Zealand Resource Management Act 1991 (RMA) consents and Notice of Requirements for the Ō2NL Project.

26. From 2002-2016, I gained extensive experience in model build, calibration, optioneering and flood forecasting in the UK, across a wide range of catchment types and gauging station flow rating calibrations for various types of gauging stations in small urban catchments and large rivers.

27. My early experience in South Africa (1994-2001) included water resources studies and river modelling, including modelling 1,400km of the Orange River.

Code of conduct

28. I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2014. This assessment has been prepared in compliance with that Code, as if it were evidence being given in Environment Court proceedings. Unless I state otherwise this assessment is within my area of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

Purpose and scope of assessment

29. Waka Kotahi is giving NoRs for designations to HDC and KCDC and is applying for the necessary resource consents from Horizons and GWRC for the Ō2NL Project. The Ō2NL Project is part of the New Zealand Upgrade Programme ("**NZUP**") and has the purpose to "*improve safety and access, support economic growth, provide greater route resilience, and better access to walking and cycling facilities*".

30. The new State Highway route was selected following a staged multi-criteria analysis ("**MCA**") of route, interchange and local road options. The process involved a consideration of the investment and project objectives and environmental impacts amongst other factors.

31. This report is one of a suite of technical reports prepared for the Ō2NL Project and assesses the actual and potential environmental effects of the Ō2NL Project on hydrology and flooding. It has been prepared to inform the AEE and to support the NoRs and application for resource consents required for the Ō2NL Project.

32. The purpose and scope of this report are to:

    (a) Provide information relating to the existing environment.

    (b) Establish the baseline scenario against which the actual and potential effects of the Ō2NL Project can be assessed.

    (c) Provide an assessment of the effects of the construction and operation of the Ō2NL Project on hydrology and flooding.

    (d) Consider the effects of structures on the hydraulic performance of water courses, and any scouring (by comparison with the existing baseline).

    (e) Identify measures to avoid, remedy or mitigate any adverse effects of the Ō2NL Project on hydrology and flooding.

33. In carrying out my assessment I have taken into consideration planned growth, for example at Tara-Ika (HDC Plan Change 4).

Assumptions and exclusions in this assessment

34. Flood probabilities are described in terms of AEP, which is the probability of the event being equalled or exceeded in any year. Because of the inclusion of low probability events (below 1% AEP), the ratio nomenclature of 1:1500 AEP is used, which is easier for many readers to interpret than 0.067% AEP. For clarity, the equivalent expressions for AEP are provided below:

Table F.1: Annual Exceedance Probability alternative expressions

Annual Exceedance Probability		
Expressed as ratio	Expressed as decimal	Expressed as %
1:10	0.1	10%
1:100	0.01	1%
1:1500	0.00067	0.067%

35. The hydrological and hydraulic modelling referenced in this assessment considers design floods from a 1:10 AEP event under the current climate to a 1:1500 AEP event including potential climate change.

36. The effects of the Ō2NL Project on smaller and more frequent events than 1:10 AEP will be much less than the above events and, therefore, are not specifically evaluated in this assessment. Further discussion on low flow hydrological behaviour is provided in Technical Assessments G and H (Hydrogeology and Groundwater, and Water Quality respectively).

37. This assessment is aimed at water quantity only. For discussion on water quality refer to Technical Assessment H (Water Quality).

38. The hydrological and hydraulic modelling considers 1-hour and 4-hour rainfall storm durations, as these result in maximum flows and water levels when assessing the effects of the Project. The basis for these calculated storm durations is presented in Appendix F.1.

39. Reference to the performance of the Ō2NL Project stormwater devices in the 1-hour or 4-hour storm is provided for assessment of potential effects on surrounding receptors. Further information on the design and operational performance of the stormwater devices in a variety of storms is provided in the Stormwater Management Design Report as Appendix 4.2 to the Design and Construction Report ("**DCR**") in Volume II.

40. For the purposes of the modelling and assessing the actual and potential effects of the Ō2NL Project, it has been assumed that upstream hydrological response to any design rainfall event will remain similar to historic behaviour. Future anthropological change, such as planned growth at Tara-Ika (not yet consented), or other land-use changes and water abstractions are assumed to cause less than minor change to the flood hydrology regime. This is considered a reasonable assumption because future projects/plans submitted for approval under the RMA will seek to avoid or minimise potential adverse effects such as increased runoff.

Ō2NL PROJECT DESCRIPTION

41. The Ō2NL Project involves the construction, operation, use, maintenance and improvement of approximately 24 kilometres of new four-lane median divided state highway (two lanes in each direction) and a SUP between Taylors Road, Ōtaki (and the PP2Ō expressway) and SH1 north of Levin. The Ō2NL Project includes the following key features:

    (a) a grade separated diamond interchange at Tararua Road, providing access into Levin;

    (b) two dual lane roundabouts located where Ō2NL crosses SH57 and where it connects with the current SH1 at Heatherlea East Road, north of Levin;

(c) four lane bridges over the Waiauti, Waikawa and Kuku Streams, the Ohau River and the North Island Main Trunk ("NIMT") rail line north of Levin;

(d) a half interchange with southbound ramps near Taylors Road and the new Peka Peka to Ōtaki expressway to provide access from the current SH1 for traffic heading south from Manakau or heading north from Wellington, as well as providing an alternate access to Ōtaki.

(e) local road underpasses at South Manakau Road and Sorenson Road to retain local connections;

(f) local road overpasses to provide continued local road connectivity at Honi Taipua Road, North Manakau Road, Kuku East Road, Muhunoa East Road, Tararua Road (as part of the interchange), and Queen Street East;

(g) new local roads at Kuku East Road and Manakau Heights Road to provide access to properties located to the east of the Ō2NL Project;

(h) local road reconnections connecting:

    (i) McLeavey Road to Arapaepae South Road on the west side of the Ō2NL Project;

    (ii) Arapaepae South Road, Kimberley Road and Tararua Road on the east side of the Ō2NL Project;

    (iii) Waihou Road to McDonald Road to Arapaepae Road/SH57;

    (iv) Koputaroa Road to Heatherlea East Road and providing access to the new northern roundabout;

(i) the relocation of, and improvement of, the Tararua Road and current SH1 intersection, including the introduction of traffic signals and a crossing of the NIMT;

(j) road lighting at conflict points, that is, where traffic can enter or exit the highway;

(k) median and edge barriers that are typically wire rope safety barriers with alternative barrier types used in some locations, such as bridges that require rigid barriers or for the reduction of road traffic noise;

(l) stormwater treatment wetlands and ponds, stormwater swales, drains and sediment traps;

(m) culverts to reconnect streams crossed by the Ō2NL Project and stream diversions to recreate and reconnect streams;

(n) a separated (typically) three metre wide SUP, for walking and cycling along the entire length of the new highway (but deviating away from being alongside the Ō2NL Project around Pukehou (near Ōtaki)) that will link into shared path facilities that are part of the PP2Ō expressway (and further afield to the Mackays to Peka Peka expressway SUP);

(o) spoil sites at various locations along the length of the Project; and

(p) five sites for the supply of bulk fill /earth material located near Waikawa Stream, the Ohau River and south of Heatherlea East Road.

42. The Ō2NL Project bridge over South Manakau Road includes span allowance for Manakau Stream. The Ō2NL Project includes an additional flood relief bridge on the northern floodplain of the Ohau River. This brings the total number of hydraulic (waterway) bridges to six.

43. Further details of the Ō2NL Project are contained in the DCR (Appendix 4 of Volume II) and in Volume III - Drawings.

METHODOLOGY

Introduction

44. To enable assessment of potential effects of the Ō2NL Project on hydrology and flooding, a baseline hydrological and hydraulic model was prepared. The baseline model was then modified to include an indicative Ō2NL Project 'concept design' to assess actual and potential effects.

45. The complete baseline flood modelling report is included as Appendix F.1. Pertinent details are referenced below.

46. The modelling baseline report was provided to Iwi Project Partners (Muaūpoko Tribal Authority and Ngāti Raukawa ki te Tonga), and key stakeholders: Horizons, HDC, KCDC and GWRC. Discussions with Horizons and their expert reviewer (both of whom are also acting on behalf of GWRC) suggested agreement in principle that the approach is reasonable when assessing the actual and potential effects of the Ō2NL Project.

47. The with-scheme modelling report is included as Appendix F.2. Pertinent details of the with-scheme model are referenced through this assessment.

Scenarios modelled

48. The proposed Ō2NL highway Importance Level ("**IL**") classification (under the Waka Kotahi One Network Road Classification) has been selected as "IL3+ National (High Volume)".

49. Scenarios were selected for modelling based on Waka Kotahi NZ Transport Agency Bridge Manual (SP/M/022, Third edition, Amendment 3, effective October 2018) ("**Bridge Manual**").

50. In accordance with the Bridge Manual, the asset design life (planning horizon) will be 100 years, from 2030 (estimated start of operation) to 2130. The design life is particularly relevant when considering the potential effects of predicted climate change.

51. The Bridge Manual sets the IL3+ main traffic Serviceability Limit State (SLS2) design scenario for flooding at 1:100 AEP with climate change, i.e., that the highway should remain open to traffic in this event.

52. The Bridge Manual is not prescriptive on details of climate change allowances (eg epoch or emissions scenario). The climate change scenario selected for SLS2 is RCP 6.0, extrapolated to 2130. This is a moderately conservative (medium-high) climate change projection and is considered appropriate for the Ō2NL Project. Given the long asset design life and high cost to upgrade culverts or bridges during their operational life, it would be impractical to follow a lower climate change scenario, as that could result in upgrades to these waterway crossings being required at a later stage.

53. The RCP 6.0 scenario was adopted, and accepted, in the recent Te Ahu a Turanga; Manawatū Tararua Highway Project (2020). The PP2Ō resource consent application in 2013 pre-dated the IPCC 5th assessment RCP scenarios but used a mid-range temperature change scenario of 2.1°C by 2090 (based on MfE, 2010) which is similar to, yet marginally higher than, RCP 6.0.

54. Use of the 1:100 AEP design event, including the potential effects of climate change, is common practice within the industry and within RMA and planning contexts. All model results in this assessment are for the SLS2 case, namely 1:100 AEP RCP 6.0 to 2130, unless stated otherwise.

55. The Horizons One Plan (Policy 9-3) references a 0.5% (1:200) AEP event under current climate in relation to siting of critical infrastructure. The 1:100 AEP RCP 6.0 to 2130 is significantly larger than the 1:200 AEP current climate, and therefore conclusions in this assessment using the larger event will also apply to the smaller 1:200 current climate event.

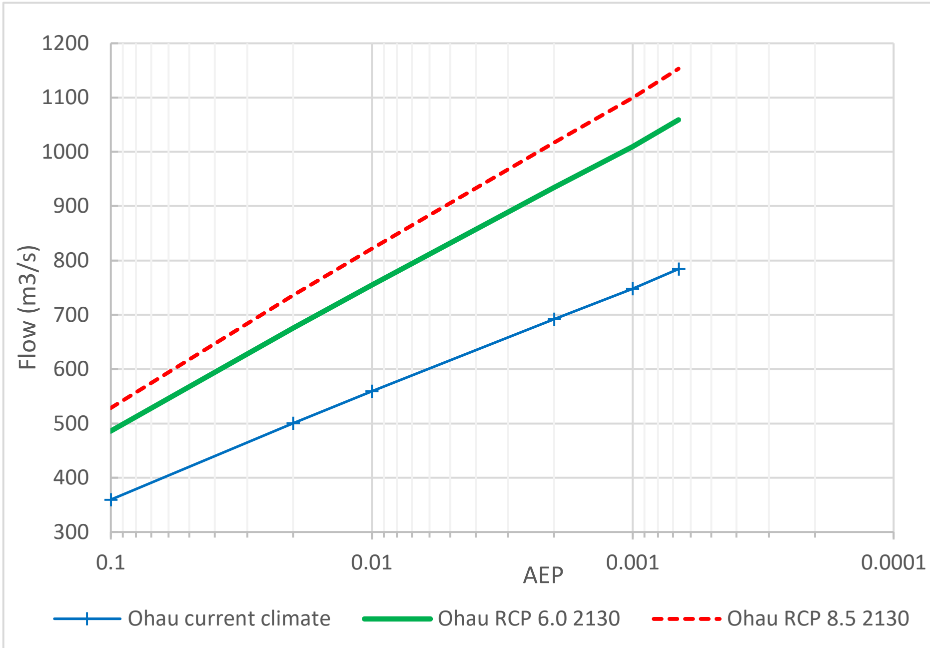


Figure F.1: Effect of climate change scenarios on flood peaks (Ohau at Rongamatane)

56. The Bridge Manual sets the Ultimate Limit State ("**ULS**") for avoidance of structural collapse on IL3+ routes at 1:1500 AEP with allowance for climate change. To understand potential structural risk if a high climate does eventuate, a more conservative climate change of RCP 8.5 extrapolated to 2130 is applied to the ULS scenario. It is best practice for major national infrastructure to identify possible high impacts of climate change. This is also consistent with Waka Kotahi Interim Specification on Climate Change for NZUP and fast-track transport projects. The Specification advises testing at least two RCP scenarios, one of which should be RCP 8.5. The results from this scenario were inspected separately to ensure that there is not a 'step change' in hydraulic performance or risk to structures. The detailed design will consider this event in more detail, and it is not discussed in this assessment of effects.

57. The derivation of climate change allowances is discussed later with reference to the baseline hydrological modelling.

58. In summary, the three modelled scenarios are presented in **Table F.2** below:

Table F.2: Modelled Scenarios

Annual Exceedance Probability		Climate Scenario	Description
1:10	10%	Current climate	Easier to relate to floods in recent history, and for construction phase
1:100	1%	RCP 6.0 2130	SLS 2, operationally functional (at least one lane open in each direction)
1:1500	0.067%	RCP 8.5 2130	ULS, resilience case (damage limitation, avoid collapse, quick recovery)

59. The same hydrological scenarios are used for both the baseline and 'with-scheme' modelling when assessing the effects of the Ō2NL Project.

Baseline hydrological modelling: Catchments

60. In line with current industry best practice, the adopted modelling schematisation is a 2D direct rainfall approach over the smaller catchments near the proposed designations and extending approximately 2km downstream. Larger catchments were represented with lumped hydrological model 'point' inflows applied at an appropriate location to the hydraulic model domain. This hybrid approach allowed baseline flooding at all locations near the proposed designations to be established, independently of design changes.

61. Existing streams and overland flow paths were assigned unique Ō2NL Project flow path identifiers ("**IDs**"). This is useful because many smaller ephemeral watercourses and overland flow paths do not have unique names. The original IDs were assigned from south to north, but in this assessment the discussion moves from north to south (i.e., from ID 42.3 down to ID 0). The flow path IDs and catchment areas are shown in Volume III - Drawings (in the drainage and catchment plan drawings set).

62. Catchment areas have been defined for the large streams upstream of the hydraulic model domain, which vary from 120km^2 (Ohau River at Muhunoa East Road) down to around 2km^2 (refer to **Figure F.6** and **Figure F.7**). These catchments have been used to calculate hydrological point inflows to the hydraulic model. Smaller catchment areas, starting closer to the Ō2NL Project, have also been defined as part of cross-checking the flows arriving at possible culvert locations.

Baseline hydrological modelling: Flow gauges

63. Locations of flow gauging stations are shown in **Figure F.7**. The flow data is shown in Figure F.2. In addition, data was obtained from the GWRC Waitohu gauge at 'Water Supply Intake', available since 1994. The Waitohu Stream is outside the Ō2NL modelled domain; hence it is only used for checking data within the modelled domain.

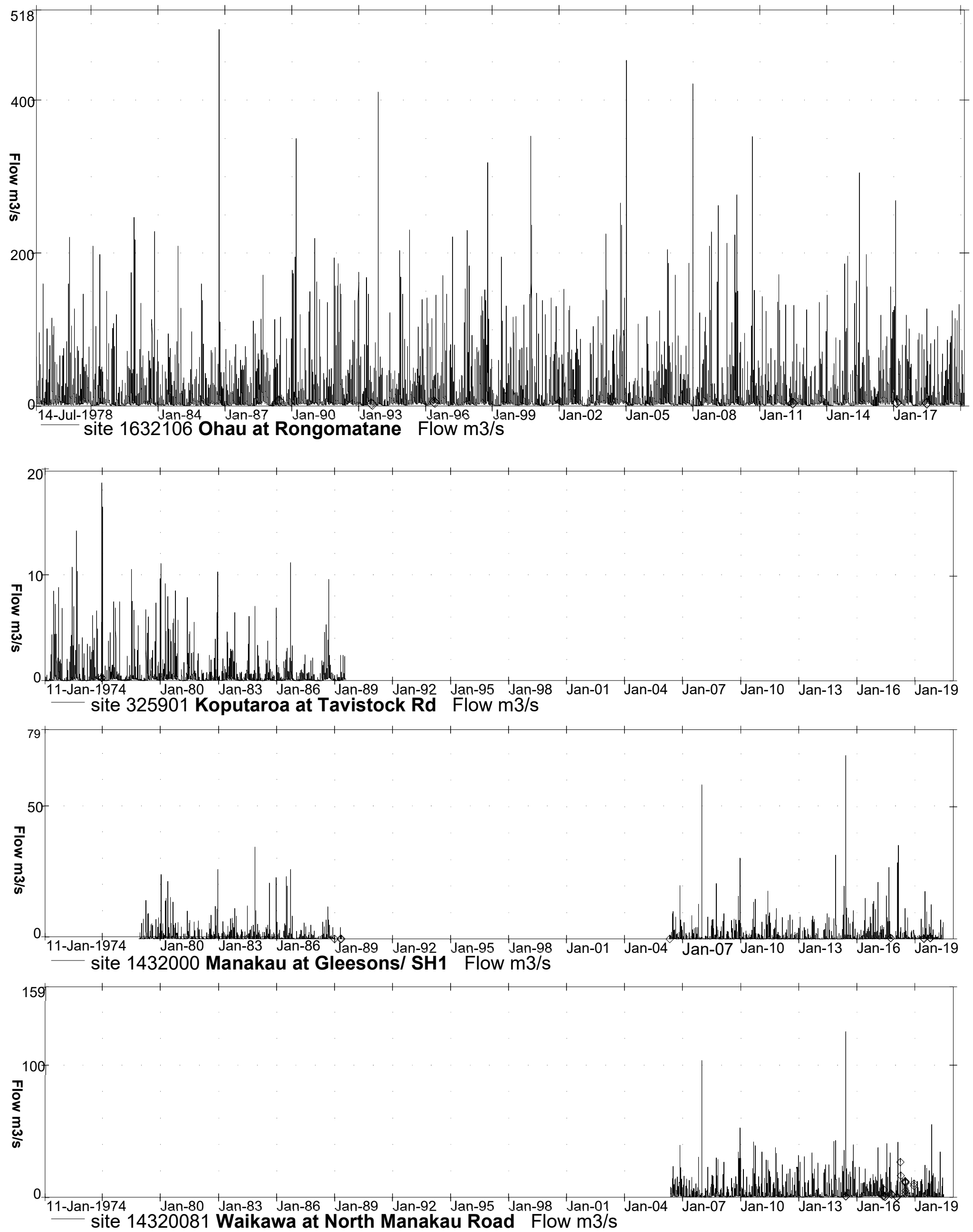


Figure F.2: Overview of flow data

64. The gauging station for the Ohau at Rongomatane provided 43 years of flow data (1978 to 2020) for analysis. There were very few gaps or periods of missing data, and the annual flood maxima (the largest peak flow each year) can be used with confidence for flood frequency analysis.

65. Flood frequency analysis of the annual flood maxima provides an estimate of the 1:100 AEP instantaneous flood peak of approximately 560m^3/s (assuming a Pearson 3 statistical distribution, i.e. the green curve on **Figure F.3**). The upward trending blue GEV curve is considered unrealistic for low frequency high magnitude events. The various statistical distributions and curve fitting are discussed further in Appendix F.1.

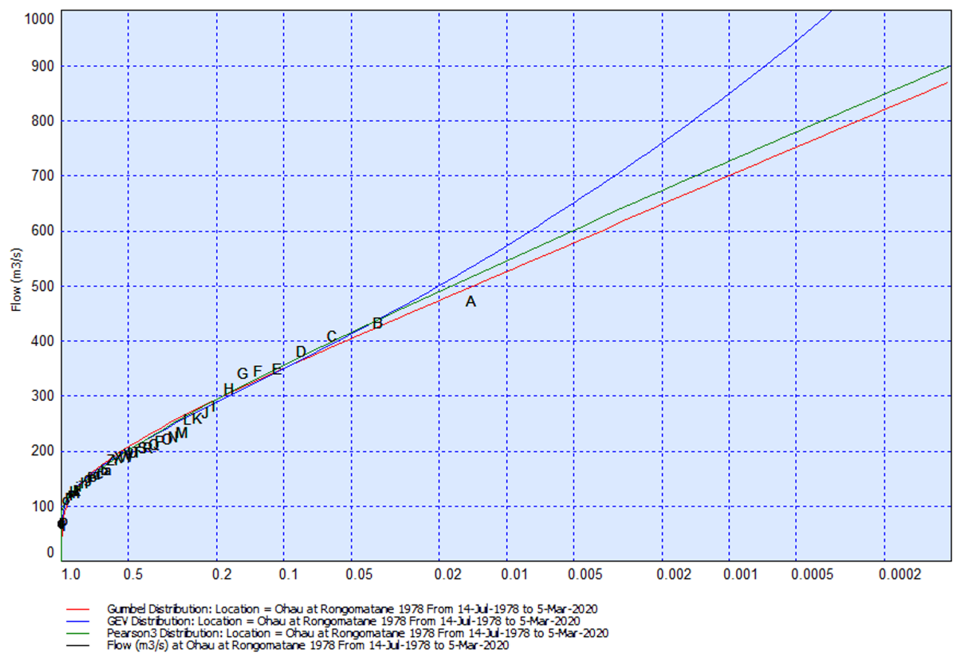


Figure F.3: Ohau at Rongomatane flood frequency analysis. The 1:100 AEP flood probability is indicated by the vertical dash line.

66. The annual flood maxima were plotted against the month in which they occurred (**Figure F.4**). Events greater than the median annual flood (around 200m^3/s) are less common in autumn and winter, but more common in spring and summer. There is a slight trend to higher monthly rainfall in winter and spring compared to summer and autumn. However, the higher monthly rainfall in winter is associated with more rain-days and longer duration events. These rainfalls are not those that generate large floods because lower temperatures and humidity in winter generally produce lower peak rainfall intensities.

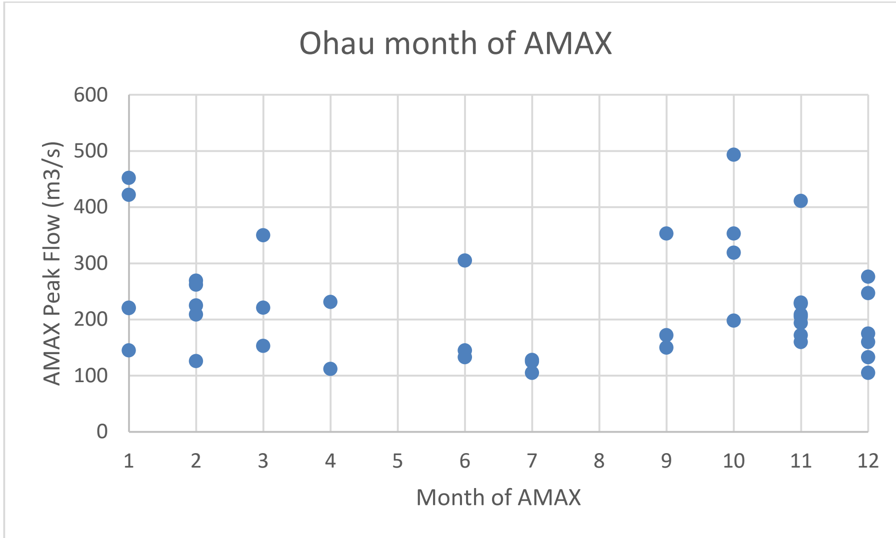


Figure F.4: Ohau at Rongomatane month of annual maxima ("AMAX")

67. Flood frequency analysis was also performed on the shorter flow records from the Koputaroa (Tavistock Road), Waikawa (North Manakau Road) and Manakau (SH1) gauges, plus the nearby Waitohu (Water Supply Intake). These analyses are presented in Appendix F.1. Because of the shorter record lengths, and therefore lower confidence in the flood frequency analyses, the results for these sites were compared to:

   (a) the flood frequencies at other sites;

   (b) design flood estimates from the rational and regional flood frequency methods; and

   (c) the results from the rainfall-runoff models (discussed below).

68. The detailed comparison and selection of final methods is presented in Appendix F.1.

Baseline hydrological modelling: Rainfall-runoff models

69. The flood frequency analyses described in the previous section only provide the peak flows for each design event. Therefore, rainfall runoff models are commonly used to derive hydrographs from various design rainfall events. These can also be used as an alternative method to derive design flows for comparison against the statistical analysis. Rainfall runoff models are used to derive hydrographs for ungauged catchments.

70. The following rainfall runoff models were developed using Hydrologic Engineering Centre's Hydrologic Modelling System ("**HEC-HMS**"):

(a) Koputaroa Stream to Tavistock Road, incorporating sub-catchment North_1 for input to the hydraulic model.

(b) Kuku Stream, an ungauged catchment, using parameters from gauged catchments, for input to the hydraulic model.

(c) Waikawa Stream to North Manakau Road gauge for input to the hydraulic model.

(d) Manakau Stream to SH1, which incorporates two nodes used as separate inputs to the hydraulic model, namely Manakau Stream and Waiauti Stream.

71. The Ohau River did not require a rainfall runoff model since robust design peak discharge values were obtained from flood frequency analysis. The approach used to derive the Ohau hydrograph is outlined below.

72. The rainfall-runoff models were calibrated to available gauge data for several flood events, as presented in Appendix F.1.

73. The calibrated models were initially run using HIRDS v4 design rainfall for various storm durations to establish the critical storm duration. This is the storm duration that produces the highest peak flow for a given design rainfall probability.

74. The critical rainfall duration was found to be 4-hours for all the HEC-HMS models, apart from the Waiauti Stream where a 3-hour storm was the critical duration.

75. For the Waikawa tributary (ID 27.1), a 4-hour storm duration was applied to match that of the Waikawa Stream. This ensures that the interaction of their flows on the floodplain in the vicinity of the Ō2NL Project is well represented. It also ensures that the correct total design flow propagates downstream of the confluence.

76. Historic flood hydrographs were analysed from the Ohau and Waikawa flow records. Both were found to have a similar rapid response to short duration rainfall. A comparison of the timing of the Waikawa and Ohau is shown below for the December 2009 event (**Figure F.5**). The hydrograph shape for the Ohau catchment was therefore based on the hydrograph shape from the Waikawa HEC-HMS model (4-hour rainfall storm) and scaled to the Ohau peak design flow derived from flood frequency analysis.

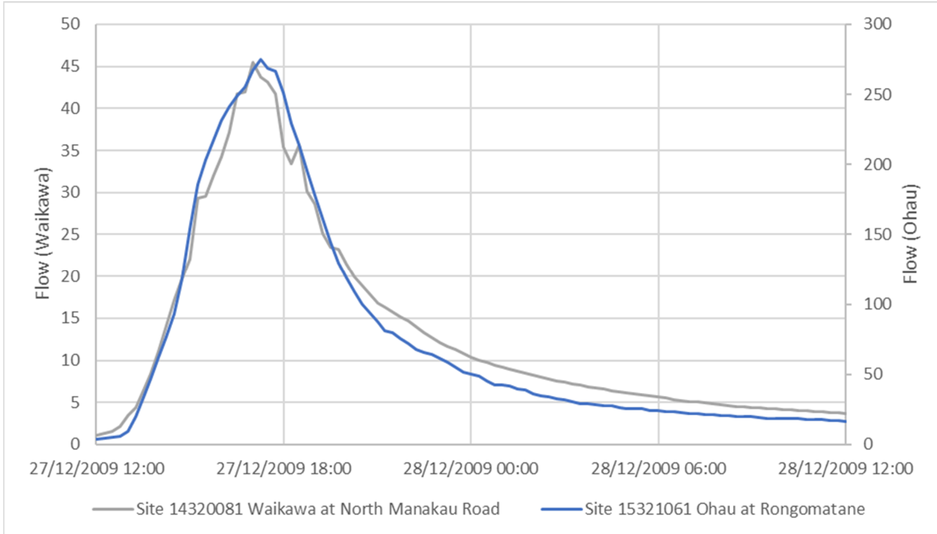


Figure F.5: Hydrograph timing comparison, December 2009

77. Comparison of the HEC-HMS flows based on HIRDS v4 design rainfall showed significant variability in catchment specific yields (peak divided by area $^{0.9}$).[5] Depth-duration-frequency analysis of rainfall data in the area showed significant variability between nearby gauges at similar elevations, and between rain gauge data frequencies compared to those of HIRDS. It was concluded that in some sub-catchments, the HIRDS v4 rainfall grid was too coarse to capture the steep rainfall gradients caused by the topography. The HEC-HMS flows based on HIRDS v4 design rainfall were therefore adjusted to improve the fit with flow gauge flood frequency analyses (which are the most relevant in-situ datasets of flood frequency in the streams). The adjusted flows provided more consistent specific yields than those based solely on HIRDS v4 rainfall.

Baseline hydrological modelling: Summary of adopted peak inflows

78. The peaks of the design event inflows to the hydraulic model are provided in **Table F.3**, along with the catchment specific yields.

[5] Regional Flood Estimation Tool for New Zealand, Part 2 (NIWA, 2018) regression analysis identified 0.9 as the preferred power parameter for North Island.

Table F.3: Modelled scenario peak values

Inflow	Catch Area km^2	Critical Duration	1:10 AEP current climate	1:100 AEP RCP 6.0 2130	1:1500 AEP RCP 8.5 2130
			Peak flows (m^3/s)		
Waiauti 14	7.2	3h	21	54	90
Manakau 15	7.1	4h	24	57	92
Waikawa 27	29	4h	91	191	302
Waikawa trib 27.1	1.8	4h	5	11	17
Kuku 32	7.5	4h	18	43	71
Makorokio 33e	11.5	4h	35	74	113
Ohau 33	120	4h	411	861	1315
North_1	7.5	4h	13	32	54
	Method summary		Specific yields (peak/area^0.9)		
Waiauti 14	HMS(HIRDS)*1.4		3.6	9.2	15.2
Manakau 15	HMS(HIRDS)*1.4		4.2	9.7	15.8
Waikawa 27	HMS(HIRDS)*0.8		4.3	9.1	14.4
Waikawa trib 27.1	Above scaled to cumulative catch increase		2.9	6.2	9.8
Kuku 32	HMS(HIRDS)*1.2		2.9	7.1	11.6
Makorokio 33e	Ohau FFA scaled to cumulative catch increase		3.9	8.2	12.5
Ohau 33	Ohau FFA scaled to cumulative catch		5.5	11.5	17.6
North_1	HMS(HIRDS)		2.1	5.3	8.8

79. Direct rainfall is applied to the 2D hydraulic model surface downstream of the point inflows. The extent of the 2D domain is shown in **Figure F.6** and **Figure F.7**. The 2D design rainfall is based on a representative sample from HIRDS v4 design rainfall. This showed a good correlation with observed rain gauge statistics and no further adjustment to the HIRDS v4 rainfall depths was required for this component.

80. Regarding the timing of the design rainfall applied to the 2D hydraulic model:

(a) A 4-hour rainfall event is applied as part of one 'scenario', ie the same 4-hour rainfall storm that generated the hydrological point inflows for the large upstream catchments. This scenario produces the highest flows and water levels near and downstream of the majority of the proposed designations.

(b) In the southern part of the model (south of the Ohau River), some small steep catchments yield slightly higher flows from a 1-hour design storm than the 4-hour event. For this scenario, the 1-hour rainfall is lagged by 1.5-hours so that the peak rainfall coincides with the peak of the 4-hour rainfall used to generate the larger upstream hydrological inflows. This hybrid storm approach with coincident critical spatial intensities is more accurate and representative of local rainfall events and flood probabilities than a nested temporal storm profile applied to the whole system.

(c) For presentation of maps and assessment of potential effects, the maximum water level from the 4-hour and 1-hour storms is used.

(d) The temporal profile used to disaggregate design rainfall depths is based on the HIRDS v4 method using the Western North Island curves, as presented in Appendix F.1.

Baseline hydraulic modelling

81. A baseline hydraulic model was built using Hydrologic Engineering Centre's River Analysis System ("**HEC-RAS**") 2D hydraulic model, to represent the hydraulic behaviour of the streams and overland flow paths in the areas upstream and downstream of the Ō2NL Project.

82. The selection of software and level of detail applied are commensurate with industry best practice for assessing effects of a project of this scale and nature.

83. The baseline flood modelling report is included as Appendix F.1. This report was provided to our Iwi Project Partners (Muaūpoko Tribal Authority and Ngāti Raukawa ki te Tonga), Horizons, HDC, KCDC and GWRC. Discussions with Horizons and their expert reviewer (both of whom are also acting on behalf of GWRC) suggested agreement in principle that this approach is reasonable when assessing the actual and potential effects of the Ō2NL Project.

Model Forecast: Approach to with-scheme hydraulic model

84. The potential effects of the Ō2NL Project were assessed by including into the hydraulic model a 'concept design' of the Ō2NL Project as reflected in Volume III - Drawings. The same hydrological scenarios as used in the

baseline model were adopted. Additional details and assumptions of the with-scheme model are provided in Appendix F.2.

85. The eventual Ō2NL Project constructed will differ from the indicative concept design used in the model. The model demonstrates that a design within the proposed designations can achieve effects that are less than minor. The detailed design will ensure that the final constructed Ō2NL Project effects on hydrology and flooding are less than minor.

86. The Ō2NL Project components added to the with-scheme model are:

(a) Earthworks (cuts and fills) for the highway, bridge abutments, new local roads and intersections. The SUP is included for most of the earthworks model, but openings are applied for anticipated SUP bridges or culverts.

(b) Bridge piers for the Ohau and Waikawa bridges. Bridge decks were not included as they remain above the water level in the 1:100 AEP design event with climate change (with at least 0.6m freeboard in line with the Bridge Manual) and also remain above the water level during the 1:1500 AEP design event, including the potential effects of climate change under a RCP8.5 scenario out to 2130.

(c) Culverts, stream realignments, and small collector channels (for capturing minor overland sheet flow above top of cuts and toes of fills, to route this water in a controlled manner to the most appropriate culvert or watercourse).

(d) Longitudinal stormwater features including swales, swale-to-swale stormwater culverts, drop structures, treatment / attenuation ponds and pond outlet structures.

87. The 'with-scheme' model results were checked to confirm that any effects of the Ō2NL Project were consistent with the anticipated hydraulic response. The effects of the Ō2NL Project were then evaluated by subtracting the 'with-scheme' water levels from the baseline scenario. This identified areas where water levels may either increase or decrease because of the Ō2NL Project. Similarly, changes in velocity were used to identify changes in scour, and thus inform the design of protection where appropriate.

88. The results show that the Ō2NL Project can be designed and constructed in a manner that any effects of the Project on hydrology and flooding are less than minor.

89. Potential material supply sites and spoil sites have been assessed qualitatively by inference from the baseline model results. The final volumes taken from these sites and their final form (following rehabilitation) will be developed as part of the detailed design phase. The modelling does not include these sites in place and so their potential benefit provided by storing floodwater is not accounted for, providing an additional layer of conservatism.

ASSESSMENT CRITERIA

National best practice criteria

90. In New Zealand, criteria for assessing the potential effects of large infrastructure projects are often based on 'context'. For example:

    (a) Te Ahu a Taranga highway hydrology assessment (2020) states, *"To recognise the uncertainty within the hydraulic model, and the fact that shallow flooding of short duration does not pose a hazard, all areas where the depth of flooding is less than 0.1m were removed. It should also be recognised that a depth of flooding of only 0.1m would not present a risk to either people or property. When comparing different scenarios, any change in depth less than ±0.1m or velocity less than ±0.5m/s was not considered significant."* and in discussion of results at Manawatū bridge, *"the 'bow-wave' upstream of Pier 2 results in a local water level increase of up to 1.4m in the design event … an increase in velocity, up to 1.5m/s, within the centre of the active channel",* while at the Mangamanaia Stream Bridge, *"the construction of the bridge will cause water levels to increase by more than 0.5m over approximately 4600m² … these changes are within the existing floodplain… flooding exceeds 0.3m in this location for only 2.2-hours"*.

    (b) As stated above, the Flood Protection Department of GWRC use an informal guideline of 0.1m for rural areas and 0.05m for urban areas,[6] when assessing significance of flood effects.

    (c) Evidence presented for the PP2Ō Expressway (2013) states *"A fundamental principle … is that of hydraulic neutrality. What this*

[6] Conversation with James Flanagan, Senior Engineer, Flood Protection, GWRC

means is that the impact of flood hazards from the Expressway should in general be no worse than in the current situation. This objective can sometimes be extremely difficult to achieve while still maintaining the required level of service for the Expressway. Where it has not been possible to achieve this desired objective, a fall-back position has been adopted whereby flood hazards that have been made worse are kept away from residential properties and instead redirected towards uninhabited rural areas." Regarding Mangapouri Stream the report states, *"[t]he inundation depths would increase from less than 0.00-0.09m in the existing situation to 0.06-0.21m in the proposed situation. We would expect the resulting flood damage costs to be similar for the six houses where the relative increases in floor level inundation are modest and slightly greater for the other houses where the relative increases in floor level inundation are more significant… In summary then, the effects of the Expressway crossing of the Mangapouri Stream and its ancillary features are minimal and acceptable."* and regarding the Ōtaki River, *"in a larger 0.2% AEP flood adjusted for possible future climate change effects to 2090 … the upstream flood levels in the basin would be about 0.3m higher than in the existing situation meaning that the depth of stopbank overtopping would be 0.3m greater in the Expressway situation over a distance of about 200m upstream of the bridge approach embankment for the Expressway. In summary, the effects of the proposed PP2O Expressway crossing of the Ōtaki River on flood levels in the Ōtaki River and within the off-channel storage basin occupied by the concrete factory will be minimal and acceptable."*

91. The hydrological effects assessment criteria should therefore consider the land-use context of the effect (ie the vulnerability or otherwise of potential receptors), the dynamic morphological context, and the potential impacts of local and downstream effects in terms of duration and spatial extent. These considerations have been used to inform the adopted criteria, which are presented in the section on assessment of effects.

Statutory considerations, including national standards, regional and district plans, and other relevant policies

92. Key planning objectives and policies relating to hydrology and flood conveyance include the National Policy Statement Freshwater Management ("**NPSFM**"), Horizons Regional Policy Statement / One Plan, Greater

Wellington Regional Policy Statement / Natural Resources Plan (Appeals Version), Kāpiti Coast District Plan and Horowhenua District Plan.

93. By way of summary, some of the planning provisions or requirements that have influenced the design and assessment seek:

(a) an integrated response to natural hazards and climate change, including to not cause or exacerbate natural hazards in other areas;

(b) avoidance of significant reduction in the ability of a river and its bed to convey flood flows, or significant impedance to the passage of floating debris;

(c) to manage freshwater in an integrated whole-of-catchment basis, including mauri, Te Mana o te Wai and fish passage;

(d) avoidance of loss of river extent and values to the extent practicable; habitats of indigenous freshwater species protected;

(e) management of erosion and sediment, both during construction and operation;

(f) to manage effects on habitats, including enhancing biodiversity, morphological diversity and protecting natural character; and

(g) that public access to rivers and wetlands be maintained and, where appropriate, enhanced.

EXISTING ENVIRONMENT

94. The topographic setting for the Ō2NL Project is shown in **Figure F.6**. The topographic and hydrological regimes are both dominated by the Tararua Range, with watercourses draining from the mountains in the east to the sea in the west. East and northeast of Levin, some catchments drain toward the Koputaroa Stream which flows north to join the Manawatū River.

95. As a result of the topography, the proposed designations traverse many streams and overland flow paths that will need to be safely passed downstream.

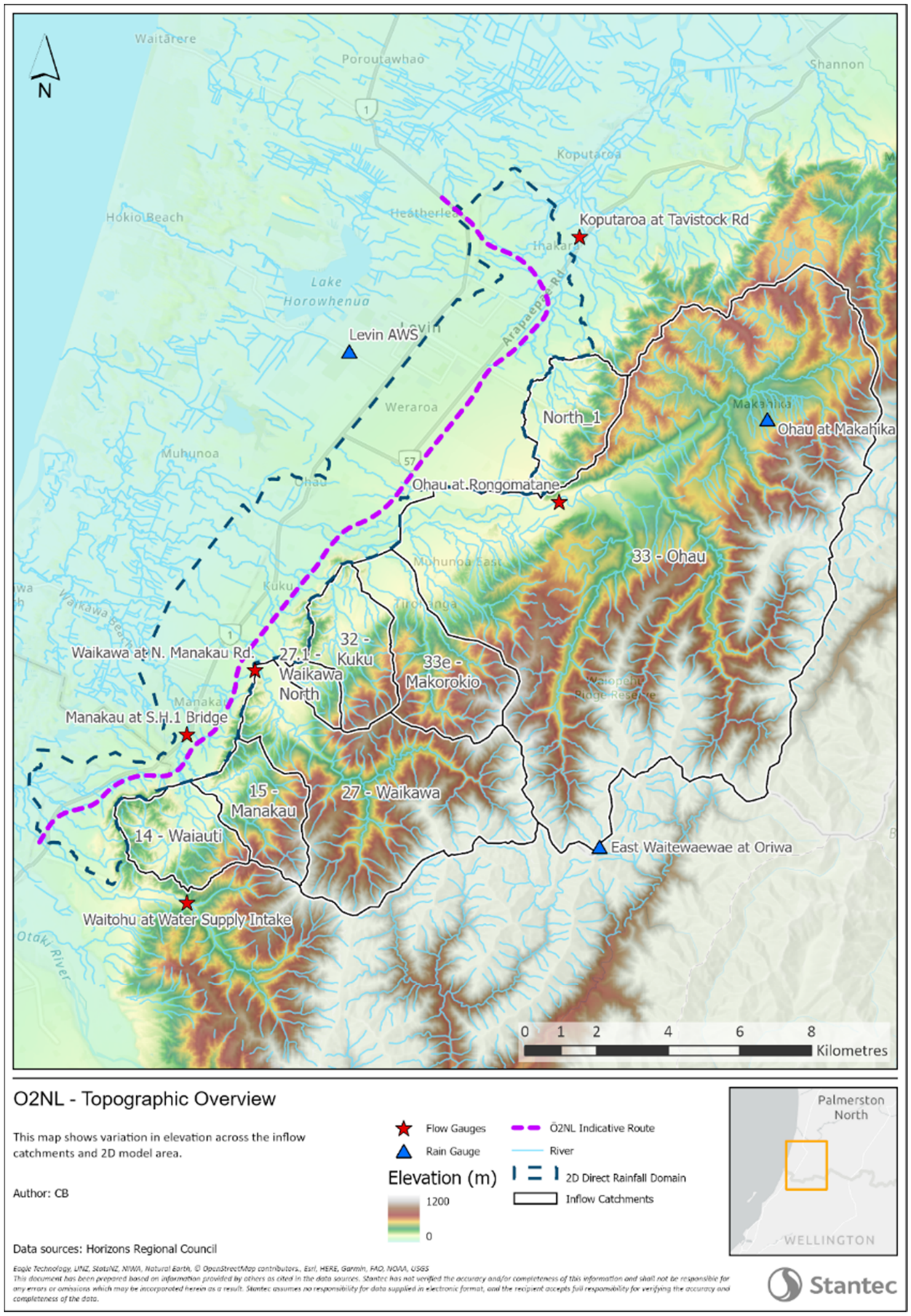


Figure F.6: Ō2NL Project topographic overview

96. The steep topography of the Tararua Range results in rapid catchment response. Streams rise very rapidly in response to intense rainfall and start to recede quickly after the rainfall stops. The critical storm durations range from 4 hours for the larger catchments down to approximately 1 hour for the small catchments near the southern extent of the Ō2NL Project.

97. These short storm durations mean that flooding in the vicinity of the proposed designations tends to persist for only a few hours. Longer duration flooding can occur downstream of the Ō2NL Project, for example on the lower Koputaroa on occasions when drainage is limited by extended high levels in the Manawatū River.

98. The larger catchments upstream of the Ō2NL Project, such as the Ohau and Waikawa, start higher up in the Tararua Range with elevations peaking over 1,000m above sea level. Because of orographic uplift (mountains forcing moist air to rise) and the prevailing westerly/north-westerly winds, these high elevations can receive up to five times the rainfall (annually or per event) of the lower plains nearer the coast.

99. The steep rainfall gradient to the east of the Ō2NL Project is illustrated graphically by the 2-hour 1:100 AEP rainfall grid from HIRDS v4 (**Figure F.7**). For each model simulation, the correct design rainfall depths and durations were applied to each sub-catchment.

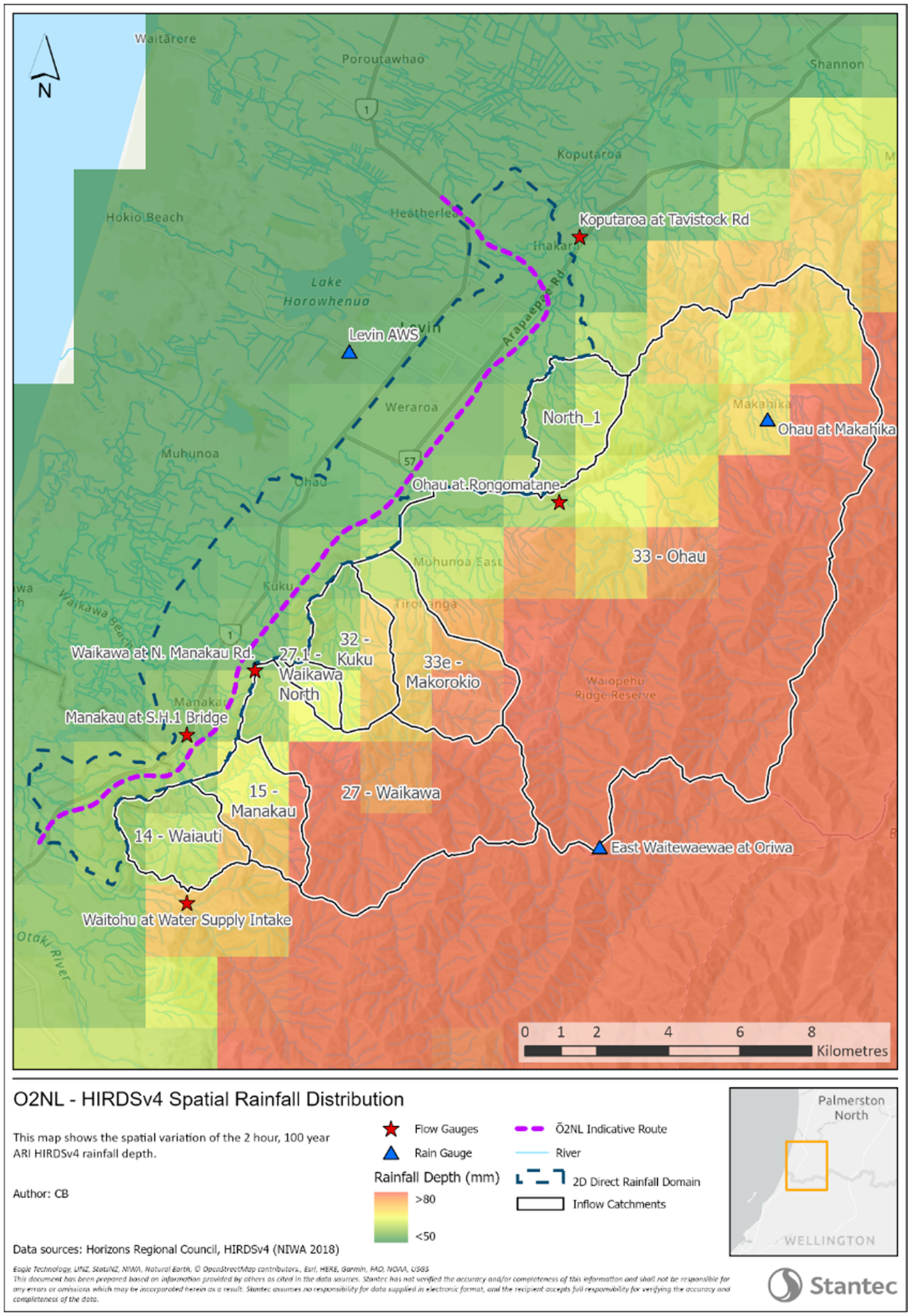


Figure F.7: Catchment rainfall spatial variation

100. Indicative catchment areas were also determined for smaller streams and overland flow paths approaching the Ō2NL Project, as shown spatially in Volume III (drawings).

101. Much of the upper catchment areas are forested. Closer to the Ō2NL Project the land-use is mostly rural pasture and agricultural, with sparse dwellings. Larger built-up areas exist a short distance downstream of the Ō2NL Project corridor, including Levin, Ohau and Manakau.

102. Most existing watercourses have a moderate hydraulic gradient in the vicinity of the proposed designations, typically varying between 0.5% and 5% (apart from a few steeper exceptions in small, incised valleys). This hydraulic gradient means that any backwater effects caused by structures do not extend far upstream.

103. In the Tararua Range the gradients are much steeper, and floods have the power to erode and move significant quantities of sediment. This process, together with underlying geology of unconsolidated erodible alluvial and marine sediments, has formed a landscape of steep incised valleys discharging onto wide alluvial fans upon exiting the hills.

104. The larger watercourses such as the Ohau River and Waikawa Stream tend to be close to equilibrium or degrading slightly in the vicinity of the Ō2NL Project. There is a trend to aggradation further downstream as gradients reduce. However, future injections of sediment from earthquakes or major storms could cause local aggradation and possibly avulsion (when a stream deviates significantly from its existing course), regardless of whether the Ō2NL Project is constructed.

105. The soils upstream of, and within the proposed designations, are predominately medium to well drained. This means that initial rainfall soaks into the ground and does do not produce much overland sheet flow. In larger events, such as those greater than the 1:10 AEP event, the ground becomes increasingly saturated, and topographic depressions fill with water, causing increased overland sheet flow.

106. On the larger streams, and particularly during larger events, the existing SH1 has been subject to historic flooding. For example, frequent flooding of SH1 has occurred at Kuku Stream bridge and the nearby marae (*Te Iwi o Ngati Tukorehe*) and the Waikawa Stream bridge (damaged in June 2015 floods, **Figure F.8**). Parts of Levin and Manakau are also susceptible to localised flooding. These sorts of events will become worse and more frequent with the predicted effects of climate change, regardless of whether the Ō2NL Project is constructed.

Figure F.8: Damage to Waikawa SH1 bridge left bank June 2015 upstream view (photo Joel Maxwell, Stuff.co.nz)

107. Maps of modelled flood extents in the vicinity of the Ō2NL Project are provided on the following pages. The largest streams have deeper maximum depths as expected. Moderate depths occur in smaller streams and some overland flow paths with long path lengths. Short streams and overland flow paths have the least wetted areas, such as those in the far northern and southern areas of the modelled domains outside of the main floodplains. More detailed information and higher resolution images of flood depths and extents are presented in Appendix F.1.

108. Impacts of climate change on flood-generating storms are considered part of the baseline case when assessing potential effects. This is because climate change will take place whether the Ō2NL Project is present or not. Climate change is predicted to cause increased peak rainfall, and therefore more frequent flooding and sediment mobility. Therefore, the potential effects of the Project are considered in the context of the future climate. This is in line with industry practice and guidance.

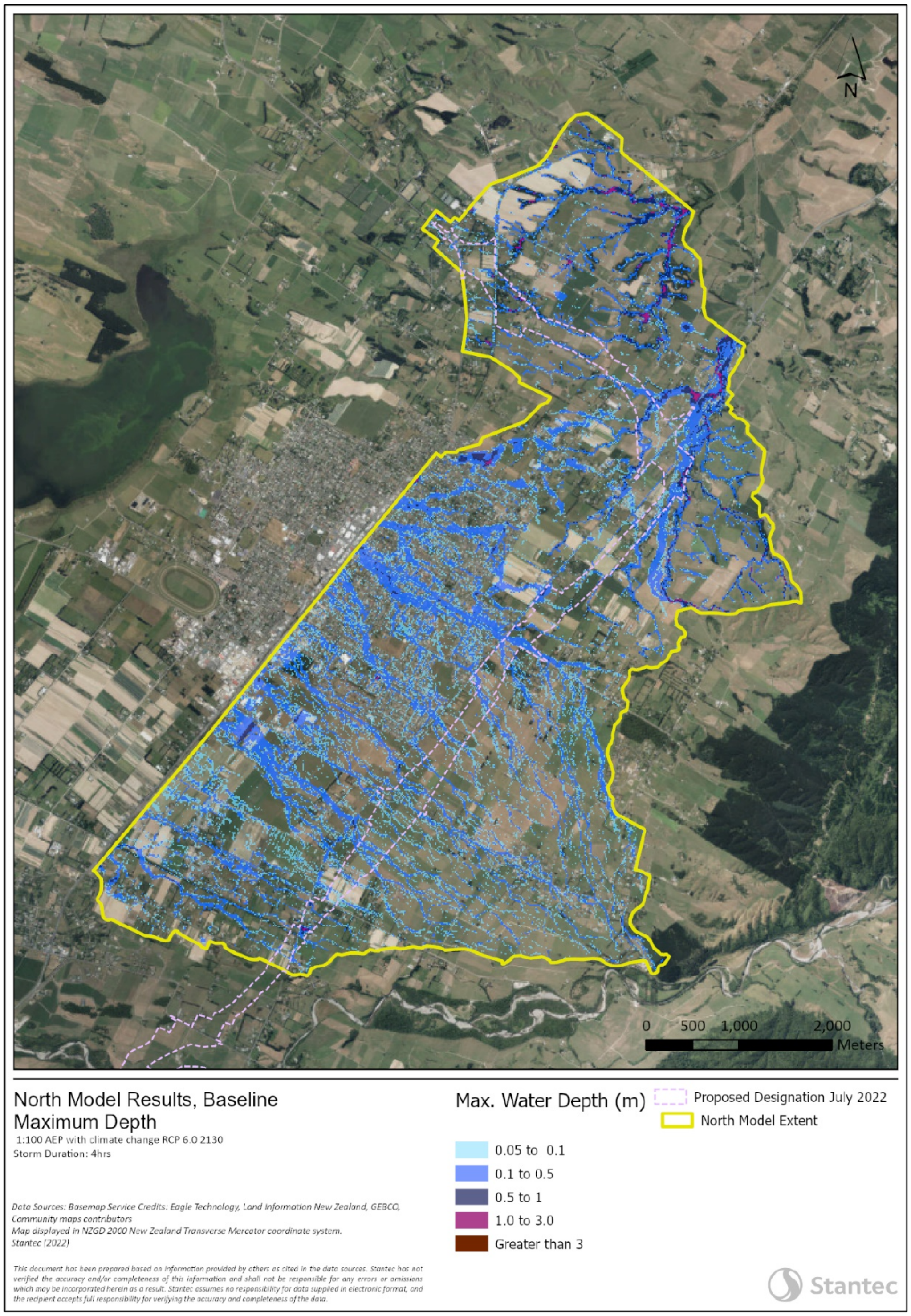


Figure F.9: Baseline (without Project) maximum modelled depths 1:100 AEP RCP6.0 2130 (North)

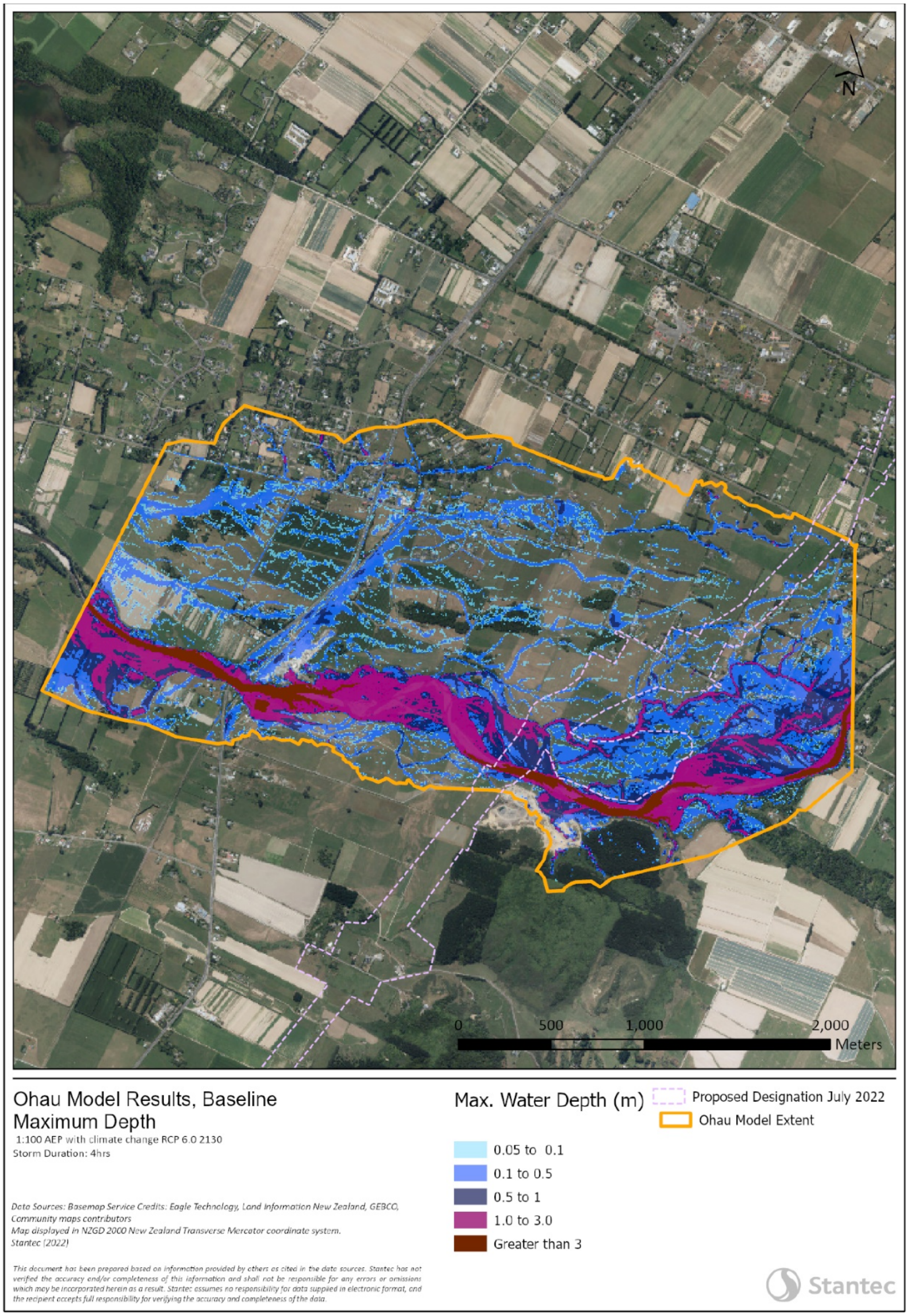


Figure F.10: Baseline (without Project) maximum modelled depths 1:100 AEP RCP6.0 2130 (Ohau)

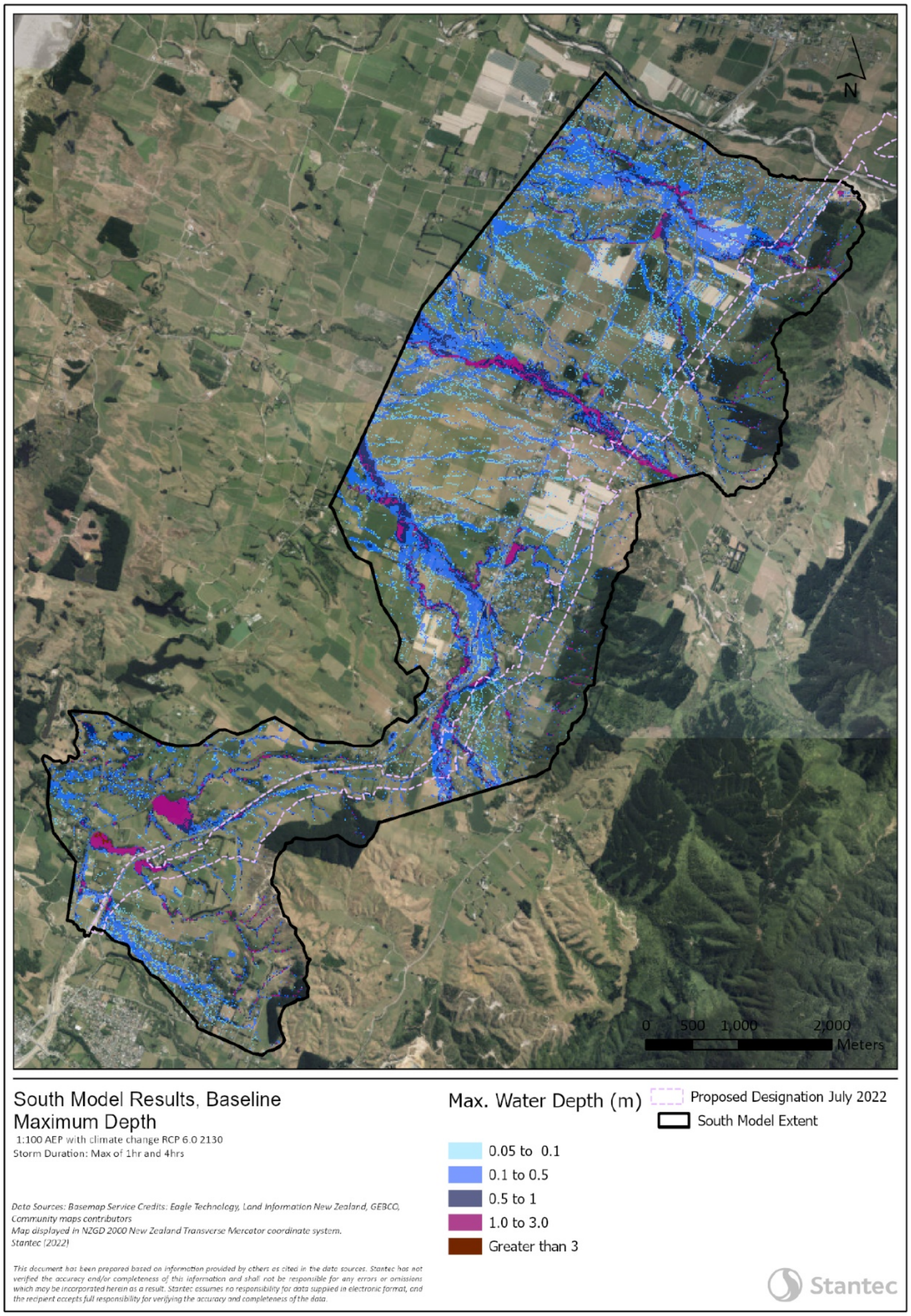


Figure F.11: Baseline (without Project) maximum modelled depths 1:100 AEP RCP6.0 2130 (South)

Ō2NL PROJECT SHAPING AND AVOIDING AND MINIMISING EFFECTS

109. My early integration into the Ō2NL Project design team has allowed me to contribute to the design to avoid or minimise potential adverse hydrological effects.

110. General principles of the hydraulic design philosophy were developed to be consistent with the Ō2NL Project Cultural and Environmental Design Framework ("**CEDF**"), included as Appendix 3 to Volume II, the principles of which will continue to guide the detailed design.

111. Examples of key principles that will help to avoid and minimise effects on hydrology and flooding include:

(a) Maintaining existing natural flow paths downstream as far as reasonably practicable, during low and flood flows. This will be achieved through suitable number, size and placement of bridges and culverts and managing intervening overland flows via small clean open diversion channels.

(b) Minimising the encroachment of proposed works into streams and their floodplains where practicable, to minimise loss of flood conveyance or storage, high value ecological habitat and disturbance of natural fluvial processes. This is achieved through the proposed bridging of the major rivers / streams and avoiding or minimising placement of other project features in floodplains where practicable.

(c) Avoiding or minimising exacerbating the existing flood hazard.

(d) Culverts on permanent streams with existing or potential fish habitat will be designed consistent with the Resource Management (National Environmental Standards for Freshwater Regulations 202 ("**NES Freshwater**") Regulation 70.

112. Additional information on the design philosophy is provided in the DCR (Appendix 4 to Volume II).

ASSESSMENT OF EFFECTS

Potential effects to be assessed

113. Potential hydrology and flooding effects from a new highway, if unmitigated, could include the following:

(a) Increase in peak flood levels, depths and durations, either upstream or downstream, which could cause damage to buildings or crops.

(b) Increase in peak velocities on account of changes in infiltration, and/or modification of flow pathways.

(c) Increase in flood hazard (a function of depth and velocity) which could pose risk to people or livestock.

(d) Increase in scour potential (a function of velocity, material composition, sinuosity, depth and other hydraulic parameters) which could result in localised erosion.

Adopted assessment criteria

114. The main design event referenced in this assessment is the 1:100 AEP event, including the potential effects of climate change (RCP 6.0 scenario to 2130). All model results refer to this event, unless stated otherwise.

115. The thresholds I have applied when considering the actual and potential effects of the Ō2NL Project on hydrology and flooding are influenced by the following factors:

(a) Land-use and receptor type, which is predominantly rural apart from Levin and Manakau. The settlement at Ohau is on a ridge that is not sensitive to any hydrological changes within the proposed designations. Any existing building in an area potentially affected by the Ō2NL Project was given careful analysis.

(b) Topography, which is dominated by moderate gradients in which upstream backwater effects are short and the downstream redistribution of any changes in flow occurs over a short distance.

(c) Flooding, which is typically of short duration because of the short catchment response times and relatively steep topography. Most plant species are not expected to be sensitive to minor changes in the depth of inundation over such short durations, given the extreme nature of the selected design event.

(d) Extent or spatial scale of potentially impacted areas.

(e) Considering the project core principles, which include Kaitiakitanga and to ‘Tread Lightly, with the whenua’.

(f) Accuracy of modelling used to assess potential effects, which is reasonable for the scale and stage of the Project.

(g) Other factors of pre-existing and ongoing change in the area, such as natural sediment mobility, which can change the course of rivers or the elevations of their beds and banks over time, including their hydraulic roughness and velocities. This process varies over time, particularly after earthquakes and/or heavy rain which can trigger injections of debris into stream systems.

116. These factors provide context to the dynamic environment in which the potential effects of the Ō2NL Project are evaluated.

117. Therefore, it is difficult to assign a single set of effects thresholds uniformly to all areas and some expert judgement is required. The criteria in **Table F.4** have been used as a guide for the assessment of effects in the context of the Ō2NL Project.

Table F.4: Less than minor effects screening criteria (project specific context)

Location of impact	1:10 AEP current climate	1:100 AEP RCP 6.0 2130
Upstream 50m beyond proposed designation, provided no buildings impacted (confirmed by model)[7]	<0.1m	<0.1m
Upstream at proposed designation, provided no buildings impacted (confirmed by model)	<0.2m	<0.5m
Within proposed designation upstream of bridges[8]	<0.5m	<1m
Within proposed designation upstream of culverts[9]	<1m	<1.5m
Downstream at proposed designation[10]	<0.2m	<0.2m
Downstream 100m beyond proposed designation[11]	<0.05m	<0.05m

118. The change criteria in each box does not imply that exceeding the threshold is necessarily unacceptable or that mitigation is required. Rather, the aim is

[7] These upstream criteria are only applicable in a rural environment with no buildings impacted. Modelling has confirmed that no buildings upstream of the designation are impacted by the Project, therefore there is no need for an additional category for impacted buildings. Distances upstream or downstream of designation can be measured as a distance buffer rather than following a particular watercourse.
[8] This threshold is a guide, and consideration is also given to site-specific velocity. For this assessment, all buildings within the proposed designations are ignored (assumed to be acquired and either demolished or later sold with an updated flood risk profile where applicable).
[9] P46 references a maximum of 2m surcharge above soffit (soffit typically being higher than the pre-project flood level), but 2m surcharge causes high culvert velocities that are not conducive to substrate stability requirements for fish passage. For this assessment, all buildings within the designation are ignored (assumed to be acquired and either demolished or later sold with an updated flood risk profile where applicable).
[10] Small lateral differences that re-distribute a short distance downstream may be tolerable in the rural context.
[11] It is important to avoid cumulative effects passing a significant distance downstream of the Project, to avoid increasing flood risk to dwellings downstream. Greater distances for lateral redistribution may be tolerable on a site-specific basis.

to identify potential increases above this threshold for consideration, even where there the effects on the receptor or receptors may be acceptable.

119. The minimum threshold of 0.05m change in water level is informed by the considerations discussed above, and the modelling tolerance when comparing simulations. It does not imply that the models are an accurate representation of actual flood levels to within 0.05m at all locations within the model domain. The model allows detection of likely relative change arising consequent of the Ō2NL Project concept design.

120. Changes within the footprint of the modelled concept design can appear to produce large changes in peak water level because of the applied changes in topography (i.e., earthworks) and can therefore be ignored. These are not discussed unless there are consequential effects such as high velocities requiring scour protection, or effects extend outside of the proposed designations.

121. Changes in velocity are assessed on a site-by-site basis, including by comparison with baseline velocity in upstream and downstream reaches.

122. Changes in maximum water level and velocity outside the proposed designations are both less than minor, and do not extend into built-up areas, therefore hazard (which is a function of depth and velocity) is less than minor and is not discussed.

123. Full maps of modelled peak water level difference (on account of the concept design) are presented in Appendix F.2. Site specific comments are provided below.

Ohau River bridge and floodplain relief bridge

124. The Ohau River bridge and floodplain relief bridge function together to pass flood flows and are therefore considered together.

125. The Ohau River has a bank full channel width of approximately 70m in the vicinity of the proposed crossing (refer to **Figure F.12**). The floodplain width varies from 300m-500m; formed by past meandering and braiding of the river along with the deposition of alluvium.

Figure F.12: Ohau River near proposed crossing (looking upstream)

126. The Ohau River bridge concept design would result in an increase of water levels in the main channel of 0.5m-0.6m relative to baseline. This is within the 1m criterion for change within the proposed designation. The increase is caused by the attenuating effect of northern embankment and associated backwater. This reduces some of the flow leaving the main channel toward the north, near and upstream of the bridge. Along the upstream proposed designation boundary, the maximum increase remains below 0.4m (ie within the 0.5m criterion). This decreases to <0.1m within approximately 70m upstream of the designation boundary, without posing risk to any buildings. The distribution of increased water levels for the main design event is shown in **Figure F.13**. The slight change in flow distribution between the main channel and floodplain returns to its original flow pattern (<0.05m change) approximately 115m downstream of the proposed designation, over undeveloped land. This effect is considered less than minor.

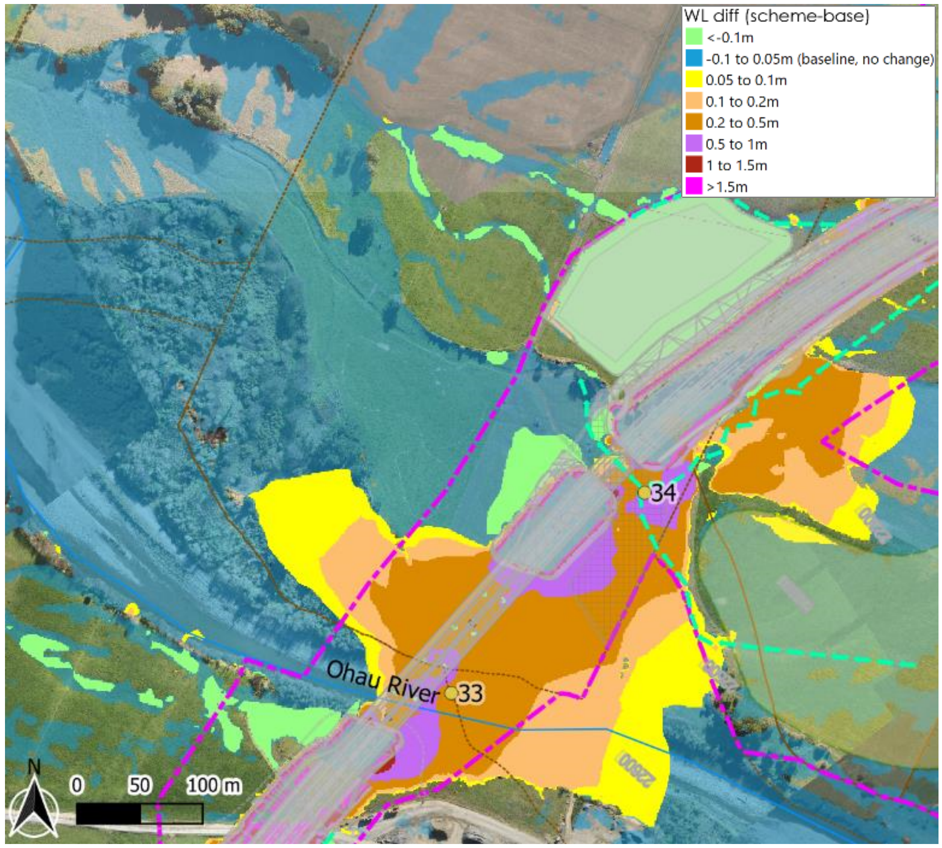


Figure F.13: Peak water level differences Ohau River and floodplain in a 1:100 AEP flood event with climate change

127. In the 1:10 AEP baseline event, there are areas of shallow flow over the northern floodplain. The small change in in-bank levels on account of the Project causes these shallow overland flows to increase slightly. The slightly modified flows (which are small in the context of the Ohau River) propagate along the floodplain for approximately 500m until the flow path re-joins and fully mixes with the main channel, as shown in Figure F.14. Given the landscape context and absence of sensitive receptors within the areas showing change, these effects are considered acceptable. It is also likely that improvements to the detailed design of the southern bridge abutment position (for the quarry access track), and refinements to the modelling of the piers and scour protection, will demonstrate lessened effects for the final design.

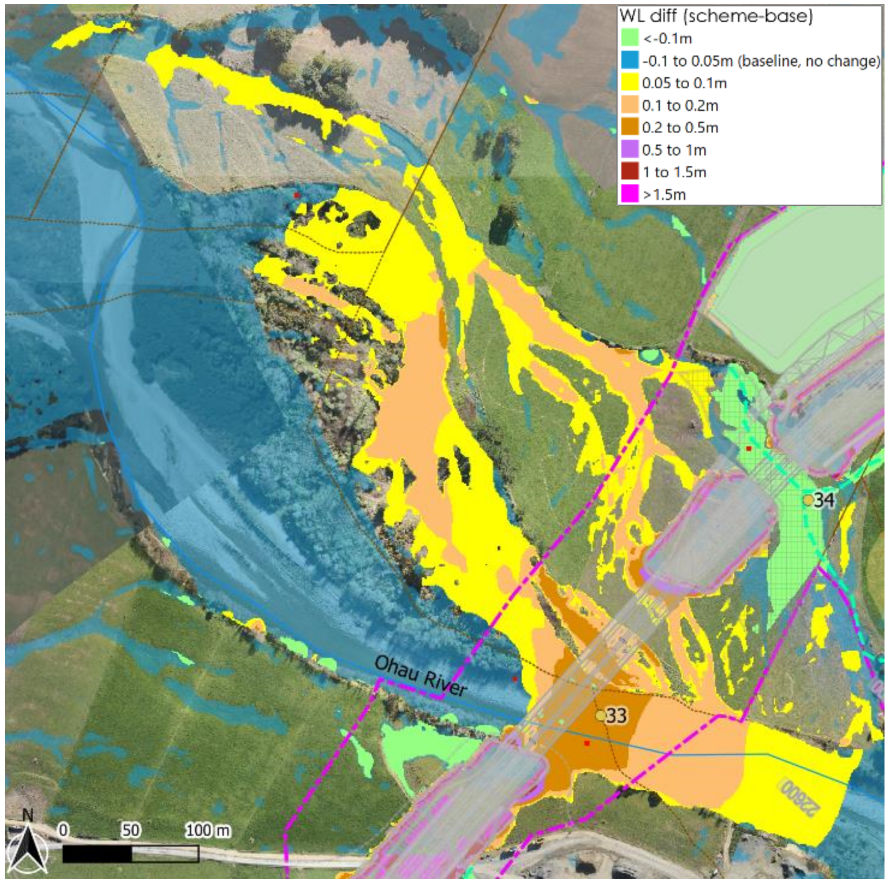


Figure F.14: Peak water level differences Ohau River and floodplain in a 1:10 AEP flood event

128. At the location where the river crosses the upstream designation, the change in water level between baseline and with-scheme (ie With Project) is illustrated by the water level hydrographs below.

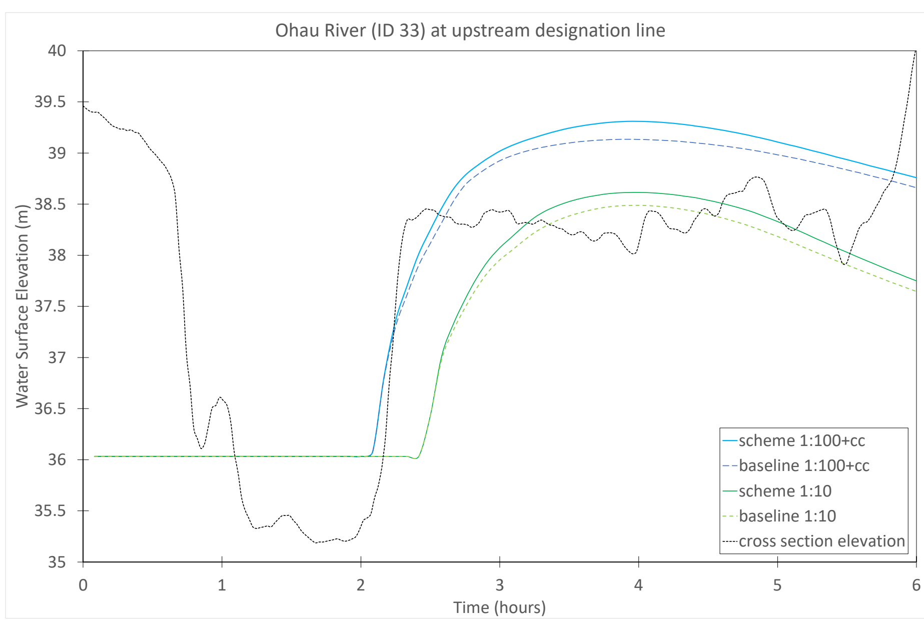


Figure F.15: Water level hydrographs on the Ohau River at the upstream designation

129. Despite the increases in peak water levels, the effect of the Ō2NL Project is considered less than minor for the following reasons:

(a) The changes within the proposed designation meet the screening criteria.

(b) The rural land-use and landscape features are not sensitive to the small, short duration of peak water level change during the extreme design event.

(c) Once the slight changes in flow distribution between the main channel and floodplain returns to the original flow pattern downstream, there are no cumulative effects passed further downstream and no existing buildings with discernible increases in flood risk.

(d) Because of the land-use and topographic contexts, effects of this magnitude are considered less than minor.

130. The indicative bridge piers (four sets of two piers) have been included in the model. There is a localised reduction in velocities around the piers (**Figure F.16**). Because the piers and the northern floodplain embankment both slightly impede the flow, the velocities are slightly increased in the spans between the piers, particularly on the northern / right bank floodplain (**Figure F.17**).

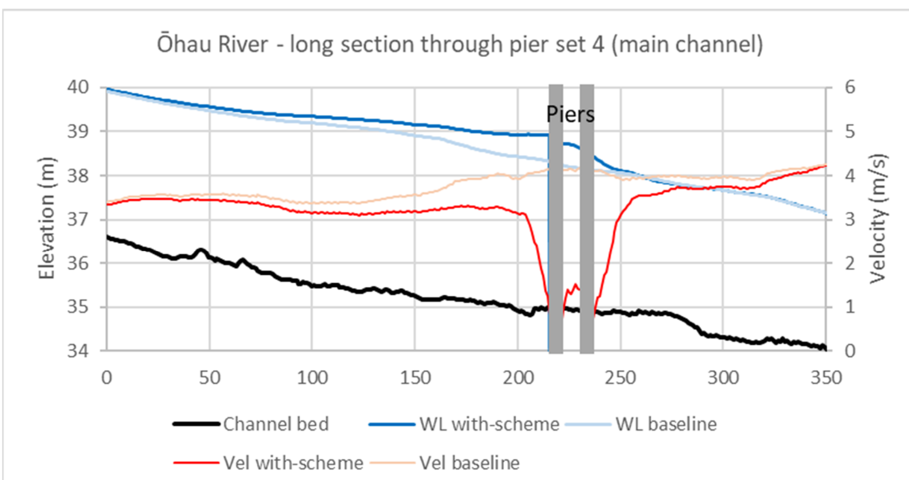


Figure F.16: Ohau River long section through pier set in a 1:100 AEP flood event

131. On the downstream true left (southern) bank of the Ohau River, the in-bank water levels closely mimic baseline behaviour. When the detailed design is progressed, including bank scour protection and provision of an access track to the quarry, the elevation of this bank can be refined to maintain the existing flood behaviour downstream.

132. The true right (northern) floodplain slopes northwards away from the Ohau River at this crossing location. A significant proportion of the total design flow is conveyed across this floodplain, including some flow that breaks out of bank much further upstream (east of Muhunoa East Road). To cater for this combined flow, the proposed flood relief bridge on the northern floodplain (flow path ID 34) has a 35m long top span, which reduces to 31m at floodplain level (because of the abutments). A wide shallow 'scrape' is applied in the concept design to improve flow capacity on the floodplain approaching and through the throat of the flood relief bridge. This feature does not influence how much flow exits the Ohau River onto the floodplain. The net result of the concept design is approximately 0.5m increase in peak levels at the bridge, relative to baseline, dissipating to <0.1m within 50m upstream of the proposed designation. Because of the land-use and topographic contexts, an effect of this magnitude is considered less than minor.

133. Velocities in the centre of the main Ohau River channel exceed 4m/s under the existing environment and the concept design scenarios. The exact locations of these peak velocities change over time because of sediment movement. This occurs independently of the Project.

134. Velocities in the throat of the flood relief bridge reach approximately 3m/s, and scour protection is proposed through this bridge. During the 1:10 AEP event, the floodplain flow is shallower, and the velocity is less than 1m/s through this bridge.

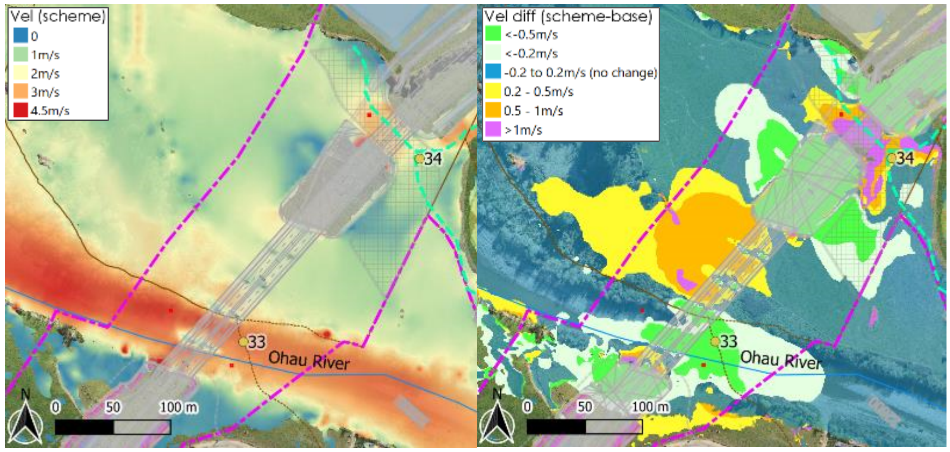


Figure F.17: Ohau River with-scheme velocity, and velocity change from baseline in a 1:100 AEP flood event with climate change

135. The presence of the combined bridges will not impede the passage of sediment and provides reasonable space for the river to migrate naturally within its floodplain.

136. Given the above findings, the overall effects on hydrology and flooding in this area are considered less than minor.

Kuku Stream bridge

137. Kuku Stream at the proposed crossing is currently traversed by a farm track with an existing pipe culvert (estimated DN1050) that appears to be partly embedded (**Figure F.18**). vThis culvert is significantly under capacity and would be outflanked and overtopped during large events. It is also at risk from blockage.

138. This undersized culvert will be replaced with a new bridge that can pass the design event with >0.6m clearance to the soffit. This freeboard allows for the passage of floating debris.

Figure F.18: Kuku Stream near proposed crossing (us/ds respectively)

139. The indicative Kuku Stream bridge has a clear width at floodplain level of approximately 17m. The modelled bridge causes an increase in flood levels relative to baseline of less than 0.5m, which is commensurate with the size of the stream (**Figure F.19**).

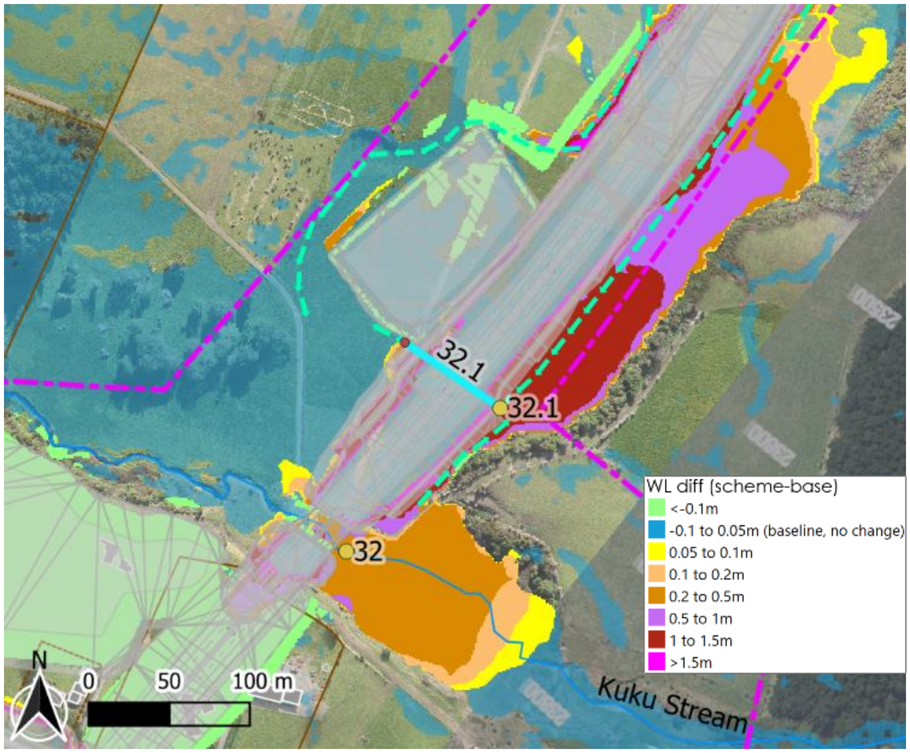


Figure F.19: Peak level differences Kuku Stream in a 1:100 AEP flood event with climate change

140. There is an existing flood berm / stop bank on the right (northern) bank upstream of the existing culvert. Historic aerial images indicate that this was built around 2017, along with some local channel straightening. This stop bank overtops during the baseline event, flowing onto the right / northern floodplain which is lower than the stream itself. This flow path is reduced by the presence of the proposed highway embankment. However, the distribution of flows rebalances quickly downstream, well within the proposed designation, to mimic the original pattern. There is no discernible change in peak water levels further downstream.

141. As indicated in **Figure F.19**, culvert ID 32.1 increases the flood level upstream by up to 1.3m along the designation boundary. It then decreases to <0.1m approximately 50m from the proposed designation, although the footprint of impacted area runs along the proposed designation for a longer distance. Given the rural land use and extreme nature of the design event, and the fact that there are no increases beyond the proposed designation for the 1:10 AEP event, these effects are considered acceptable. The extent of increased modelled water levels for the 1:10 AEP current climate event is shown in **Figure F.20** below.

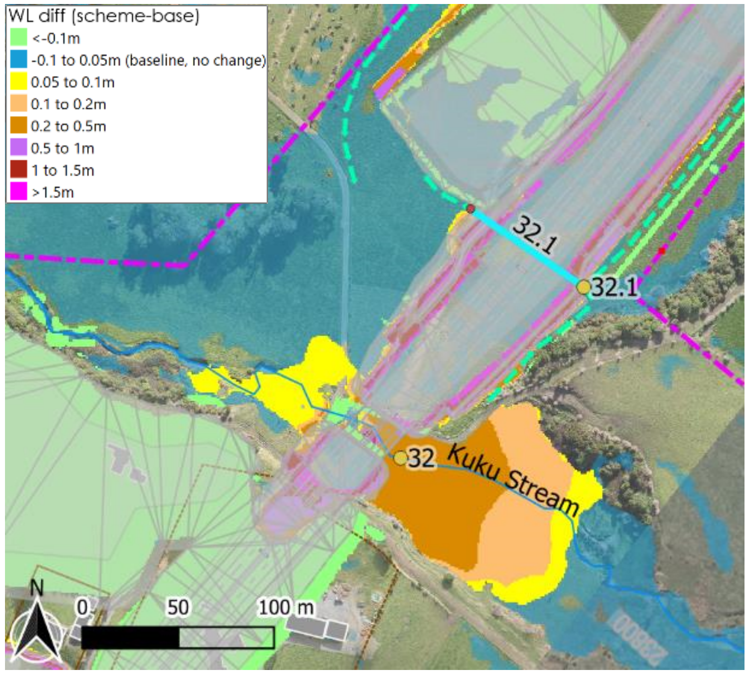


Figure F.20: Peak level differences Kuku Stream in a 1:10 AEP flood event

142. Velocities in the throat of the Kuku Stream bridge reach almost 3m/s during the design event, compared to approximately 2m/s in the baseline. Therefore, scour protection may be necessary to retain a stable channel.

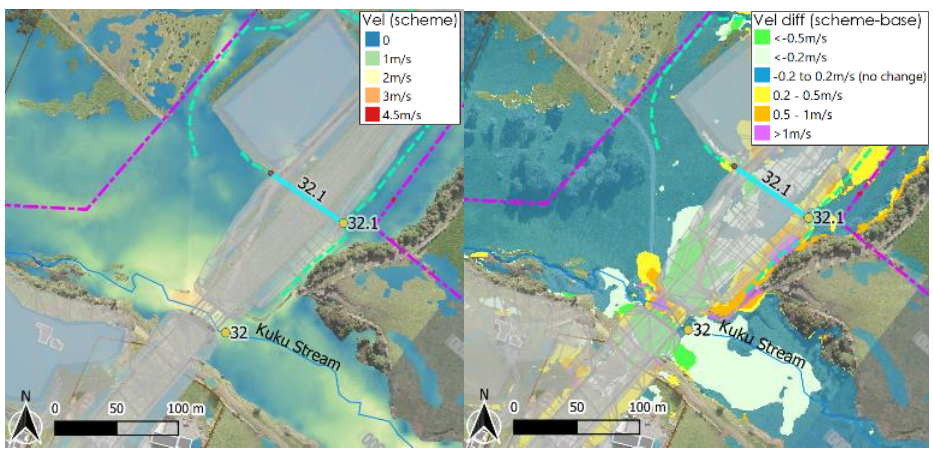


Figure F.21: Peak velocity, and velocity differences Kuku Stream in a 1:100 AEP flood event with climate change

143. The effects of Kuku Stream bridge on hydrology and flooding meet the proposed criteria for less than minor. The new bridge will be substantially more resilient than the existing SH1 bridge which floods frequently and results in closure of the State Highway.

Waikawa Stream bridge and floodplain culvert

144. The Waikawa Stream (ID 27) is an actively mobile stream with a terraced floodplain (**Figure F.22**). The main bankfull channel near the proposed crossing is approximately 25m wide, although the width varies considerably. Historical aerial photography shows that the location of the stream centreline moved approximately 45m northwards between 2005 and 2017, a period of just 12 years. The piers and abutments will be designed to allow and withstand lateral movement.

Figure F.22: Waikawa Stream photographs near proposed crossing site

145. The total width of the floodplain is around 400m. The contemporary floodplain, inundated in the 1:10 AEP design event is around 110m wide. The proposed location of the main Waikawa bridge span and abutment will avoid encroaching on this part of the floodplain. The Waikawa Stream concept bridge modelled has a 140m long total top span. The effective width reduces at floodplain level because of the spill-through abutments and the three pier sets. The resulting upstream increase in water levels compared to baseline is less than 0.3m in the main channel. There is no perceptible difference in peak water level in the main channel, either upstream or downstream of the proposed designation boundaries. It is considered that effects of this magnitude are less than minor.

146. The Waikawa tributary (ID 27.1) has a catchment area of 2km^2 but at the location of the proposed crossing also carries some excess flow from the Waikawa Stream's right bank (northern) floodplain. As a result, it has been modelled with a large culvert, with a 10m total waterway width (split into a triple box culvert). This culvert results in a relatively large increase in water levels upstream (approximately 1.2m). The difference is just over 0.5m at the upstream proposed designation boundary but dissipates rapidly to <0.1m over an additional 30m upstream.

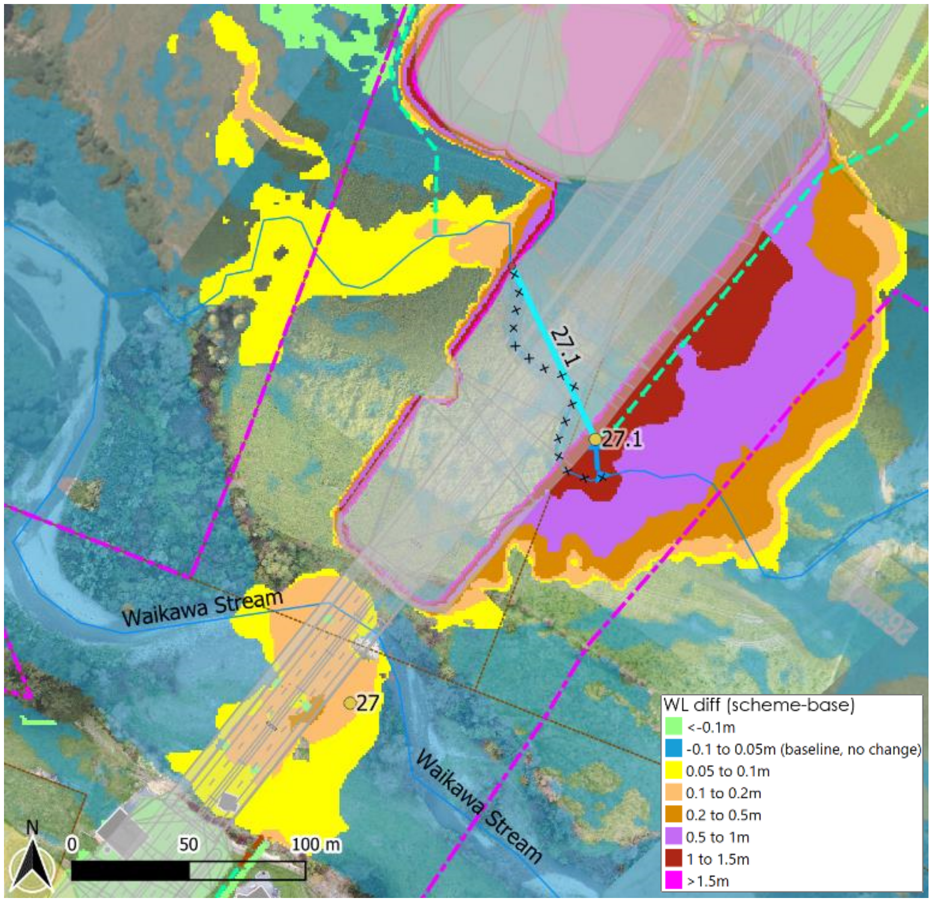


Figure F.23: Peak level differences Waikawa Stream and tributary in a 1:100 AEP flood event with climate change

147. During the 1:10 AEP current climate event, the effects on the main channel remain well within the proposed designation. On the floodplain, the upstream impacts dissipate approximately at the proposed designation. There are shallow overland flow paths on the floodplain that show a mix of reduction and increase of approximately 0.1m extending downstream of the proposed designation. These differences dissipate to original pattern (<0.05m) approximately 50m downstream of the proposed designation where the tributary joins the main Waikawa Stream floodplain. Given the land use context effects of this magnitude are considered less than minor.

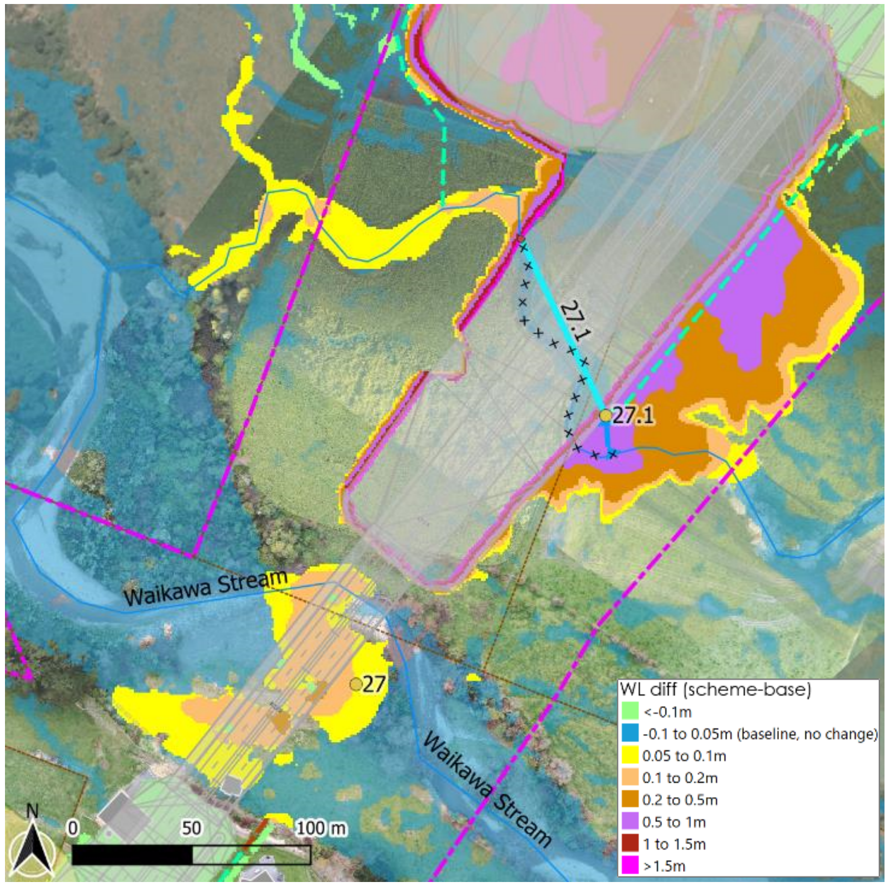


Figure F.24: Peak level differences Waikawa Stream and tributary in a 1:10 AEP flood event

148. At the location where the tributary crosses the upstream designation, the change in water level between baseline and with-scheme is illustrated by the water level hydrographs below.

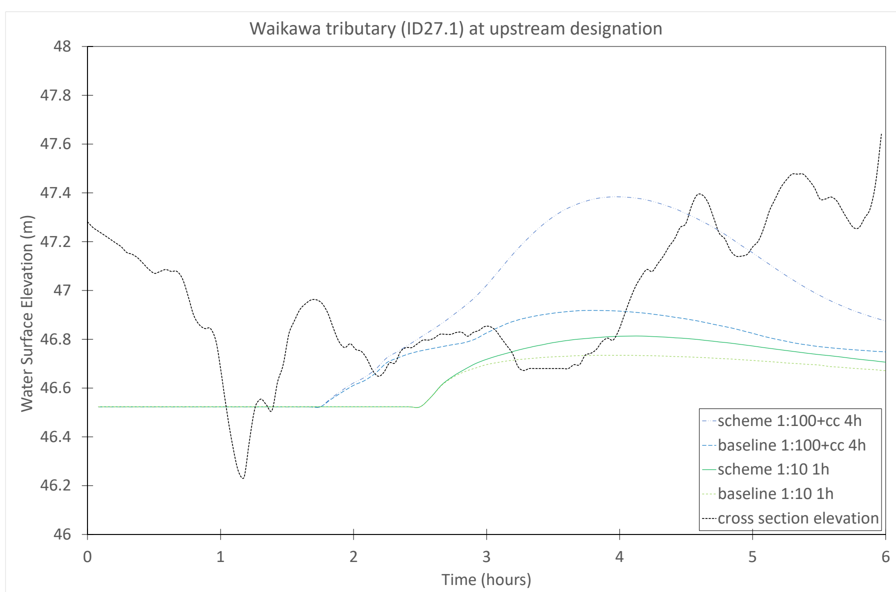


Figure F.25: Water level hydrographs on the Waikawa tributary at the upstream designation

149. At the main Waikawa Stream bridge, three sets of double piers have been included in the model. There is a slight reduction in velocities around and downstream of the piers. In the free spans between the pier sets there is a slight localised increase in velocity, but this is mainly a shift in where the peak velocities occur across the section (**Figure F.26**). Peak velocities in both the Ō2NL Project and baseline models are approximately 3m/s. Velocities on the northern floodplain are reduced as they approach culvert ID 27.1, because of the embankment. Patches of slightly increased velocity occur downstream on the floodplain, associated with small changes in shallow depth and therefore less than minor in effect.

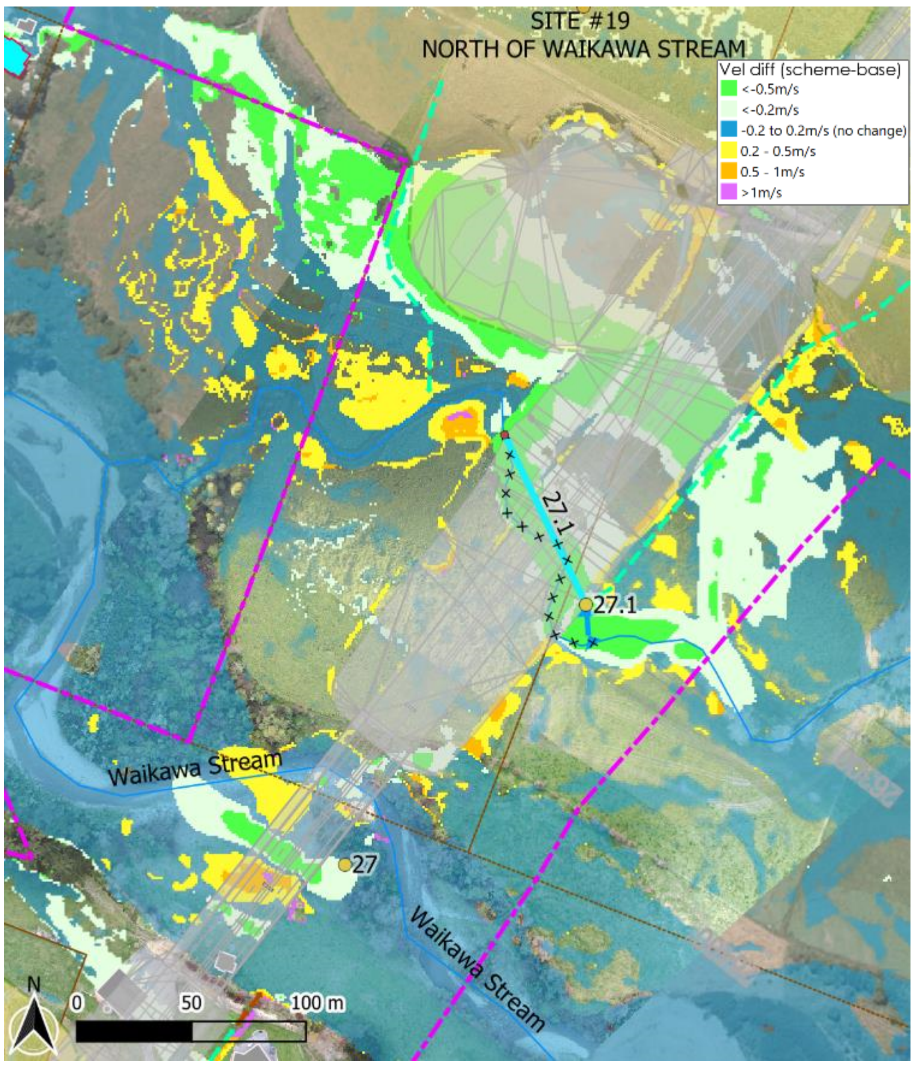


Figure F.26: Peak velocity differences Waikawa Stream and tributary in a 1:100 AEP flood event with climate change

150. Given the above, any effects of the Ō2NL Project on hydrology and flooding can be considered less than minor.

151. The Ō2NL Project offers the benefit of being much more resilient than the existing SH1 bridge.

Waiauti & Manakau stream bridges

152. Manakau Stream (ID 15) is a small meandering stream, although the floodplain is not particularly wide or well defined near the proposed crossing. Manakau Stream is currently constrained by South Manakau Road and the existing bridge (to be retained) immediately downstream of the proposed crossing (**Figure F.27**).

153. The existing bridge is 9m wide, and the opening is partly filled with gravel on the right-hand (eastern) side. The existing channel upstream varies in width but is typically around 5m wide.

Figure F.27: Manakau Stream existing bridge downstream of proposed crossing

154. The indicative concept bridge will span both the watercourse (modelled as 13m of 28m) and the existing South Manakau Road (15m of 28m for road and SUP).

155. Assuming this design, peak water levels increase by 0.3-0.4m approaching the embankment (**Figure F.28**). There is a slight reduction in levels through the throat because of the necessary realignment of one meander loop under the design modelled. A small amount of spill over South Manakau Road

occurs in both the Ō2NL Project and baseline models (in events larger than 1:10 AEP current climate). The presence of the new highway embankment will not change the depth or duration of flooding over the existing road.

156. Downstream of the existing Manakau Stream bridge, the model shows that minor changes dissipate well within the proposed designation for the main design event.

157. Peak velocities in some parts of the modelled realignments for the main design event reach approximately 3m/s compared to 2m/s peaks in the baseline situation. This is the result of realigning the channel.

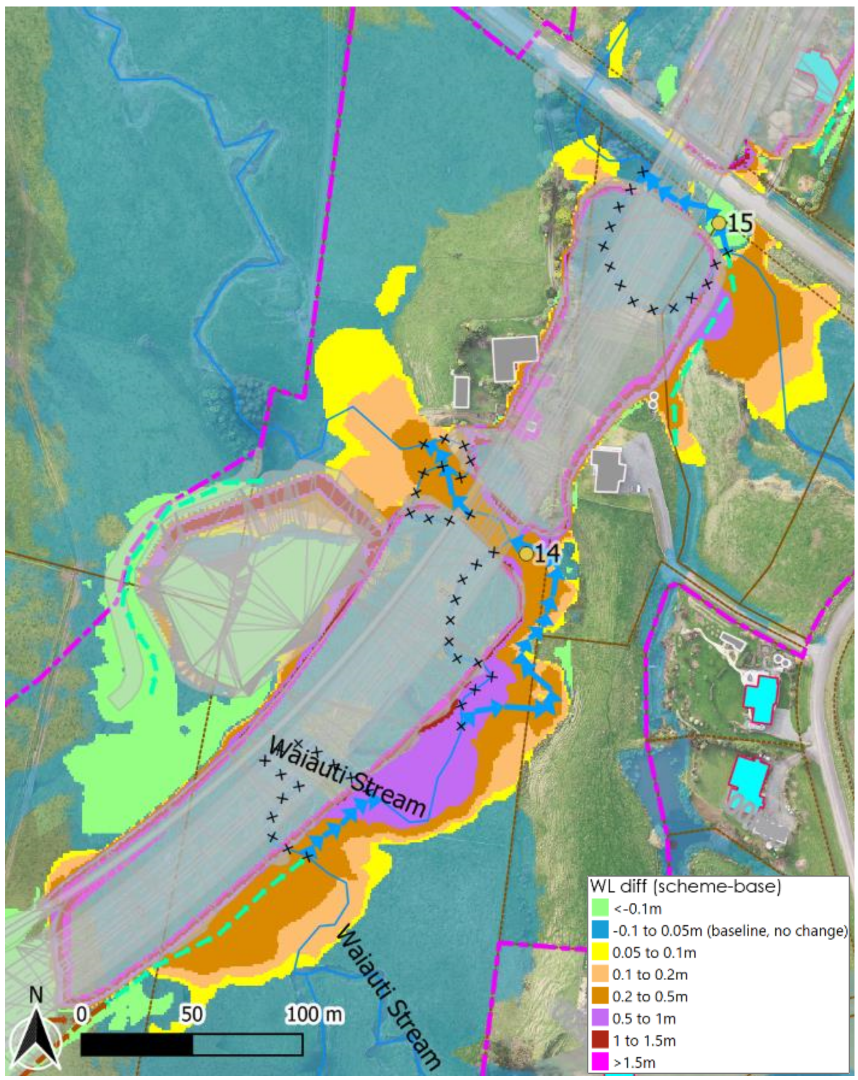


Figure F.28: Peak level differences Manakau and Waiauti streams in a 1:100 AEP flood event with climate change

158. The Waiauti Stream (ID 14) is a small meandering stream (**Figure F.29**) with a relatively wide floodplain (approximately 250m).

Figure F.29: Waiauti Stream looking downstream toward proposed crossing

159. The indicative embankment occupies a considerable proportion of the floodplain, with a new bridge towards the true right (northeast) corner of the floodplain. Constructed meanders will be designed to mitigate the loss of fluvial environment under the embankment.

160. The modelled opening between the bridge abutments is approximately 20m (**Figure F.30**). The upstream peak water levels in the throat of the bridge increase by approximately 0.3m relative to the baseline, although differences of up to 0.7m are noted near the embankment. This may be the result of a combination of shortening of the stream, and slight under-sizing of the modelled realignment channel in this area; however, any effect is considered to still be within acceptable limits.

161. Downstream of the Waiauti Stream bridge, the slight increase in water levels that is caused by the lateral concentration of flow through the bridge rebalances within the proposed designation. There is no difference in flood flows or water levels downstream of the proposed designation.

162. Peak velocities in the throat of the bridge range from 2-2.5m/s, compared to around 1.6m in the baseline (noting that the route of high velocities changes because of the realignments). Any effects from velocity caused by the final design can be mitigated by scour protection within the proposed designation.

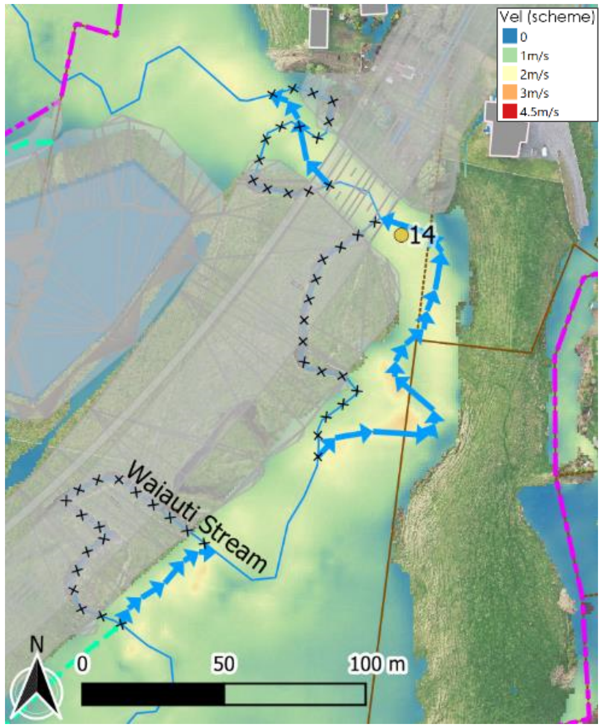


Figure F.30: Waiauti Stream peak velocity in a 1:100 AEP flood event with climate change (concept design stream diversions shown as blue arrows and stream to be removed indicated with black dashed line)

163. In the 1:10 AEP event, slight changes in lateral distribution between the Manakau and Waiauti floodplains dissipates to original patterns (<0.05m) within 100m downstream of the proposed designation. There are no cumulative effects passed further downstream and no existing buildings with discernible increases in flood risk.

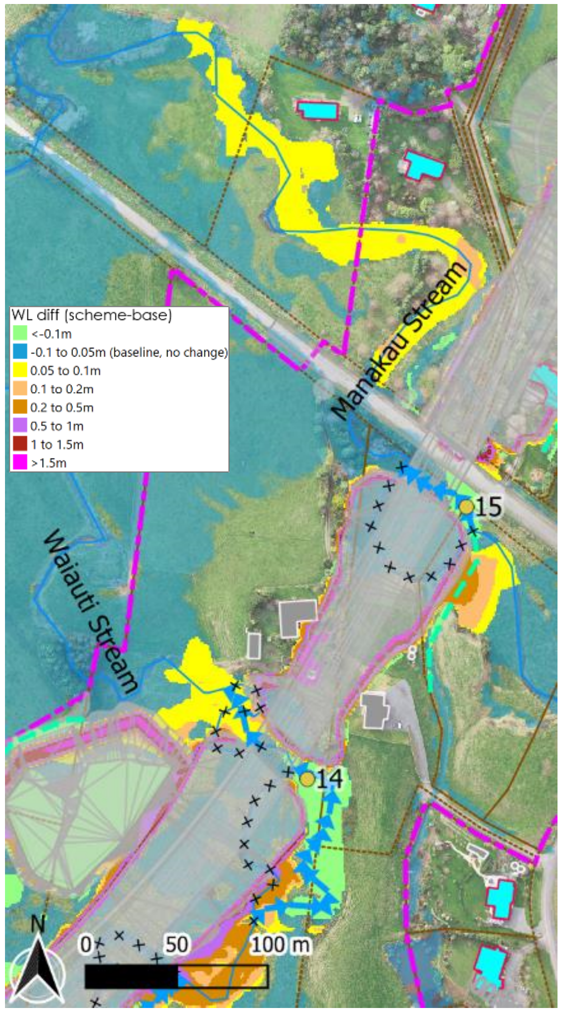


Figure F.31: Peak level differences Manakau and Waiauti streams in a 1:10 AEP flood event

164. Given the above, the effects of the Manakau and Waiauti Stream bridges on hydrology and flooding are considered less than minor.

Smaller streams and overland flow management

165. Ephemeral overland flows that approach the Ō2NL Project at the top of cut sections or toes of fill embankments are captured in clean open channels to avoid excessive ponding or erosion against the Project. The small flows captured by these channels are routed to the most appropriate stream or culvert so that prevailing flow paths downstream are maintained.

166. The catchments leading to indicative culvert locations tend to have relatively steep narrow valleys. As a result, the localised increases in peak flood levels at the inlets to most culverts are predominantly contained within the proposed designations. Only a few modelled culverts show peak level increases

approaching or marginally exceeding 0.5m at the upstream proposed designation boundaries, which dissipate rapidly to <0.1m within less than 50m upstream of the boundaries, which is considered less than minor given the land use and topographic context.

167. Any lateral changes in flow distribution at the culvert outlets are rebalanced within the proposed designations. There are no cumulative increases in peak flood flows or peak water levels downstream of the proposed designations.

Queen Street East

168. During extreme events (e.g., the 1:100 AEP RCP 6.0 2130), there is a substantial overland flow path adjacent to Queen Street that carries runoff from the east toward Levin.

169. East of the Ō2NL Project, most of the flow is on the northern side of Queen Street. This flow is therefore taken underneath the proposed new Queen Street East raised embankment and then underneath the Ō2NL highway. The downstream flow distribution toward Levin will remain essentially unaltered and consequently the Ō2NL Project will have less than minor effects on the existing situation.

Material supply sites and spoil sites

170. The exact volumes and final form of the material supply and spoil sites are not known and will remain somewhat uncertain until detailed design has occurred, and construction commences, because of potential material variability on site.

171. On a conservative basis, the potential hydraulic behaviour and effects of the full development of these sites and their consequent rehabilitation (as shown in the CEDF) have been inferred from the available model results.

172. **Site #34a (Koputaroa tributary)**: There would be no adverse effects on flooding either upstream or downstream because of material extraction. The indicative material supply boundary is set back from the (ephemeral) stream floodplain, although it is understood that the site will be integrated into an online wetland (i.e., not separated from the stream). The site could represent a very slight advantage in terms of flood risk in some events (from the additional storage of flood water on a wider floodplain).

173. **Site #36 North Ohau**: There would be no adverse effects on flooding upstream or downstream because of material extraction. The site could represent a small advantage in terms of flood risk, because of the additional storage of flood water on a wider floodplain during some events. The indicative outline currently shows a small clash with an overland flow path on the north-western side of the site (near Ō2NL chainage 22250). This could be addressed easily by either modifying the proposed outline or by re-alignment of the overland flow path within the proposed designation extent. Parts of the terrace site does have some overland flow in major events (larger than 1:10 AEP current climate). Whilst the river is relatively stable currently, there remains the possibility that future injections of gravel from earthquakes or severe storms could increase aggradation, lateral erosion and avulsion. The Ō2NL Project and this material supply site will not change this risk, but if this scenario eventuates then deep-seated scour protection on the upstream face of the Ō2NL highway embankment will mitigate effects by steering flows toward the flood relief bridge. Periodic monitoring and maintenance may be required, which will be further specified through detailed design and may also be influenced by the final form.

174. **Site #19 North of Waikawa (east and west)**: There would be no adverse effects on flooding upstream or downstream because of material extraction. The site has the potential to offer a very slight flood benefit if allowed to fill with flood water during major events by offering additional floodplain storage potential. The velocities in this area will be low because of the Ō2NL highway embankment. Integration of the stormwater pond into the western side will be an important design consideration to maximise material recovery and legacy outcomes.

175. **Site #15 South of Waikawa**: There would be no adverse effects on flooding upstream or downstream because of the material extraction. The site could provide a slight benefit in terms of flood risk, by the capture and attenuation of overland flow toward the west of the site. There is a small, discontinued water race across the site. The material supply site will capture and route a similar size catchment to the outlet, so that flows will closely mimic the existing situation. The route of the historical water race will still be used as an overland flow path to pass excess runoff. The design of attenuation will ensure that the future peak discharge would be similar to or less than the baseline. The site outline currently shows a small extension onto the Waikawa floodplain near the proposed O2NL bridge. This is understood to

be a potential access corridor rather than forming part of material supply. Care should be taken in detailed design to protect the riverbank in this location, to avoid increasing the potential risk of accelerated lateral scour from the highly mobile Waikawa Stream.

176. In summary, the material supply sites represent no adverse effects on flooding and may reduce existing flood risk very slight because of additional flood storage during.

177. Spoil sites will be subject to detailed design so that they avoid or minimise affecting flood storage or flow paths. Spoil site boundaries, shape and/or the route of open collector channels will be designed ensure no aggravation of the existing flood risk outside the proposed designations. With reasonable care during the design process, the magnitude of effects arising from the spoil sites will be less than minor.

Longitudinal stormwater management features

178. Stormwater management devices have been proposed to capture, convey, treat, and attenuate runoff from the road surface and cuts. During the 1-hour and 4-hour events simulated in the hydraulic model, the stormwater management system is effective in preventing increases in flood levels downstream. The final shapes of the devices, landscaping and optimising of outlet dimensions to mimic existing pre-development peak runoff rates will be completed through detailed design.

179. An illustration of the attenuation performance of stormwater pond 4 (chainage 13400, near the proposed SH57 roundabout) is provided in **Figure F.32**. Additional detail is provided in the Stormwater Management Design Report (Appendix 4.2 to the DCR).

180. Pond 4 discharges toward the Koputaroa Stream catchment. Post development outflows are throttled to pre-development rates during a 24-hour storm. All shorter duration events display a substantial reduction in pond peak outflow compared to the same duration pre-development peak flow.

181. The stormwater management features of the Ō2NL Project therefore provide a benefit of reducing downstream flood risk in most storms compared to the baseline scenario.

182. Koputaroa Stream is constrained by stop banks that limit its flow capacity and cause it to overtop the stop banks in most years. During these frequent events, the proposed stormwater management devices will significantly reduce peak flows from the Project's contributing area compared to the baseline situation. This represents a slight reduction in the existing flood risk to areas behind the Koputaroa stop banks. The magnitude of the benefit will be small because the Ō2NL Project's contributing area is only 13 hectares ($0.13km^2$). This is only 0.2% of the total $54km^2$ Koputaroa catchment area upstream of its confluence with the Manawatū River.

183. The Koputaroa Stream is occasionally hindered from draining during high levels in the Manawatū River, because of long duration storms higher up in the Manawatū catchment. During these events, flooding of the land behind the stop banks is common, despite the lower intensity rainfall over the Koputaroa catchment. Flooding is caused by local rainfall and inflows from the Koputaroa and Waoku streams which are prevented from draining effectively to the Manawatū River.

184. While the stormwater management devices slightly reduce the magnitude of the peak discharge in the Koputaroa Stream, the Ō2NL Project may result in a very slight net increase in hydrograph volume because of the runoff from new paved areas. The effects of this volume increase are less than minor as explained below using two example events:[12]

(a) During a 24-hour 1:10 AEP event, the lower Koputaroa floodplains are already heavily inundated in the baseline situation over an area of approximately $3km^2$. The additional (delayed) volume contributed by the four stormwater management ponds constructed for Ō2NL in the Koputaroa catchment could be about $13,000m^3$. Distributed over $3km^2$, the potential accumulated increase in depth would be only 4mm after 72 hours (if high levels in the Manawatū prevent gravity drainage). This change is considered less than minor because the area would already be flooded for many hours.

(b) During a 24-hour duration 1:100 AEP event, the lower Koputaroa floodplains are already heavily inundated in the baseline situation over an area of approximately $3km^2$. The additional (delayed) volume contributed by the four stormwater management ponds constructed for

[12] Areas of potential inundation estimated using GIS. Volume estimates obtained from Mr Nick Keenan, author of the Stormwater Management Design Report (Appendix 4.2 to the DCR).

Ō2NL in the Koputaroa catchment could be about 19,000m³. Distributed over 3km², the potential accumulated increase in depth would be only 6mm after 72 hours (if sustained high levels in the Manawatū prevent gravity drainage). This change is considered less than minor because the area would already be flooded for many hours.

185. Koputaroa Stream has sensitive water quality and ecological constraints, which are addressed in Technical Assessment H (Water Quality) and Technical Assessment K (Freshwater Ecology).

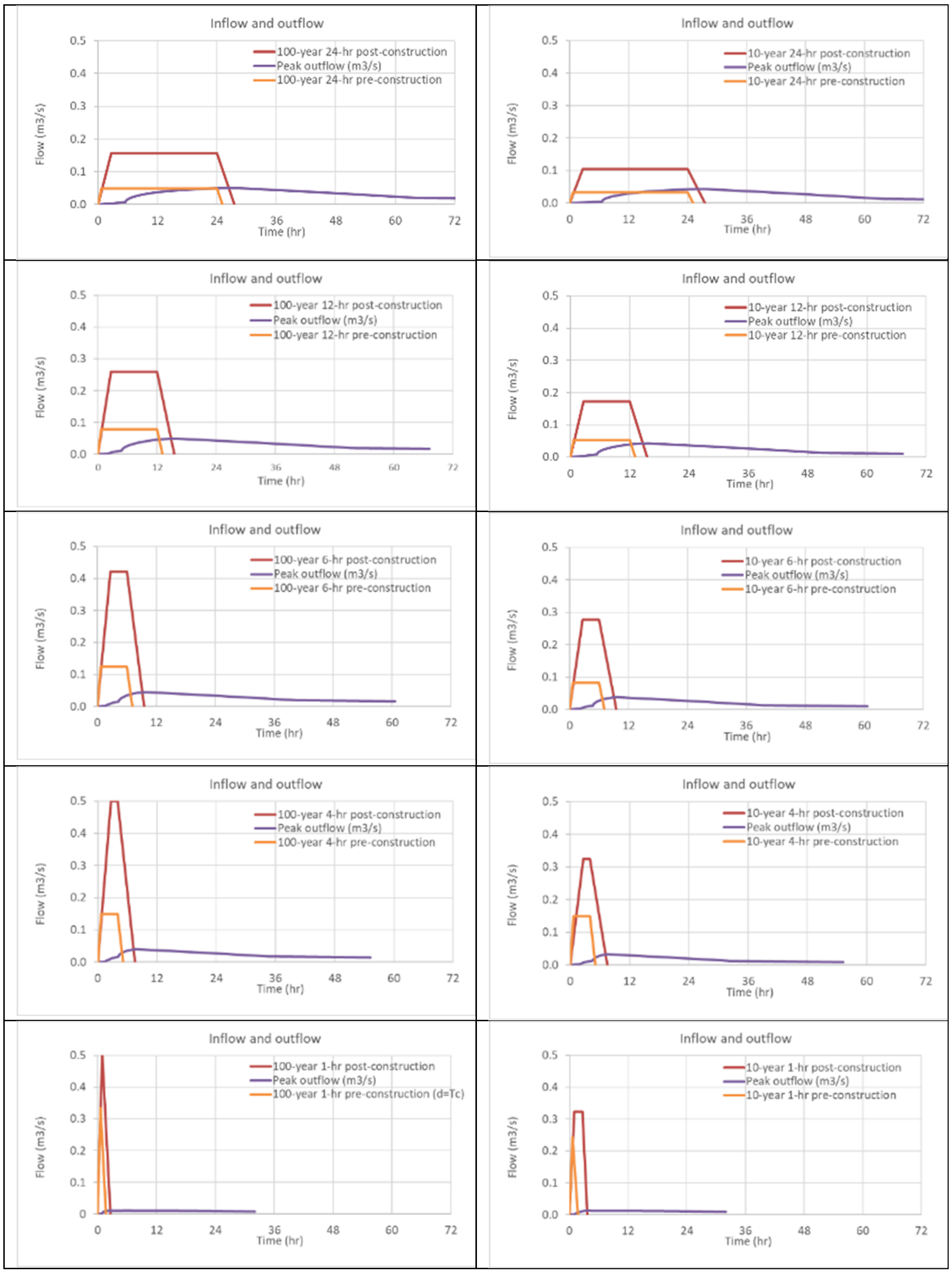


Figure F.32: Stormwater pond 4 attenuation performance illustration

186. For the remainder of the Ō2NL Project area that does not drain toward the Koputaroa Stream, the same stormwater attenuation performance principles have been followed to ensure sufficient space for stormwater management in the proposed designations. The final design of the Project will ensure that the peak pond discharges do not exceed 80% of the pre-development peak flow rate during a critical 4-hour storm up to 1:100 AEP. The 80% factor is intended to avoid any cumulative hydrological effects that could increase the peak flow downstream.[13]

187. Where ground conditions allow, such as south-east of Levin, some treated stormwater will be discharged to ground. These treatment devices have been sized to allow soakage of all runoff during the 1:100 AEP event. A factor has been included to allow for change in efficiency over time. Excess flows in events above this threshold will be routed to mimic existing overland flow paths that otherwise exist in the without Project scenario.

188. As a result of this design philosophy, it is anticipated that the Ō2NL stormwater system will have effects on flooding and hydrology that are less than minor.

189. Some existing receptors may experience marginally less flooding during some events because of the attenuation of highway runoff.

190. Further discussion on stormwater design philosophy and volumetric performance is provided in the Stormwater Management Design Report (Appendix 4.2 to the DCR).

191. Further discussion on the water quality effects of the Ō2NL Project is provided in Technical Assessment H (Water Quality).

Tararua Road / existing SH1 / NIMT improved intersection

192. The proposed improvements to the Tararua Road intersection with existing SH1 include a new level crossing of the NIMT. The proposed works will be essentially 'at grade' with the existing terrain. The NIMT railway line is the highest local hydraulic control at this location, and the works will not change the elevation or drainage of the NIMT railway.

[13] Stormwater Treatment Standard for State Highway Infrastructure, Waka Kotahi NZ Transport Agency, 2010.

193. The detailed design of the new road works will minimise any modification of existing overland flows in flood events and therefore any effect on hydrology and flooding will be less than minor.

Summary of net effects downstream of the Ō2NL Project

194. Results of computational hydraulic modelling have been used to test an indicative concept design for the Ō2NL Project. Slight changes in lateral distribution downstream of some of the bridges redistribute over a short distance and no cumulative effects are passed further downstream. No existing buildings beyond the proposed designations are subject to discernible increases in flood risk. Any effects of the Ō2NL Project on hydrology and flooding are considered less than minor.

195. In addition, the Ō2NL Project will provide a more resilient highway during heavy rainfall that is predicted to increase with climate change. The proposed Ō2NL Project will lower risk exposure and provide greater regional resilience benefits to emergency responders, operators, and users of the road network, compared to the existing SH1.

Construction phase considerations

196. Early construction activities (as discussed in the DCR) will typically include the following activities that are pertinent to hydrology and flooding (some may occur in parallel or in a different order, or broken into project areas):[14]

(a) Preparation of Temporary Works Areas ("**TWAs**"): most TWAs proposed on the drawings have low flood risk, however TWA 4 (north of Tararua Road) and TWA 7b (south of South Manakau Road) both have overland flow paths through the site that could occasionally flow (estimated 1:5 to 1:10 AEP current climate). Since the flows are relatively small and shallow, site layouts could be designed to minimise risk to occupants or equipment and without changing flow patterns downstream.

(b) Preparation of erosion and sediment control measures[15] include open collector channels (to reduce runoff into the main works areas), silt fences, decanting earth bunds, sediment retention ponds, construction water storage ponds, etc. Most of these features are aligned with or will form part of the permanent works associated with the Ō2NL Project.

[14] Refer to Design Construction Report, Volume II, for more detail on construction methodology.
[15] Refer to Erosion and Sediment Control report, Appendix 4.3 to DCR Volume II.

Since these involve only small flows from a very small percentage of each catchment, any changes in flood hydrology will be less than minor.

(c) Temporary access and haul roads created for construction purposes may include some temporary culverts with facilities for controlled overtopping. The design of temporary culverts will ensure that the effects on flooding that are similar or smaller than those of the permanent culvert, ie effects that are less than minor. Fish passage will be maintained on permanently flowing streams.

(d) Placement of permanent culverts on smaller streams or ephemeral overland flow paths, which may involve temporary and/or permanent flow path realignments as discussed in the DCR.

(e) Bridge piles, abutments, and piers will be designed and constructed to avoid increasing flood risk to inhabited buildings, scour or obstructing fish passage. Temporary works design and construction methodology are discussed in the DCR.

(f) Construction water abstraction, storage and application (e.g., for dust suppression). The small abstraction and application rates will not have an impact on flood hydrology. The proposed maximum abstraction rates are within catchment allocations in the Regional Plans,[16] in order to avoid or minimise effects. Abstraction will be reduced or ceased during periods of low flow. The management of water takes to avoid or minimise potential effects during periods of low flow is discussed in Technical Assessments K (Freshwater Ecology) and Technical Assessment G (Hydrogeology and Groundwater).

197. Many of these activities will take place relatively early, prior to much of the bulk earthworks, and under current climate rather than future climate. Therefore, the effects of the construction phase on hydrology and flooding will be less than those of the operational stage. In summary, construction phase effects will be less than minor.

---

[16] Discussed in Chapter 4.7.6.8 of the DCR, Table 4.4.

Operational phase considerations

198. The effects discussed throughout this report are applicable to a medium-high RCP 6.0 climate scenario after 100 years. This is considered a conservative case in terms of hydrological boundary conditions applied to the assessment.

199. The detailed design stage will develop monitoring and maintenance plans for managing scour, debris and sediment where required (especially after significant floods). This will include regimes to clear debris arrestors upstream of culverts, sediment traps and stilling basins.

SUMMARY RATING OF EFFECTS

200. Overall effects of the Ō2NL Project on hydrology and flooding will, in my opinion, be less than minor.

201. **Upstream** changes in peak water levels greater than 0.05m relative to baseline (for 1:100 AEP with climate change RCP 6.0 to 2130) have been mapped and evaluated, with the following findings:

   (a) Increases in flood levels upstream of bridges and culverts are generally contained within the proposed designation boundaries. Modelled increases dissipate to less than 0.1m within 50m upstream of the proposed designation boundaries (70m in the case of the Ohau River) and are commensurate with the landscape and land-use context and the extreme nature of the design event. The short durations of increased water levels are considered unlikely to have a material effect on sediment deposition or crop recovery.

   (b) No buildings outside the proposed designations are impacted by the modelled increase in flood levels for the 1:100 AEP with climate change RCP 6.0 to 2130.

   (c) In more frequent flood events such as the 1:10 AEP current climate, the peak flood level changes are contained within the proposed designations, except for backwater effects on the Ohau River that dissipate to less than 0.1m approximately 50m upstream of the proposed designation.

   (d) Therefore, given the rural context, the extreme nature of the design event (1:100 AEP with climate change RCP 6.0 to 2130), and the short duration and small footprint of impacts, I consider these effects less than minor.

202. **Within the proposed designations,** the design philosophy for bridges and culverts allows for effective passage of water and sediment underneath the Ō2NL Project:

(a) Localised increases in velocity within the proposed designations are small and will be managed with scour protection.

(b) Flows redistribute laterally to confirm to their original floodplain pattern within a very short distance downstream of the structures, and generally within the proposed designations.

(c) Fish passage is provided except for some culverts on ephemeral flow paths where no fish are present, and no viable habitat exists upstream.

(d) Stormwater from the highway will be managed within the proposed designations, including treatment and attenuation of any discharge. Scour protection will be provided where necessary, and any effects on hydrology and flooding will be less than minor.

203. **Downstream** of the bridges and culverts:

(a) Flows redistribute laterally to confirm to their original floodplain pattern (<0.05m relative to baseline) within the proposed designations or a short distance downstream (<115m in the case of the Ohau River for the 1:100 AEP design event with climate change).

(b) In the 1:10 AEP event, the only locations to show modelled increased levels downstream of the proposed designations are the Ohau River, Waikawa Stream tributary and Manakau Stream. These are all because of small changes in lateral distribution that totally redistribute upon returning to the main channel a short distance downstream.

(c) There are no cumulative effects passed further downstream, and no existing bfuildings with discernible increases in flood risk.

Conclusion

204. Based on my detailed assessment, my professional opinion is any adverse effects of the Ō2NL Project on hydrology and flooding in the area will be less than minor.

205. Increase in heavy rainfall anticipated from climate change is predicted to exacerbate flooding along the existing SH1. The proposed Ō2NL Project will lower risk exposure and provide greater regional resilience benefits to emergency responders, operators, and users of the road network, compared to the existing SH1.

MEASURES TO REMEDY OR MITIGATE ACTUAL OR POTENTIAL ADVERSE HYDROLOGICAL OR FLOODING EFFECTS

206. My assessment above concludes that any adverse effects of the Ō2NL Project on hydrology and flooding in the area will be less than minor.

207. No measures to remedy or mitigate actual or potential adverse flood effects are required outside of the proposed designations.

208. Within the proposed designations, the potential effects of increased velocity (for example at bridges, culvert outlets, or steep open collector channels) will be mitigated by scour protection measures. Potential effects of increased runoff from paved surfaces will be remedied by stormwater management devices that capture, treat, attenuate, and discharge runoff in a manner that mimics pre-development rates.

209. Potential effects during construction will be mitigated by appropriate construction methodologies with managed overflow pathways that do not exacerbate flooding elsewhere. Construction water abstractions and application will not have an impact on flooding patterns.

210. In my opinion, no additional measures will be required to remedy or mitigate actual or potential hydrological or flooding effects.

CONCLUSION

211. Based on a detailed assessment, any adverse effects of the Ō2NL Project on hydrology and flooding in the area will be less than minor. The new highway will provide significant resilience benefits to operators and users of the road network.

Andrew Craig

14 October 2022

BIBLIOGRAPHY

Adapting to Climate Change in New Zealand. MfE. 2018.

Blockage Guidelines for Culverts and Small Bridges. Australian Rainfall & Runoff report. 2015.

Bridge Manual, 3rd edition. Waka Kotahi NZTA SP/M/022. 2018.

Bridge Scour. Coleman S.E., Melville, B.W. Transfund NZ Report 196. 2001.

High Intensity Rainfall Design System (HIRDS), v4. Carey-Smith, T., Henderson, R., Singh, S. NIWA. 2018.

Interim Specification: Approach to climate change assessments for NZUP and Fast-Track Consenting land transport infrastructure projects. Waka Kotahi. 2021.

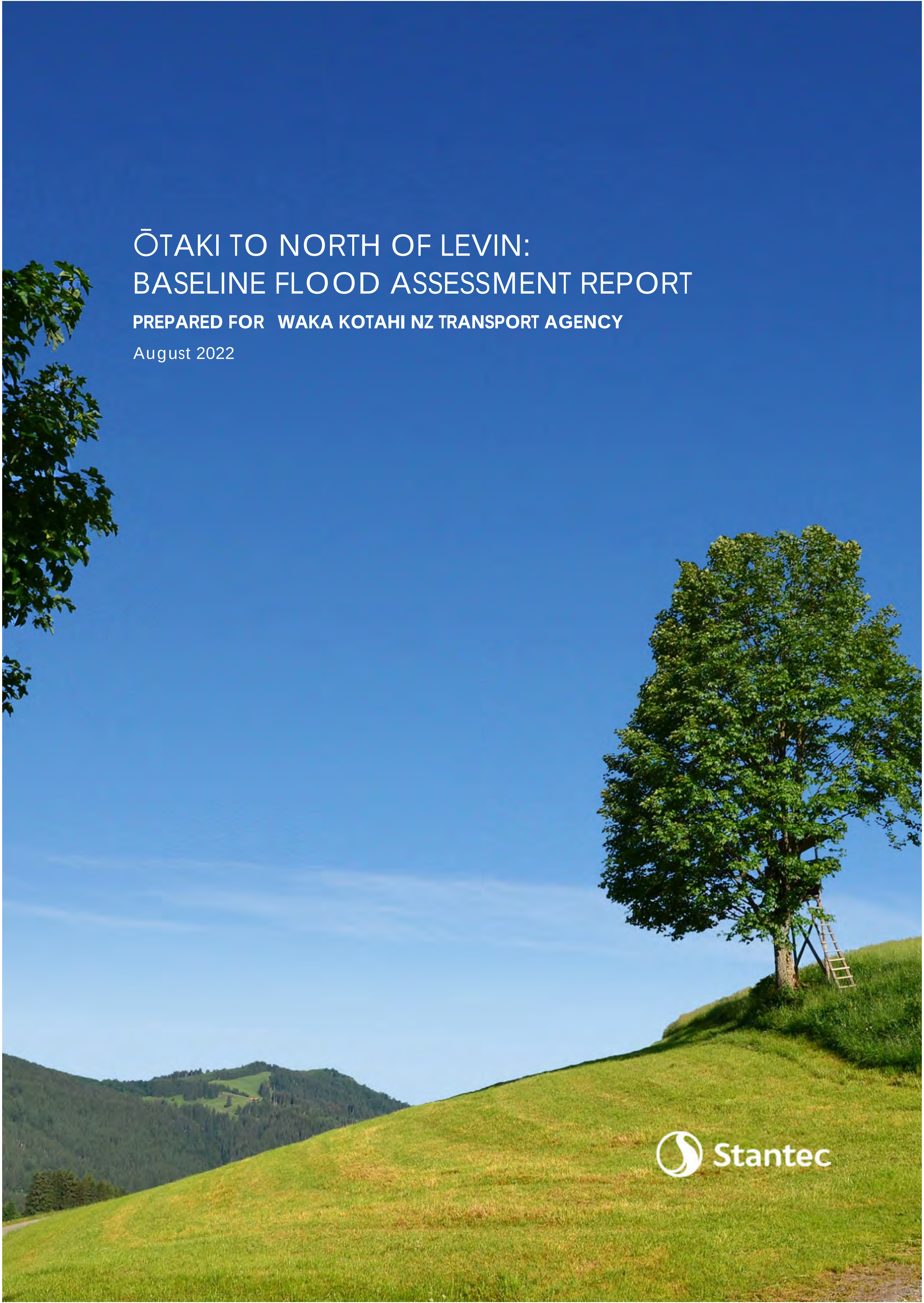
New Zealand Fish Passage Guidelines for structures up to 4m. NIWA/DOC. 2018.

Regional Flood Estimation Tool for New Zealand, Part 2. NIWA. 2018.

Resource Management National Environmental Standards for Freshwater Regulations. MfE. 2020.

Stormwater Specification. Waka Kotahi NZTA P46. 2016.

APPENDIX F.1: BASELINE FLOOD REPORT



ŌTAKI TO NORTH OF LEVIN: BASELINE FLOOD ASSESSMENT REPORT

PREPARED FOR WAKA KOTAHI NZ TRANSPORT AGENCY

August 2022

Stantec

QUALITY STATEMENT

PROJECT MANAGER	PROJECT TECHNICAL LEAD
Jon England	Phil Peet

PREPARED BY		
Andrew Craig	………………………………..........	18/08/2022
CHECKED BY		
Nick Keenan	………………………………..........	26/10/2021
REVIEWED BY		
Jamie Povall	………………………………..........	26/10/2021
APPROVED FOR ISSUE BY		
Jamie Povall	………………………………..........	26/10/2021

WELLINGTON
Stantec House
Level 15, 10 Brandon Street, Wellington 6011
PO Box 13-052, Armagh, Christchurch 8141
TEL +64 4 381 6700,

REVISION SCHEDULE

Rev No.	Date	Description	Signature or Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
0	17/04/2020	Preliminary Baseline Flood Assessment Report	AC	JP		
1	12/02/2021	Baseline Flood Assessment Report: Draft final	AC	NK	JP	JP
1.2	26/10/2021	Baseline Flood Assessment Report: Draft Final	AC	NK	JP	JP
1.3	04/03/2022	Baseline Flood Assessment Report: Final (update selected figures)	AC	NK	JP	JP
1.4	18/08/2022	Baseline Flood Assessment Report: Final (update selected figures)	AC	NK	JP	JP

Abbreviations

Abbreviation	Full Name
AEE	Assessment of Environmental Effects
ARF	Aerial Reduction Factor
AEP	Annual Exceedance Probability
DBC	Detailed Business Case
DEM	Digital Elevation Model
FFA	Flood Frequency Analysis
FSL	Fundamental Soil Layer
GWRC	Great Wellington Regional Council
HDC	Horowhenua District Council
HIRDS	High Intensity Rainfall Dataset
HRC	Horizons (Manawatū-Whanganui) Regional Council
h	Hour(s)
IPCC	International Panel on Climate Change
KCDC	Kapiti Coast District Council
LiDAR	Light Detection and Ranging (airborne survey to prepare DEM)
LINZ	Land Information New Zealand
NES-F	Resource Management (National Environmental Standard for Freshwater) Regulations 2020
MfE	Ministry for the Environment
Ō2NL	Ōtaki to North of Levin Project
PMP	Probable Maximum Precipitation
PP2Ō	Peka Peka to Ōtaki Expressway
RCP	Representative Concentration Pathway (IPCC climate scenario)
SLS	Serviceability Limit State
SH1	State Highway 1
ULS	Ultimate Limit State
Waka Kotahi	Waka Kotahi New Zealand Transport Agency

WAKA KOTAHI NZ Transport Agency

Ōtaki to North of Levin:
Baseline Flood Assessment Report

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1. Introduction

1.1 Background to the Project

Waka Kotahi NZ Transport Agency (‘Waka Kotahi’) is investigating a new 24km offline highway from Ōtaki to north of Levin (Ō2NL). The Project extent is between the SH1 / Koputaroa Road intersection north of Levin, to south of Taylors Road near Ōtaki where it links with the Peka Peka to Ōtaki (PP2Ō) Expressway.

Previous stages of the project looked at various corridor routes, which led to selection of the preferred corridor passing east of Levin. The preferred corridor identified in the Indicative Business Case (IBC) was approximately 300m wide. This has since been refined to the corridor shown approximately in Figure 1-1 (the final Designation extents may differ). The project is currently progressing through Detailed Business Case and intermediate level design toward preparation of consent applications (Resource Consent and Notice of Requirements).

This baseline flood assessment report presents an improved understanding of the flood risk near the corridor, which will be used to test the potential effects and mitigation design for the Project. Therefore, this report is not sensitive to design changes, and any reference to the corridor or the potential design only serves to highlight the area of greater interest or focus for the baseline model. A separate report will discuss the scheme representation and assessment of effects post scheme.

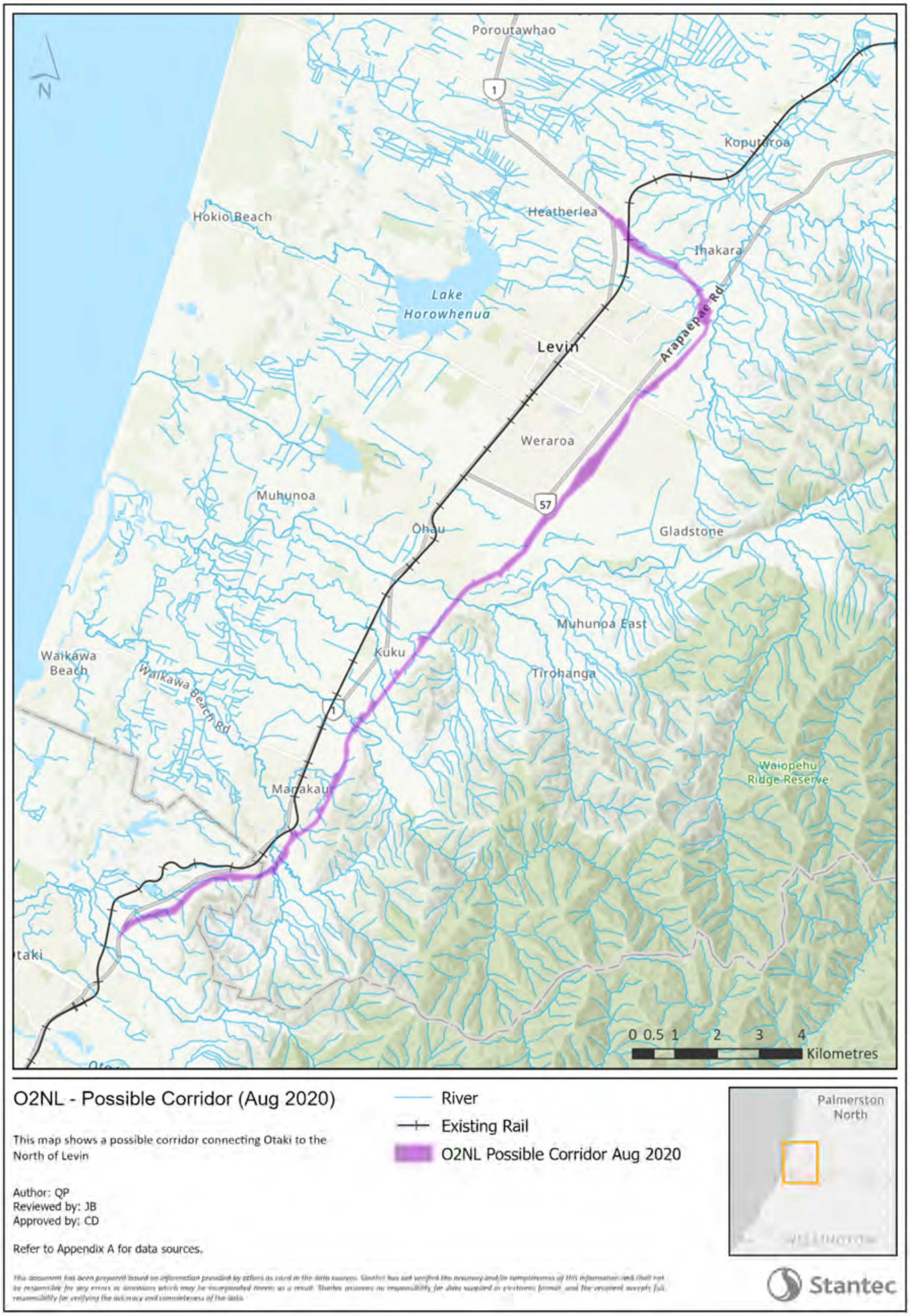


Figure 1-1: Location map and indicative Ō2NL Corridor

1.2 Purpose and Scope of this Assessment

This Baseline Flood Assessment Report presents a description of flood risk information in the vicinity of the Ō2NL Project corridor. It is based on existing topographical and asset information but includes an assessment of future climate change factors. This will provide Waka Kotahi and local councils with confidence that a sound baseline understanding will be used for the assessment of effects. The updated baseline information will also inform ongoing design work for the DBC.

There will necessarily be some assumptions and limitations, due to information gaps or modelling processes. These have been captured through the reporting process, and some may need to be revisited during Detailed Design to test whether the assumption has bearing on the final design or mitigation measures.

2. Reference Information

Key reference datasets obtained as foundation to this study are outlined below. The application of the datasets in analytical context is described later in the report.

2.1 Previous Ōtaki to Levin Studies Relevant to this Report

During the previous IBC Phase, flooding of the existing State Highway 1 (SH1) was identified as a key concern and resilience risk to the operation and availability of the existing highway. Flooding has caused the closure of SH1 numerous times in recent years. There is no possible alternative route for much of the project length, so providing an alternative and resilient transport corridor was a key project objective identified during the IBC stage.

The Multi-Criteria Analysis undertaken as part of the IBC included an Engineering Considerations criterion, part of which considered potential flooding risk of the corridor options. Horizons Regional Council provided advice on flood risk and known problematic locations during the IBC. The District Plan flood risk areas were also utilised previously to inform early stages of the project.

No 'new' flood modelling assessments were completed in previous phases of the project.

2.2 Regional Information Sources and GIS

2.2.1 Horizons Regional Council

The following relevant datasets have been obtained from Horizons Regional Council (HRC):

- A large proportion of the LiDAR derived DEM dataset towards the North and West of the study area. This data was captured over the course of multiple surveys between 2005 and 2018 at 1m resolution, and in the Wellington 1953 vertical datum. See Figure 2-1 below for coverage extent.
- Indicative modelled 1:200 AEP flood extents for the larger rivers in the region.
- Flow data for the Ōhau river at the Rongomatane river level gauge. A flood frequency analysis was also provided.
- Flow data for Koputaroa, Manakau and Wakawa streams, as discussed in Section 4.3.
- Rainfall data as discussed in section 4.2.1.
- Aerial imagery for the Horizons Region, captured in the summer of 2016-17, obtained via the LINZ data service.
- Existing surveyed cross section data for the lower Ōhau River (June-July 2018), from just upstream of the Rongomatane river level gauge to just downstream of the existing SH1.
- Background reports on the Koputaroa Drainage Scheme (scheme reviews 1997, 2007, 2014).

2.2.2 Greater Wellington Regional Council

The following relevant datasets have been obtained from Greater Wellington Regional Council (GWRC):

- LiDAR derived DEM covering the southern portion of the route, captured in 2013 and 2016 at 1m resolution, and in the NZD2016 vertical datum. See Figure 2-1 for coverage extent. We intend to adjust this data to Wellington 1953 vertical datum to provide a consistent vertical datum for the project.

- Aerial imagery for the Greater Wellington Region, captured in the summer of 2016-17, obtained via the LINZ data service.
- Rainfall data for the Ōtaki River at Depot, East Waitewaewae at Oriwa and Waitatapia Stream at Taungata gauges.

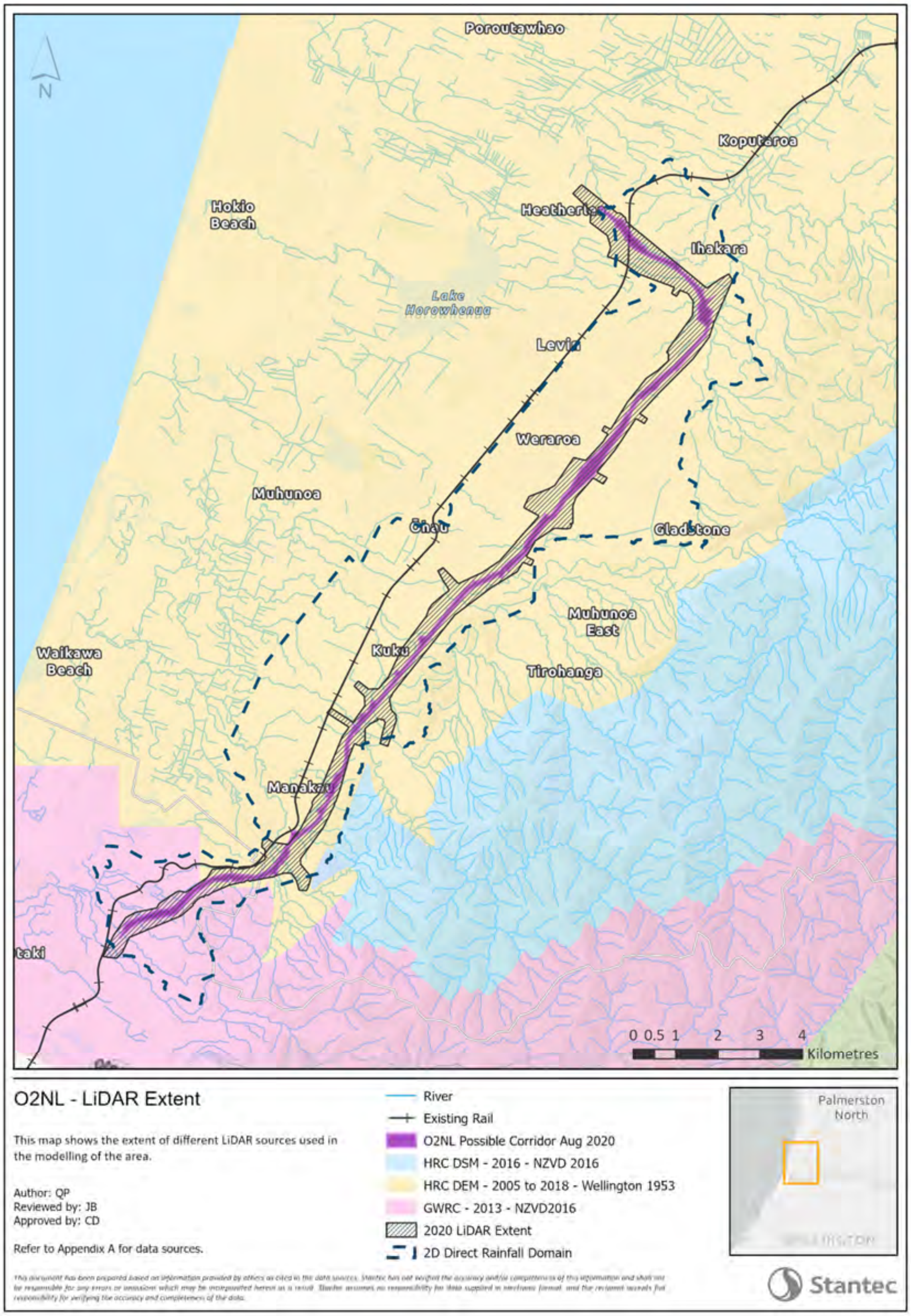


Figure 2-1: Extents of LiDAR datasets (source authority, year captured, and vertical datum)

2.2.3 Horowhenua District Council

The following relevant datasets have been obtained from Horowhenua District Council (HDC):

- Aerial imagery captured in the summer of 2015-16, obtained via the LINZ data service.
- Existing bridges and drainage asset information.
- Existing stormwater models for the built-up areas of Levin and Ōhau.
- Background reports on Catchment Management Plan modelling for the urbanised areas of Levin and Ōhau.
- Interim information on the proposed development of Tara-Ika east of Levin.

2.2.4 Kapiti Coast District Council

The following relevant datasets have been obtained from Kapiti Coast District Council (KCDC):

- Aerial imagery captured for the Kapiti Coast District Council area, captured in the summer of 2016-17, obtained via the LINZ data service.
- KCDC stormwater asset data.

2.2.5 Waka Kotahi NZ Transport Agency

The following relevant datasets have been obtained from Waka Kotahi:

- Existing State Highway bridges and drainage pit asset information
- Construction drawings and hydraulic model for the northern end of Peka Peka to Ōtaki Project (PP2Ō). The PP2Ō–Post Project Hydraulic Model files were used to update the northern end of PP2Ō construction details that represent the starting baseline conditions for assessment of the southern part of the Ō2NL project. The PP2Ō DHI MIKE model files were utilised to modify the proposed highway embankment north of the Waitohu River, including the proposed Greenwoods culvert.

2.2.6 KiwiRail

The following relevant datasets have been obtained from KiwiRail:

- KiwiRail existing bridge and culvert datasets.

2.2.7 Landcare Research

The following relevant datasets have been obtained online from Landcare Research using the Land Resource Information Systems (LRIS) portal[1]:

- Land Environments of New Zealand (LENZ) soil drainage layer – national level dataset providing a key component of the hydrology.
- Land Cover Database version 5.0 (LCDB v5) was extracted from the LRIS portal to classify the land cover on the hydraulic modelling extent. The LCDB v5 is a multi-temporal, thematic classification of New Zealand's land cover. It identifies 33 mainland land cover classes (35 classes once the offshore Chatham Islands are included). LCDB v5 was released in January 2020.

2.2.8 NIWA

The following relevant datasets have been obtained from NIWA:

- HIRDS v4 rainfall digital dataset.
- Levin MAF and Levin AWS rain data

2.2.9 2020 high-resolution aerial imagery and DEM

The present study included a new drone-based survey which captured aerial imagery and generated a DEM using photogrammetric processing. The survey campaign was flown by Cardno in July 2020 and

[1] https://lris.scinfo.org.nz/

covered the indicative project extents. The final point cloud has a point spacing of approximately 0.1m. The coordinate reference system is NZGD 2000 Transverse Mercator and the datum is Wellington 1953.

2.3 Key Guidance and Design Standards Referenced

The following standards are particularly relevant to this report:

- Adapting to Climate Change in New Zealand (MfE, 2018)
- HIRDS High Intensity Rainfall Design System (v4, NIWA, 2018)
- NZTA SP/M/022 Bridge Manual (3rd edition, NZTA, 2018)

2.4 Selection of Design Scenarios

Whilst this report focusses on baseline risk, it will be required to focus on scenarios that will be used to inform design and/or assessment of effects. For design purposes, the highway classification (under the NZTA One Network Road Classification) has been selected as "IL3+ National (High Volume)". The associated serviceability and ultimate limit state design scenarios are provided in Table 2.1 of the NZ Bridge Manual, reproduced below:

Table 2-1: Design scenarios (reproduced from NZ Bridge Manual Table 2.1)

Bridge categorization	Importance level (as per AS/NZS 1170.0(4))	Bridge permanence*	Annual probability of exceedance for the ultimate limit state		Annual probability of exceedance for the serviceability limit state	
			ULS for wind, snow and floodwater actions	DCLS for earthquake actions	SLS 1 for wind, snow and floodwater actions	SLS 2 for floodwater actions
Bridges of high importance to post-disaster recovery (eg bridges in major urban areas providing direct access to hospitals and emergency services or to a major port or airport from within a 10km radius). Bridges with a construction cost (including associated ground improvements) exceeding $16 million (as at June 2018).	4	Permanent	1/2500	1/2500	1/25	1/100
		Temporary	1/1000	1/1000	1/25	1/100
Bridges on highways classified as National (High Volume in the One Network Road Classification (ONRC).	3+	Permanent	1/1500	1/1500	1/25	1/100
		Temporary	1/700	1/700	1/25	-
Bridges on highways classified as National, Regional, Arterial, Primary Collector or Secondary Collector in the ONRC.	3	Permanent	1/1000	1/1000	1/25	1/100
		Temporary	1/500	1/500	1/25	-

The design life (planning horizon) will extend to 100 years in accordance with the Bridge Manual. Assuming a start of operation around 2030, the design life will extend until at least 2130. This is particularly relevant for climate change. The allowances for climate change are based on HIRDS v4, noting this is based in turn on IPCC 5th assessment of 2014. The main SLS2 design scenario for flooding will be 1:100 AEP, with climate change scenario RCP6.0 extrapolated to 2130. HIRDS v4 only provides climate adjusted tables out to the epoch 2081-2100, and the extrapolation approach used to extrapolate out to 2310 is discussed in Section 4.2.7. RCP6.0 is a moderately conservative (medium-high) climate projection, which is considered suitable for the Ō2NL highway as the main SLS2 design case for operational use. The RCP6.0 scenario was also applied for the recent Te Ahu a Turanga; Manawatū Tararua Highway Project. The potential impacts of higher climate outcomes will be tested through the ULS case, namely the 1:1500 AEP with a more conservative RCP8.5 extrapolated to 2130. In summary, the following key scenarios will be used:

Table 2-2: Selected key scenarios

Annual Exceedance Probability		Climate Scenario	Description
1:10	10%	Current climate	Easier to relate to floods in recent history
1:100	1%	RCP6.0 2130	SLS2, operationally functional (at least one lane open in each direction)
1:1500	0.067%	RCP8.5 2130	ULS, resilience case (damage limitation, avoiding collapse)

Storm durations used are discussed further in Section 4.4.2. Adjustments for climate change are discussed in Section 4.2.7.

The modelling for future epochs is based on current topography, drainage assets and estimated infiltration rates. These may change slightly in future through natural morphological change (including earthquakes and associated debris load in addition to gradual erosion and aggradation processes), and/or anthropological changes in land-use with associated impacts on infiltration/runoff. For the purposes of the modelling, it is assumed that hydrological catchment net response to any depth-duration rainfall event will remain similar to historic performance to up 1:100 AEP with climate change, despite future anthropological or morphological change. This is considered a reasonable assumption because plans submitted under the RMA seek to ensure hydraulic neutrality to avoid or minimise potential adverse effects.

3. Existing Environment

3.1 Topographic Overview and Land Use

Along most of the route from Ōtaki to East of Levin, the topography slopes from the hills in the east towards the flatter coastal plains in the west, as shown in Figure 1-1. As the northern extent of the route wraps around the northern side of Levin, the drainage is generally north-eastwards toward the Koputaroa and Manawatū River floodplain. Over 30 significant catchments have been identified that drain across the corridor, although the final number will depend on the final alignment (work still in progress). The catchment definition process is described in Section 4.1. The Tararua Range forms the eastern boundary of most of the catchments, and with a maximum elevation (just outside the catchment) of 1570m this range generates significant orographic precipitation effect (refer Section 4 and Figure 4-8).

Catchment land use varies per catchment, but typically includes forested areas (approximately one third on average, notably on the hills and along the banks of some watercourses) and rural farmland with relatively low density scattered dwellings. As a result, all catchments are considered rural for the purposes of determining hydrology.

The geology is dominated by unconsolidated sediments of both fluvial and marine provenance, and as a result the soils are predominately medium to well drained as defined by Land Environments New Zealand (Soil Drainage, LRIS portal[2]).

3.2 Rivers and Streams

The largest watercourse crossing is the Ōhau River, which is a relatively high energy braided river with mobile bed material. Smaller watercourses include the Waikawa, Manakau, Waiauti and Kuku streams, plus several smaller unnamed streams and drains. These smaller drains were identified using LINZ online mapping plus LiDAR and high-resolution aerial imagery referenced in Section 2.2.

3.3 Existing Infrastructure

As described in Section 2.2, information was gathered from various local and national authorities on existing bridges and culverts, plus road and rail embankments, that will influence the progression of floodwaters in the area. The application of these in the hydraulic model is described in Section 5.

[2] https://lris.scinfo.org.nz/

4. Hydrology

4.1 Catchments

4.1.1 Catchment boundaries for input into the hydraulic model

LiDAR and high-resolution aerial imagery were used to initially identify locations of watercourses that cross the indicative Project corridor. Catchments were then delineated above these proposed crossing points, to allow estimation of design flood flows by various methods. For the larger catchments above approximately 2km^2, point inflows will be used as inputs to the hydraulic model. Direct rainfall is then applied to the small catchments closer to and downstream of the corridor. This allows a baseline understanding of peak flood levels to be achieved everywhere in the vicinity of the corridor, irrespective of the eventual alignment (which was not known when the baseline model was first being developed).

Sub-catchments were delineated where necessary within the larger catchments to allow a more detailed representation of their respective contribution and timing in the hydrological modelling. Catchment and sub-catchment boundaries are shown in Figure 4-2. The application of the catchments within the modelling are discussed further in the subsequent sections of this report.

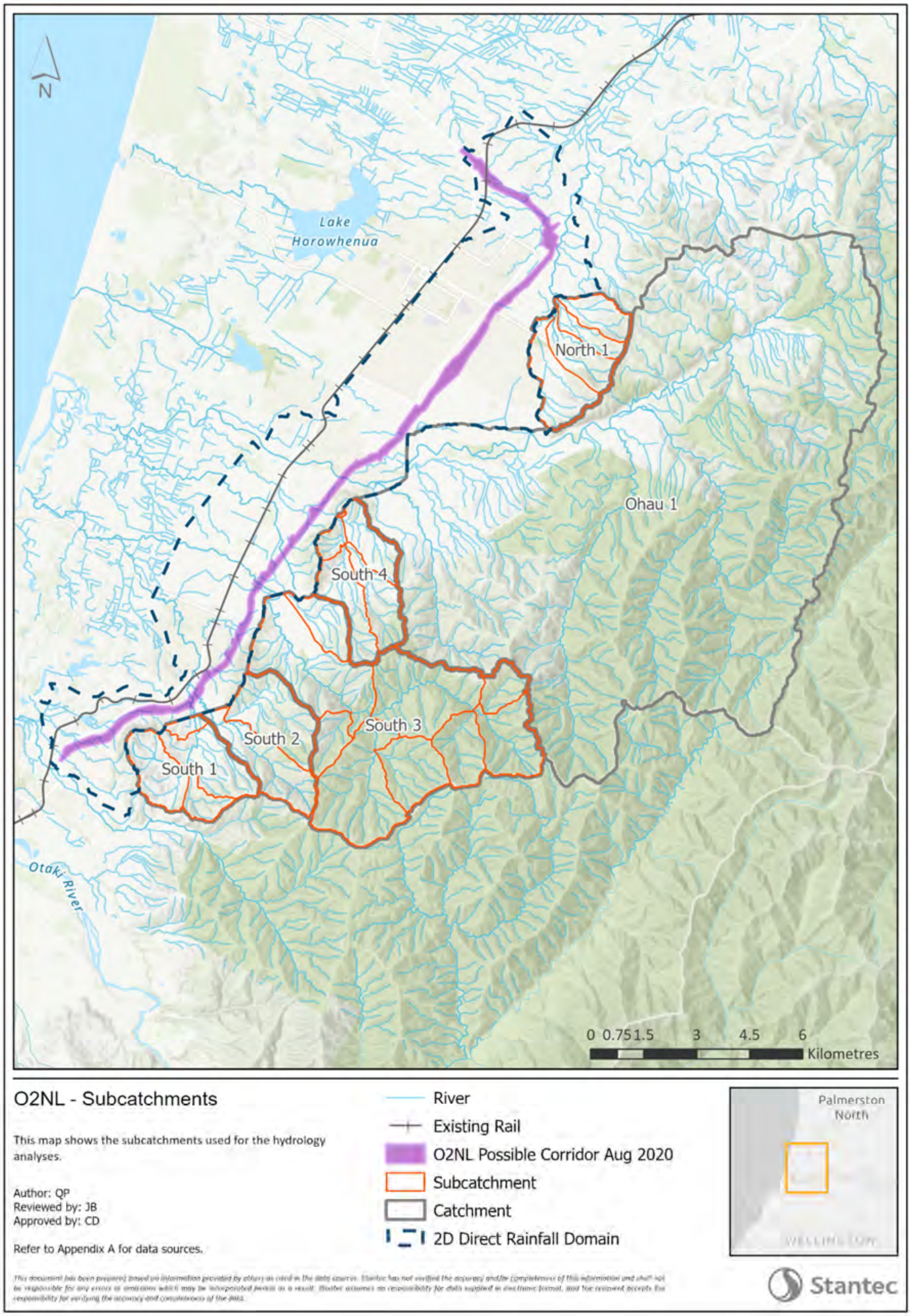


Figure 4-1: Catchment & sub-catchment delineation

4.1.2 Additional Validation Catchments

Manakau and Koputaroa catchments were also delineated further downstream of the Ō2NL corridor, where suitable flow gauge data was available to aid validation of the hydrological model. The Waikawa at North Manakau Rd flow gauge was also used to validate the Waikawa (South 3) catchment hydrological model. Refer to Section 4.3 for discussion regarding flow gauge & data suitability.

Catchment 39 (one of the catchments draining to a large culvert under the proposed Ō2NL highway, within the Koputaroa catchment) was used as an additional comparison point between the hydrological and hydraulic model results. These additional catchments are shown in Figure 4-2 below.

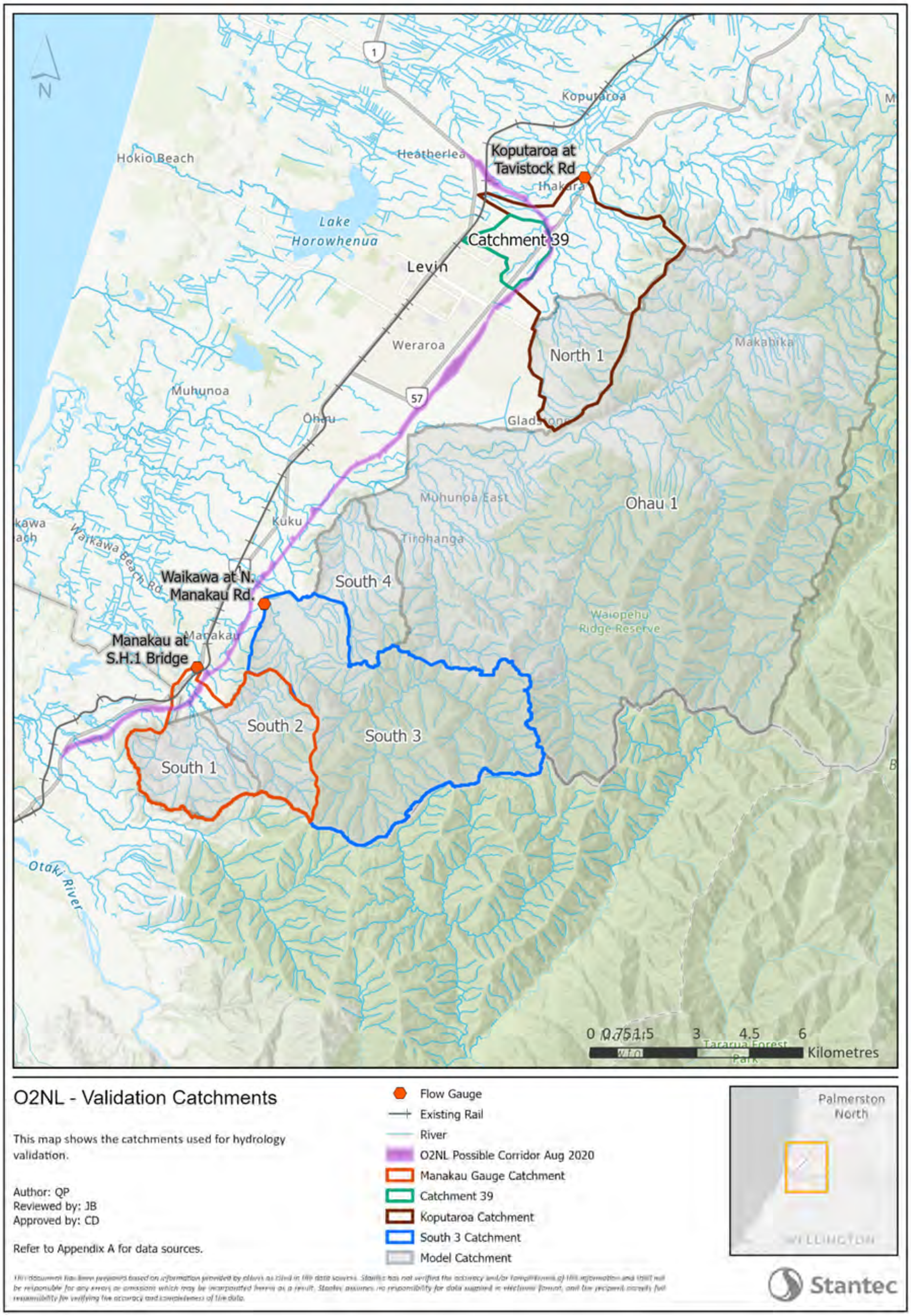


Figure 4-2: Catchments used for validation

4.2 Rainfall

4.2.1 Rain gauges

There are 8 rainfall gauges in or near the study area, where data has been collected for potential use in the calibration of rainfall runoff models and analysis of rainfall variability. These are summarised in Table 4-1 below. The temporal availability of data is shown in Figure 4-3, and the locations are shown on Figure 4-4.

Table 4-1: Rain gauges in or near the catchments

Name	Site Number	Latitude	Longitude	Recording Authority	Start of Data	End of Data	Altitude
Manawatū at Moutoa	55303	-40.4914	175.37207	HRC	Oct-99	Jun-20	5
Mangahao at No1 Dam	56403	-40.6252	175.47793	HRC	Jan-00	Jun-20	390
Ōhau at Makahika	56404	-40.6413	175.40065	HRC	Dec-09	May-20	240
Levin AWS	3275	-40.6199	175.2595	NIWA	Jan-95	Jan-13	15
Levin MAF	3277	-40.65	175.269	NIWA	Jan-86	Jan-91	46
East Waitewaewae at Oriwa	57302	-40.7496	175.34851	GWRC	Sep-91	Dec-20	1050
Waitatapia Stream at Taungata	58201	-40.8102	175.25687	GWRC	Sep-91	Dec-20	980
Ōtaki River at Depot	57106	-40.7693	175.14467	GWRC	Jun-92	Sep-20	17

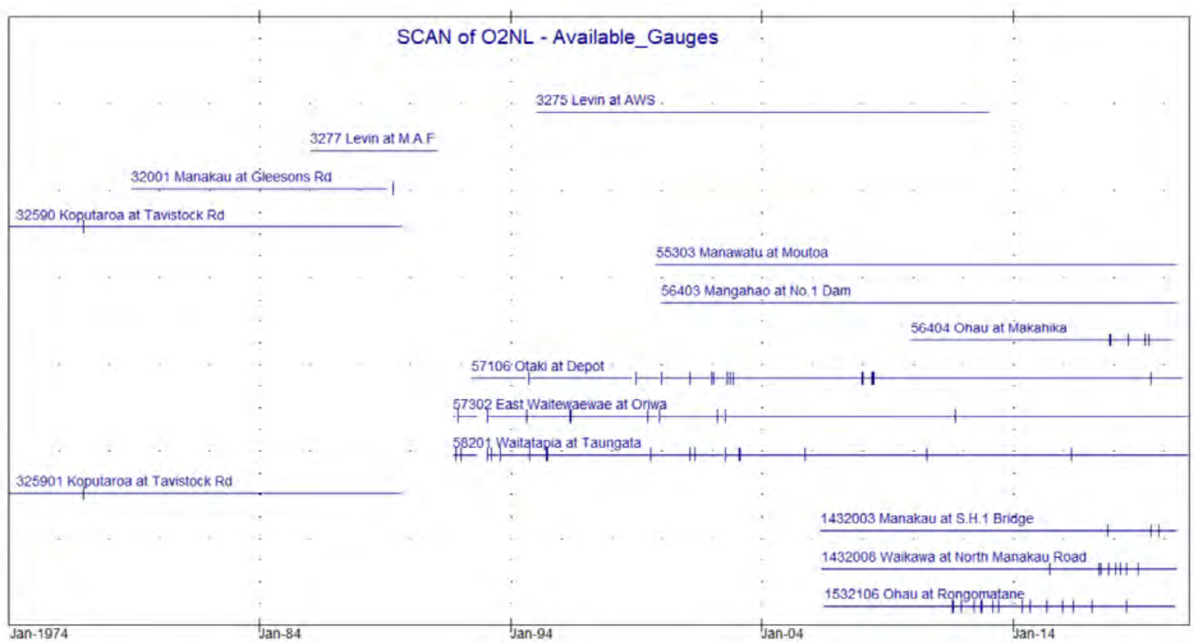


Figure 4-3: Graph showing availability of rainfall and flow gauge data

As illustrated in Figure 4-4 there are gauges at low elevations and at high elevation in the Tararua ranges which aid in estimation of the orographic precipitation gradient present in the larger catchments. For the gauges located in the ranges, the recording authority notes that they suffer from large evaporation discrepancies and are occasionally tampered by trampers.

Figure 4-5 shows cumulative rainfall plots for each gauge. This shows generally increasing rainfall gradient with elevation, although the gauge at Oriwa reports much more rainfall than Taungata which is at a relatively similar elevation and distance into the Tararuas. The disparity between these two gauges is discussed later in this chapter. The gauges on the coastal plain show a generally flatter gradient. There are no significant changes in cumulative rainfall gradient for these graphs, which confirms that there have been no significant changes in gauge exposure. Gaps in the data are indicated by squares.

Thiessen polygons were created based on the available gauge data for each observed event, to derive weighted catchment-average rainfall timeseries for use in the calibration process. An example of Thiessen polygons for the January 2008 event is shown in Figure 4-6. Given the sparse spacing of the rain gauges relative to the steep rainfall gradient, this method has limitations and might not accurately represent catchment average rainfall for some events. This application of catchment average rainfall is discussed further in 4.4.3 and Appendix C.

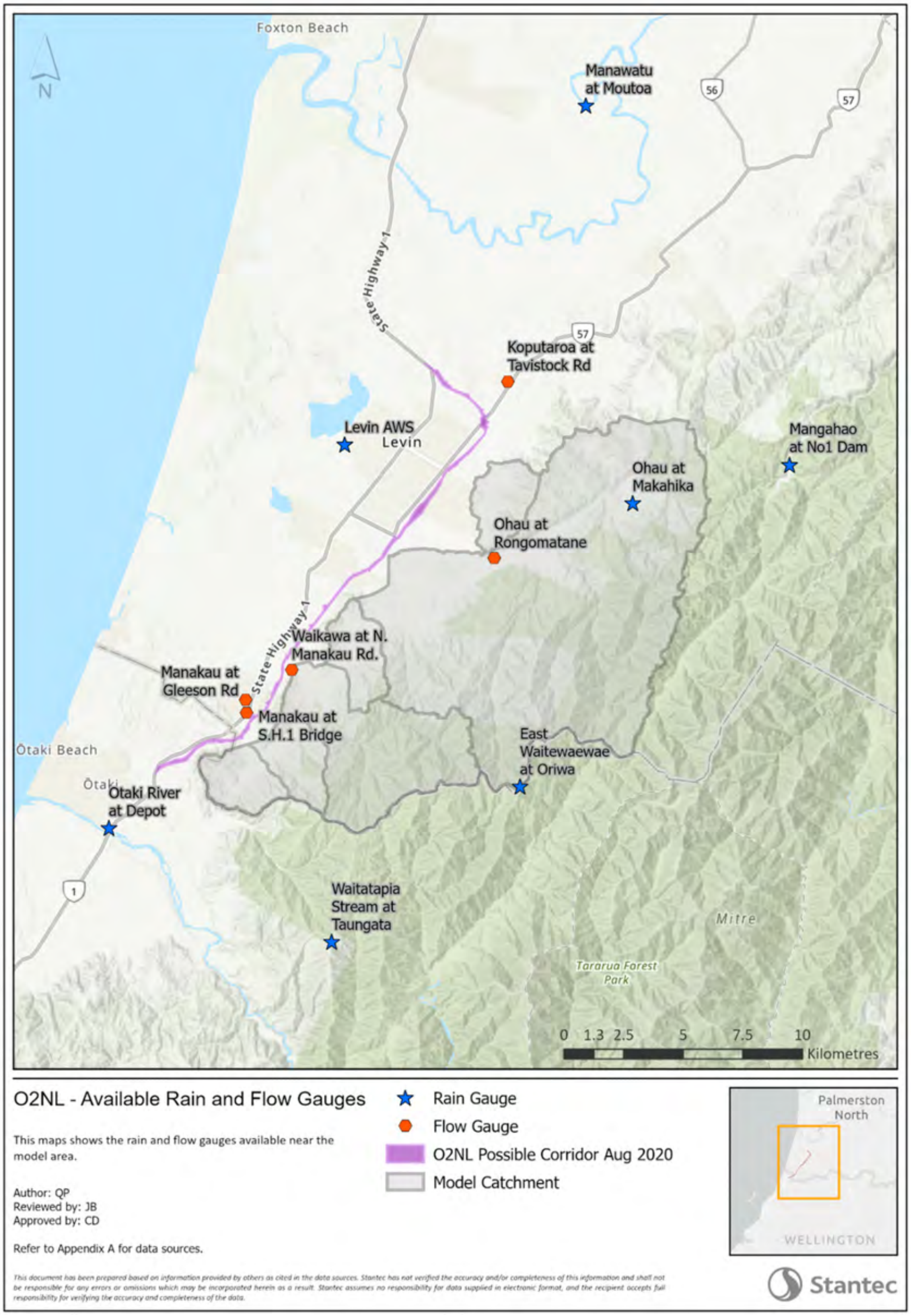


Figure 4-4: Available rain and flow gauges

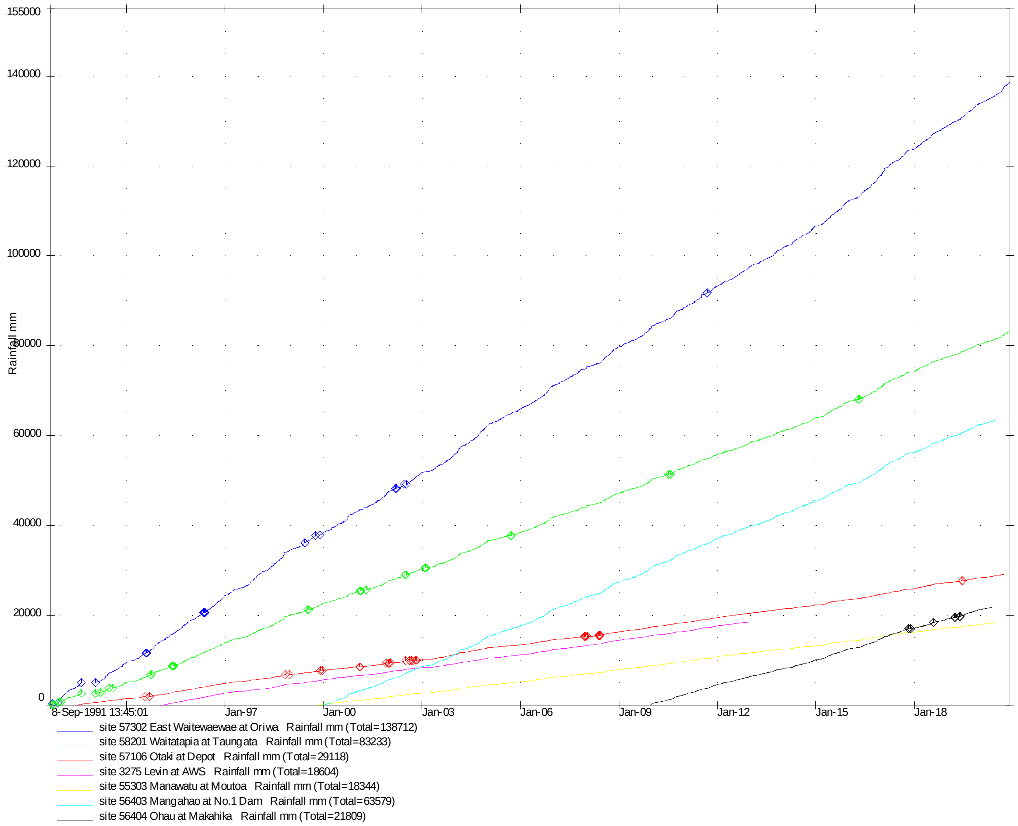


Figure 4-5: Cumulative rainfall plots

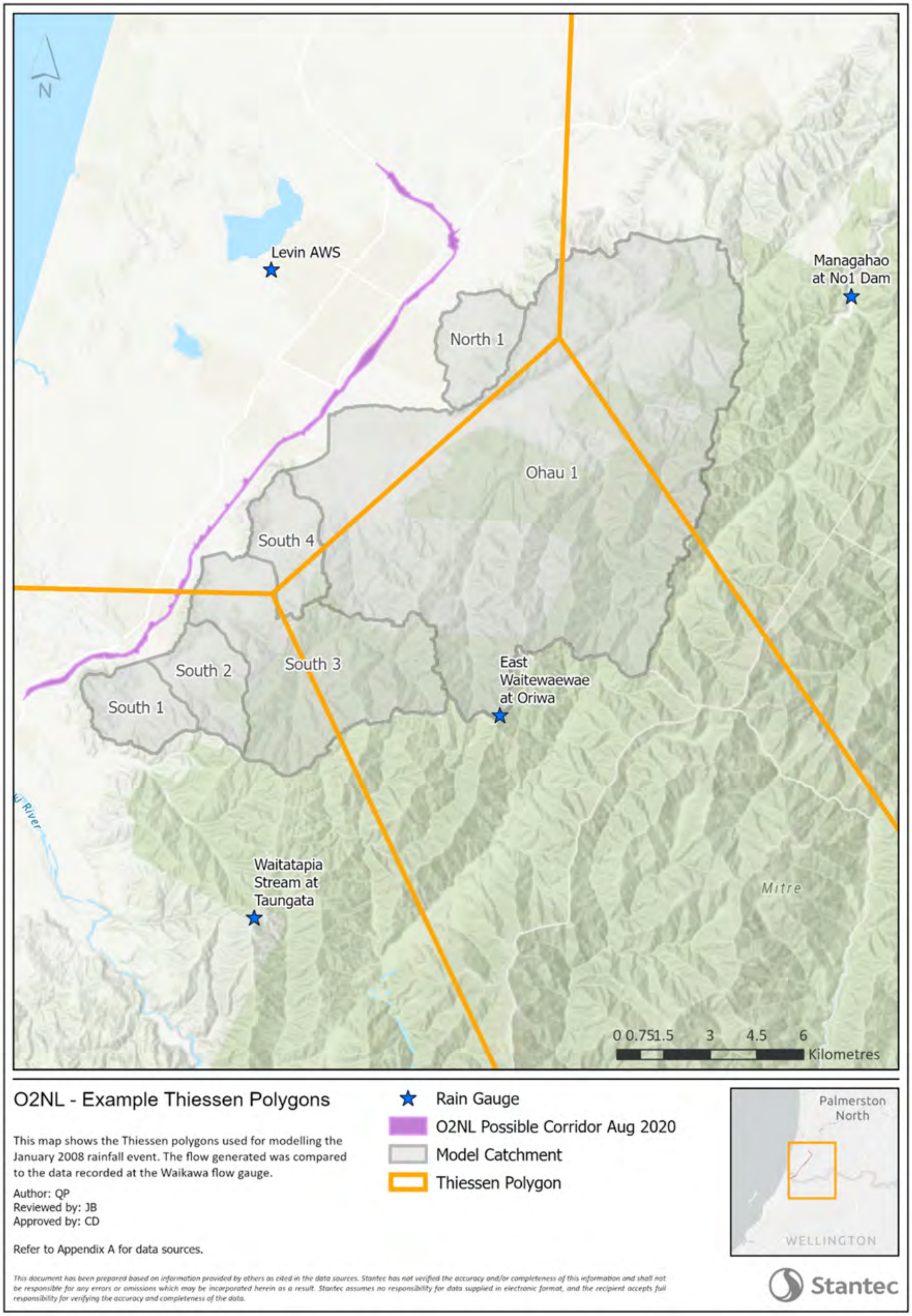


Figure 4-6: Thiessen polygons for the January 2008 event

4.2.2 Design rainfall up to 1:100 AEP

Design rainfall was required as input to the different hydrological approaches or processes that feed into the baseline flood modelling, notably:

- Design rainfall input to HEC-HMS rainfall runoff models (used to derive hydrograph shapes for medium-large catchments).
- Design rainfall inputs to the Rational Method for a subset of catchments as an independent check on the HEC-HMS and HEC-RAS modelling.
- Design rainfall for use in the 2D direct rainfall hydraulic model domain/s covering the smaller catchments, including near and downstream of the proposed Ō2NL corridor.

To prepare these rainfall inputs, HIRDS v4 design rainfall tables were downloaded for the centroid of each sub-catchment to account for spatial variation across the models. A further description of rainfall spatial variation is provided in Section 4.2.4.

Table 4-2: Example rainfall depths (mm) for Waikawa sub-catchment 1, current climate HIRDS v4

Event/Duration	10m	20m	30m	1h	2h	6h	12h	24h
1:10 AEP	13.1	17.9	21.5	29.5	40.1	63.5	82.8	105
1:100 AEP	20.8	28.0	33.5	45.3	61.0	95.1	123	154

4.2.3 Extreme rainfall (1:1500 AEP)

Whilst HIRDS v4 table downloads only extend to an AEP of 1:250, the HIRDS v4 online tool allows manual entry of a 1:1500 AEP probability to obtain associated rainfall depths. These values were checked by interpolation between the probable maximum precipitation (PMP), and HIRDs v4 1:50, 1:100 & 1:250 AEP events. Estimates of the PMP followed the method described in Tomlinson, (1993). An example interpolation check is shown in Figure 4-7 below.

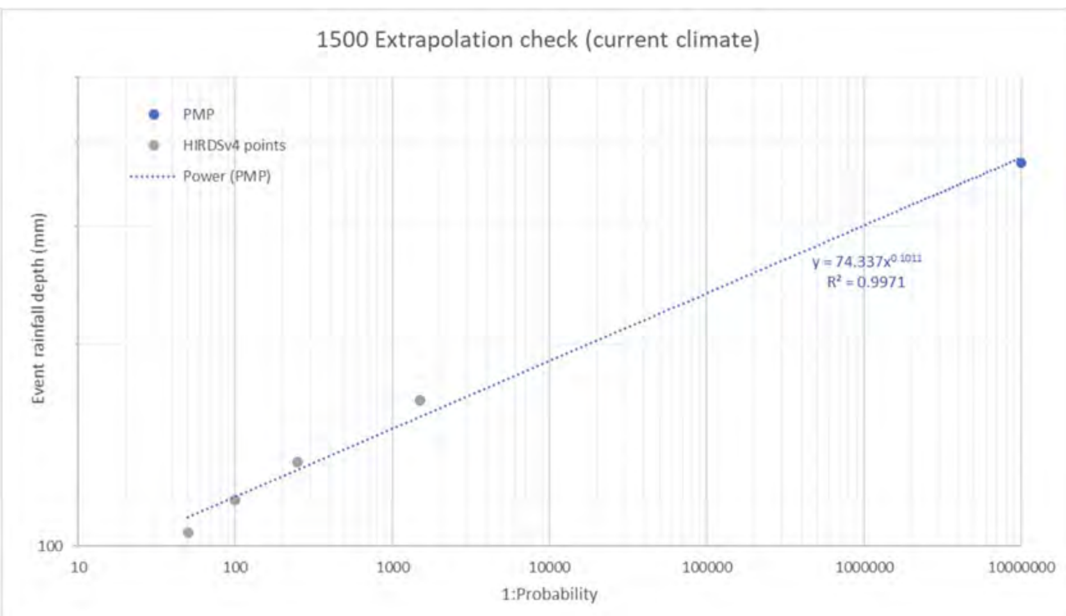


Figure 4-7: Example check on 1:1500 AEP rainfall (Waikawa catchment current climate)

4.2.4 Spatial Variation

As described in Section 4.2.2, the location of the catchments between the coast and the Tararua Ranges is within an area of significant orographic influence causing steep gradients in rainfall depths. Therefore, as a starting point for design rainfall, HIRDS v4 depths were calculated to the centroid of each modelled sub-catchment, including the 2D direct rainfall modelling zone. Figure 4-8 shows the spatial distribution based on HIRDS v4 2h 1:100 AEP. The 2h event is used for visual illustration only, as a compromise between the 1h and 4h storms that were analysed in the modelling.

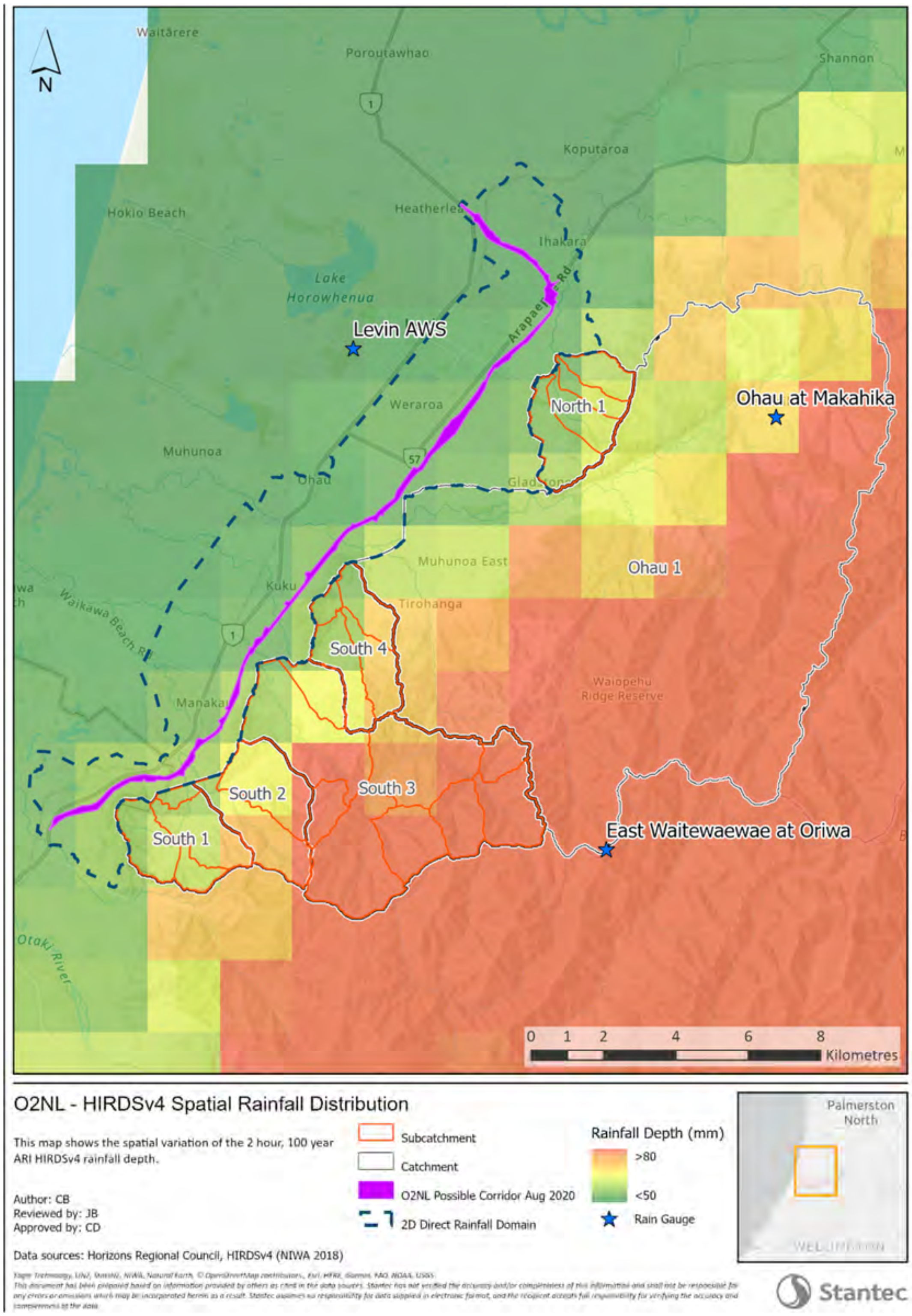


Figure 4-8: HIRDS v4 spatial rainfall distribution (2h 1:100 AEP)

4.2.5 Temporal Profile

Design rain temporal profiles were based on the method outlined in the HIRDS v4 report (Carey-Smith, Henderson & Singh, 2018) using the Western North Island curves. Multiple curves were produced for different storm durations - 1h, 2h, 3h, 4h, 6h. As the 3h and 4h profiles were not standard durations used in the HIRDs v4 method, a linear interpolation was used between the available four curve parameters to obtain temporal curve parameters for the 3h and 4h durations which could then be scaled to the required event rainfall depth. Figure 4-9 below shows the 4h 1:100 AEP temporal profile created from the Western North Island curves, prior to scaling for the various sub-catchment total rainfall depths (Table 4-3, in Section 4.2.8). Since the rise and recession limbs are separate parameter sets, it is not uncommon to see a shape change after the peak, but the correct total event rainfall depth is still applied.

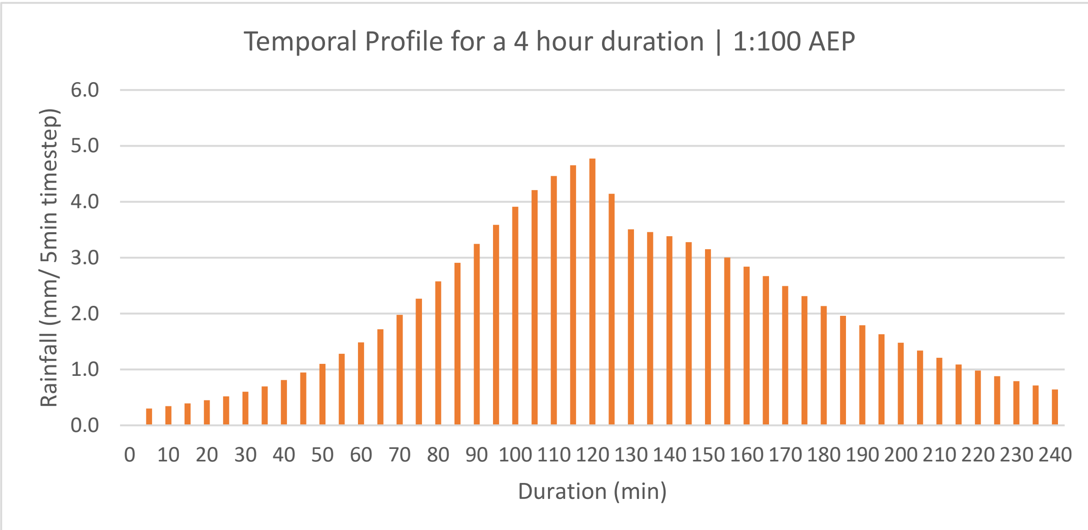


Figure 4-9: 4h temporal rainfall profile for 1:100 AEP

4.2.6 Areal Reduction Factors

An Areal Reduction Factor (ARF) was applied based on each catchment's area for the hydrological model events up to 1:100 AEP. The ARF estimation method was based on the method described in Carey-Smith et al (2018). ARF values ranged from 0.93 (30km² Waikawa 1:100 AEP) up to 0.97 (7km² catchments 1:10 AEP), and therefore only had a relatively minor impact on the rainfall totals.

4.2.7 Climate Change

HIRDS v4 provides climate change rainfall depths up to the 2081 – 2100 epoch (nominally 2090) and so depths for 2130 were extrapolated. The extrapolation was based on Table 8 in Carey-Smith et al 2018 which gives predicted temperature increase through to 2110. Values were extrapolated using a fitted curve to 2130 as shown in Figure 4-10. As described in section 2.4, RCP6.0 was used for 1:100 AEP event, and RCP8.5 was used for the 1:1500 AEP ULS scenario.

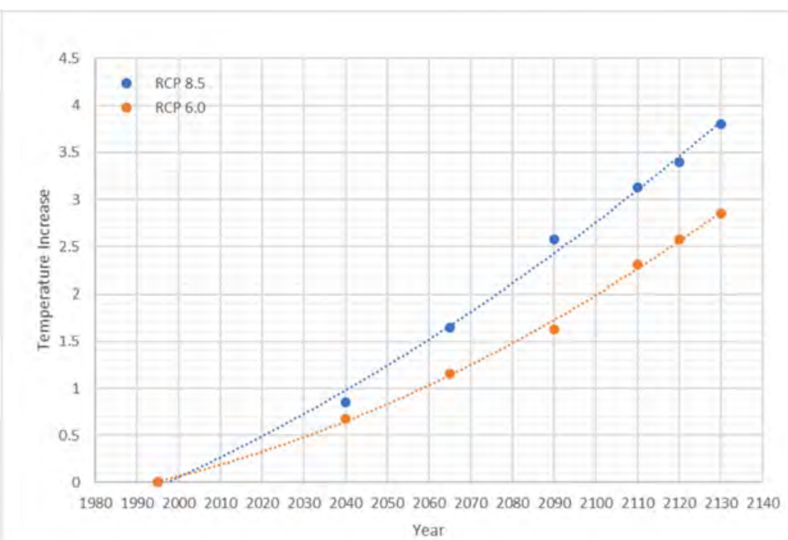


Figure 4-10: Estimated temperature increase to 2130

Percentage change factors per degree of warming were then based on Table 6 of Carey-Smith et al 2018.

To obtain the relevant climate change factor for the 1:1500 AEP RCP8.5 scenario, advice from Trevor Carey-Smith at NIWA (lead author of the HIRDS v4 report) was to use the percentage increase of warming given for the 1:100 AEP event (Table 6 of the HIRDS v4 report), and the extrapolated increase for RCP 8.5 (Table 8 of the HIRDS v4 report).

4.2.8 Summary of HIRDS-based Rainfall Design Event Totals

Table 4-3 below provides a summary of the total rainfall depths for the preliminary design events based on HIRDS and the preceding steps. The main differences in rainfall depths between the various catchments are the orographic effects (influence of higher elevation topography on rainfall) and the critical storm duration (for example the 3h and 1h durations has lower total rainfalls but higher intensity in mm/h compared to a 4h storm). The selection of critical storm duration is discussed in Section 4.4.2. For the 2D rain on grid area, both 1h and 4h durations are presented as these are used for different purposes as discussed later in the report. The conditional colour formatting helps to highlight trends, notably that the Waikawa catchment has substantially more rainfall compared to its neighbouring catchments of Kuku and Manakau. This HIRDS-based data is thought to be influenced by the rain gauge East Waitewaewae at Oriwa, which reports much higher rainfall than Waitatapia at Taungata just a little further south and at similar elevation. This disparity in observations is illustrated by the cumulative chart in Figure 4-5 and in table below.

Table 4-3: HIRDS-based rainfall depth (mm) for each catchment with ARF & climate change

Catchment name (ID)	Sub-catchment name	Critical Duration (h)	1:10 AEP current climate (mm)	1:100 AEP RCP 6 2130 (mm)	1:1500 AEP RCP 8.5 2130 (mm)
Koputaroa (North_1)	Nth_s_1	4	49	**99**	153
	Nth_s_2		47	**97**	150
	Nth_s_3		47	**97**	150
	Nth_s_4		49	**100**	154
Kuku (32)	S4_1	4	51	**103**	159
	S4_2		59	**119**	182
	S4_3		53	**107**	165
	S4_4		47	**95**	147
	S4_5		46	**94**	145
Waikawa (27)	S3_1	4	51	**102**	156
	S3_2		74	**147**	224
	S3_3		80	**159**	242
	S3_4		87	**173**	262
	S3_5		97	**192**	289
	S3_6		88	**175**	264
	S3_7		56	**113**	172
	S3_8		83	**165**	250
	S3_9		68	**135**	207
Manakau (15)	S2_1	4	62	**126**	192
	S2_2		57	**115**	176
Waiauti (14)	S1_1	3	43	**89**	137
	S1_2		44	**89**	138
	S1_3		48	**99**	152
	S1_4		46	**94**	145
2D model rainfall zones	2D_Mesh	1	26	**56**	84
		4	43	**89**	147

The very high design rainfall in the Waikawa catchment produced simulated flows from the calibrated HEC-HMS models (refer section 4.4) that appeared much higher than flood frequency analysis (refer section 4.3). Rainfall duration frequency analysis was therefore undertaken at each rain gauge, and compared to the corresponding HIRDS v4 cell data, for a 4h storm. The comparison is presented in Table 4-4 below. The fitted distributions at Taungata may be slightly low considering its elevation, but at Oriwa appear extremely high and may be unrealistic. This analysis helped to confirm adjustments to the simulated flows from the HIRDS rainfall, in line with the flow gauge flood frequency analyses which are anchored in real observations near the Ō2NL corridor.

Table 4-4: Comparison of HIRDS vs rain gauge frequency analysis for 4h storm

Gauge location (altitude)	4h 1:10 current climate			4h 1:100 current climate			4h 1:10 ratio		4h 1:100 ratio	
	HIRDS cell	Gumbel	Pearson	HIRDS cell	Gumbel	Pearson	Gumbel	Pearson	Gumbel	Pearson
Manawatu at Moutoa (5m)	41	38	38	63	53	53	93%	94%	85%	84%
Levin AWS (15m)	40	36	35	59	50	44	90%	89%	85%	74%
Levin MAF (45m)	40	47	48	59	66	75	118%	121%	111%	127%
Mangahao at No1 dam (390m)	86	79	81	130	107	116	92%	94%	82%	89%
Ohau at Makahina (240m)	63	69	70	95	97	102	109%	111%	102%	108%
East Waitewaewae at Oriwa **(1050m)**	**128**	**155**	**161**	**189**	**233**	**287**	122%	126%	124%	152%
Waitatapia at Taungata **(980m)**	**85**	**85**	**84**	**127**	**117**	**109**	99%	99%	92%	86%
Otaki River at Depot (17m)	50	47	46	75	64	55	94%	93%	85%	74%

4.3 Flow Gauges and Flood Frequency Analyses

Available flow gauging station records are summarised in Table 4-5 below. A graph of the data period of each gauge is shown in Figure 4-3 and a map of gauge locations provided in Figure 4-4 in Section 4.2.1.

The data was used to select flood events for calibration of rainfall-runoff models. Flood frequency analysis was also carried out as described below.

Advice from Horizons Regional Council is that the Koputaroa, Waikawa and Manakau stream gauges are primarily for water resource assessment and might not be rated with confidence for flood flows. This is taken into account in the discussions that follow. Accordingly, flood frequency results and calibrated runoff model results based on these gauges were not used on their own but were also compared with other methods including data transfer from donor sites. An overview of the available flow timeseries data is shown in Figure 4-11 below.

The gauging station for the Ōhau at Rongomatane provides a 43-year record with relatively few gaps. The station has a slack line cableway upstream of the site, where flows up to 250m$^{3/s}$ have been gauged, and a model used to extrapolate above this. If future design decisions are considered very sensitive to the design flow, then further investigation could be carried out on the confidence of the rating curve and flow data for the highest peaks. Appropriate sensitivity testing and freeboard allowances should still be considered, depending on the level of conservatism required and tolerance of design decisions.

Flow data was also obtained for the GWRC gauge Waitohu at Water Supply Intake, since 1994 (27 years of record). This gauge is just south of the Ō2NL project extent, but serves as a useful gauge with a good record for analogous transfer of data into the project catchments.

Table 4-5: Flow gauges in or near catchments

Name	Site number	Latitude	Longitude	Recording Authority	Start of data	End of data
Koputaroa at Tavistock Rd	32590	-40.59663923	175.337058	HRC	Jan-74	Aug-89
Ōhau at Rongomatane	15321061	-40.66345725	175.3326475	HRC	Jul-78	Mar-20
Waikawa at N. Manakau Rd.	1432008	-40.70775371	175.2335565	HRC	May-06	Jun-20
Manakau at Gleeson Rd	32001	-40.71952056	175.2110066	HRC	Nov-78	May-89
Manakau at S.H.1 Bridge	1432003	-40.72439913	175.2116174	HRC	May-06	Jun-20

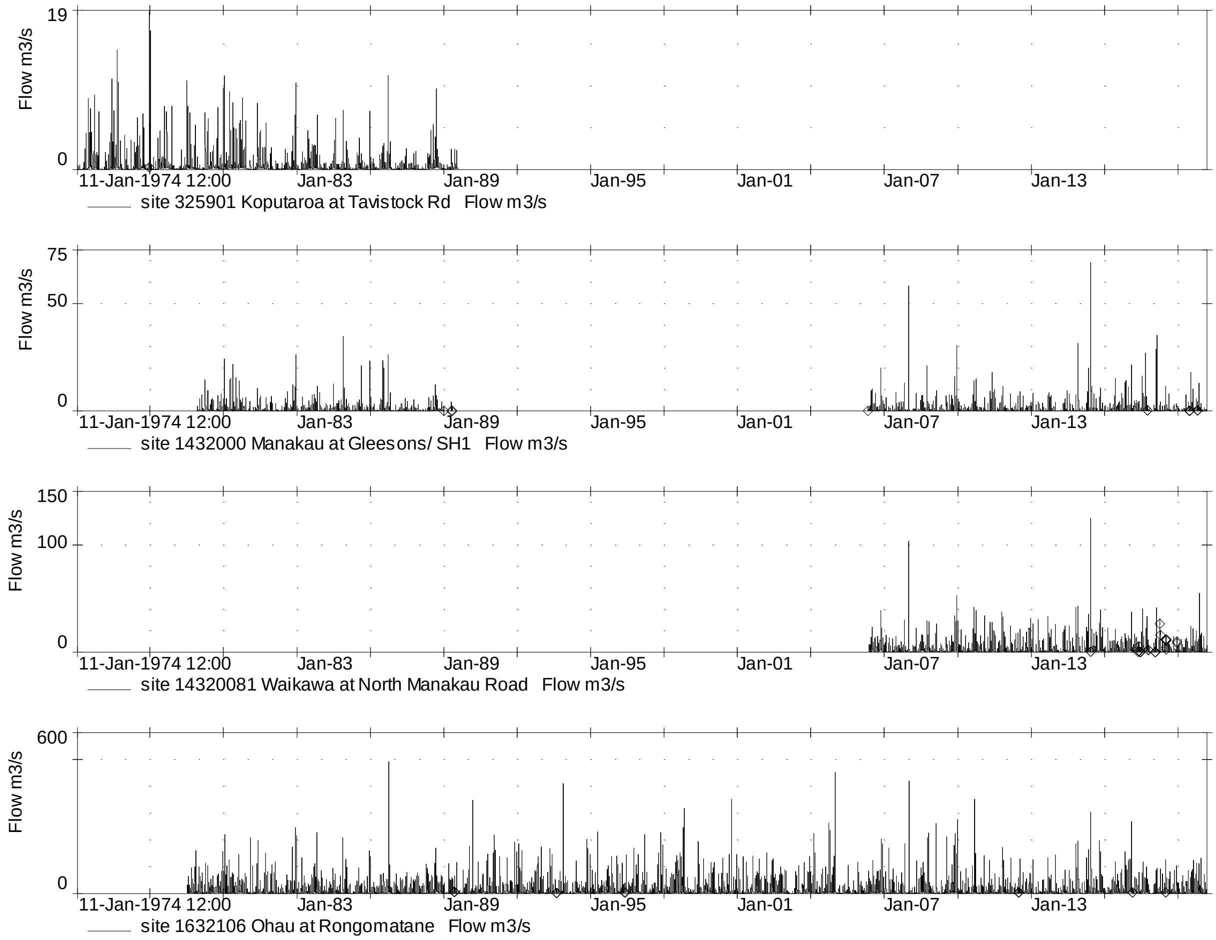


Figure 4-11: Overview of recorded flows

Flood Frequency Analysis (FFA) was carried out for the Ōhau River at Rongomatane. The best estimate for the Ōhau 1:100 AEP flood peak is 559 m^3/s using the full record and a Pearson3 curve. The Pearson3 was only slightly higher than Gumbel and was selected to provide the slightly more conservative peak estimate. The GEV curve appears unrealistically high for extreme (low probability) events and was therefore discarded. Pearson3 was also tested for shorter periods (for example after the 1986 flood to 2020, or 2006 to 2020 to coincide with the period of data at Waikawa). These showed a relatively small spread, with the reduced record producing slightly lower curves.

Previous flood frequency estimates by Horizons Regional Council for the period 1976 to 2006, including testing the impact of including four historic floods from the 1940's and 50's and using a range of fitting formulae gave 1:100 AEP estimates ranging from 545 m^3/s to 656 m^3/s.

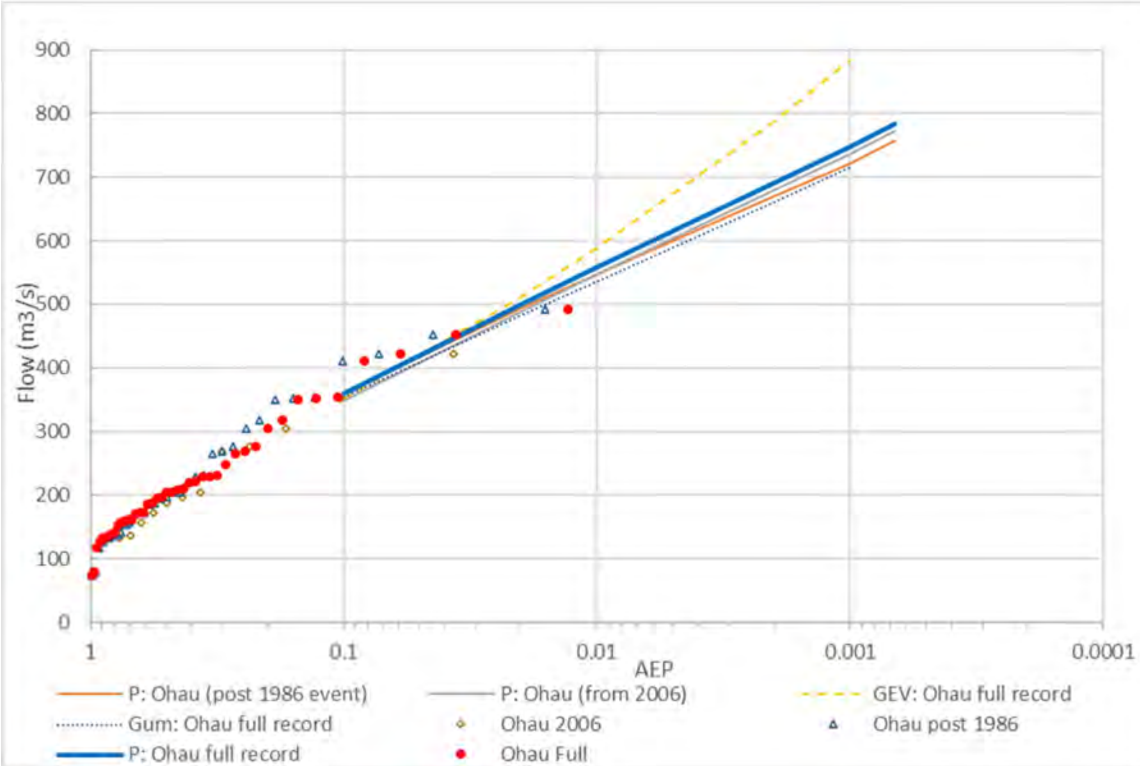


Figure 4-12: Ōhau at Rongomatane flood frequency analysis

The Ōhau peak flows were required for input to the hydraulic model near Muhunoa East Road, approximately 6km downstream of the Rongomatane gauging station. Over this distance, the catchment area increases from 104km² at the gauging station to approximately 120km² at Muhunoa East Road. The Rongomatane peak flows have therefore been increased by the ratio of 'catchment area to the power 0.9' in line with the North Island relationship in NIWA Regional Flood Estimation Tool for New Zealand Part 2 (Henderson et al, 2018). The same method was used to estimate the cumulative flow downstream of Makorokio Stream confluence (stream ID 33e) that joins just downstream of Muhunoa East Road, so that the correct total flow is found in the model just downstream of the confluence. Hydrograph shapes for the Ōhau at Muhunoa East Road and the Makorokio Stream (stream ID 33e) were both derived from the Waikawa 4h HEC-HMS model (as discussed in 4.4.2 scaled to the respective calculated peak. Climate change was applied based on a multiplier of 1.35 for RCP6.0 2130 and 1.47 for RCP8.5 2130, based on extrapolation of HIRDS data as discussed in 4.2.7.

The results will not be sensitive to slight changes in hydrograph shape or relative timing, because the storage and attenuation in the relatively short length of modelled domain is very small compared to the large design event flow rates.

Flood Frequency Analysis was also carried out on the available data for the Koputaroa, Waikawa and Manakau streams. As mentioned earlier, the primary purpose for these gauges is water resource assessment rather than flood monitoring. However, they are anchored in observations within the catchment close to the Ō2NL corridor and are therefore a valuable information source that is less susceptible to uncertainties in rainfall data (observed and/or HIRDS as discussed previously).

For the Waikawa at North Manakau Road, the Gumbel curve appears to correlate well with distributions scaled from the Ōhau River at Rongomatane and Waitohu Stream at Water Supply Intake. The Pearson3 appears too high as does the GEV. The calibrated HEC-HMS model (refer section 4.4) using the HIRDS design rainfall (refer section 4.2.8) significantly overestimates the preferred data sources (Waikawa 1:10 and transfers from Rongamatane and Water Supply Intake). The HEC-HMS design flows are therefore scaled down to fit the other distributions in a more balanced way and provide balanced yield per km² as presented in section 4.5. The scaled HEC-HMS hydrographs are used as inputs to the hydraulic model.

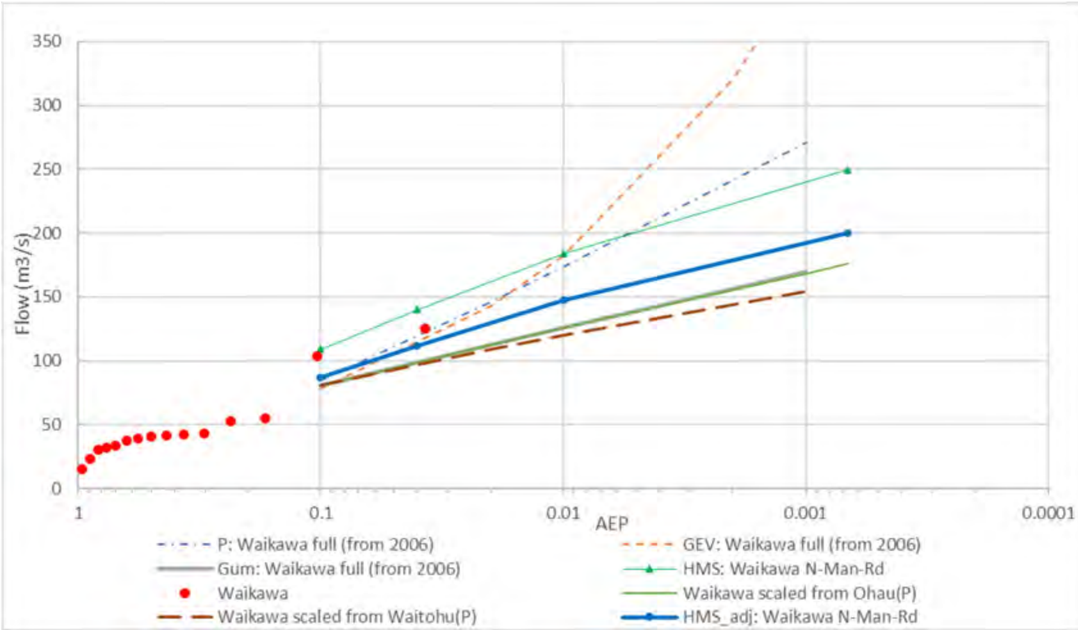


Figure 4-13: Waikawa at North Manakau Road flood frequency analysis

The Manakau Stream has a gauge at SH1, and an earlier period of record at Gleesons Road a short distance downstream. The FFA therefore tested the use of the merged record and the SH1 record only (from 2006). Visual inspection of the timeseries (Figure 4-11) and the FFA suggests that the earlier period at Gleesons Road may have been underestimating flows. The scaled distributions from Ōhau River at Rongomatane (Pearson), Waikawa at North Manakau Road (Gumbel) and Waitohu Stream at Water Supply Intake all show a reasonable correlation but might not account for the slightly lower rainfall within the slightly lower elevation Manakau catchment. The Manakau (from 2006) GEV is once again too high, especially for the low probability events. The Manakau (from 2006) Pearson distribution appears to correlate well with the preferred Pearson curve from Waitohu at Water Supply Intake, especially for the 1:100 AEP which is a key input to the design process. The calibrated HEC-HMS model (refer section 4.4) using the HIRDS design rainfall (refer section 4.2.8) significantly underestimates and has therefore been scaled up to match more closely to the Pearson distribution and the scaled distribution. The scaled HEC-HMS hydrographs are used as inputs to the hydraulic model.

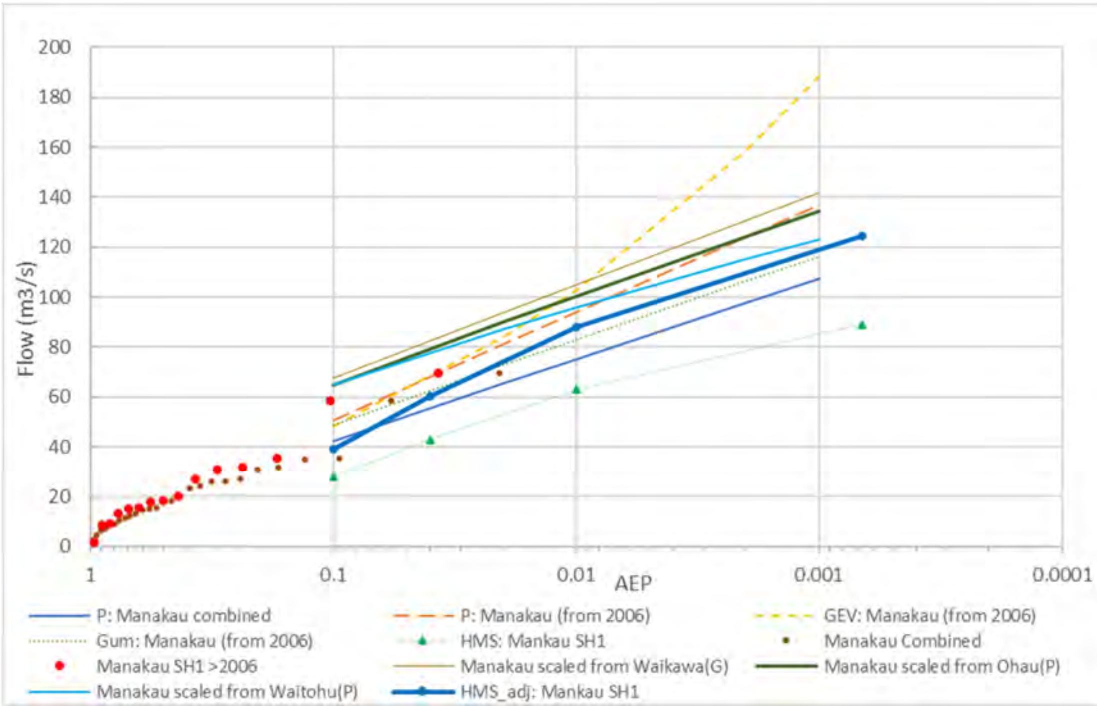


Figure 4-14: Manakau at Gleesons/SH1 flood frequency analysis

The FFA for the Koputaroa Stream at Tavistock appears to provide unrealistically low catchment yield (runoff per km^2) compared to other catchments and other methods (HEC-HMS model and the Regional and Rational methods). This may be on account of the drowning of the gauge due to the low channel capacity downstream. The maximum gauged flow at the gauging station is only 9m^3/s, which is in the order of 1:3 AEP. The FFA based on gauge data is therefore considered unreliable, and the HEC-HMS model with HIRDS design rainfall is adopted as the preferred method. The HEC-HMS model as discussed in section 4.4 and Appendix C is calibrates reasonably against low gauged events that are between 5-10m^3/s. Despite the disparity in observed rainfall frequencies between the two gauges in Levin (refer Table 4-4), in the absence of other more liable data it is reasonable to assume that HIRDS v4 is a reasonable approximation for design rainfall as it will be less susceptible to orographic influences for the Koputaroa catchment. The catchment yield (runoff per km^2) for the adopted HEC-HMS model appears reasonable by comparison to other methods and comparable locations (when adjusting for differences in rainfall).

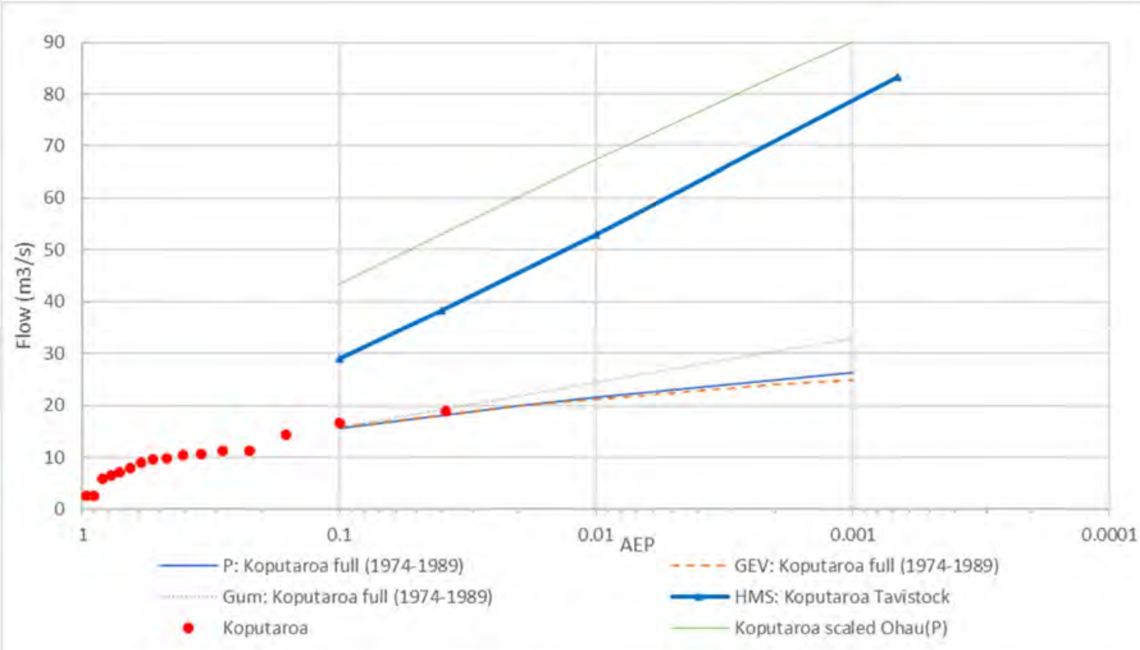


Figure 4-15: Koputaroa at Tavistock Rd flood frequency analysis

4.4 Rainfall – Runoff Model

4.4.1 Model Build

The rainfall – runoff modelling software Hydrologic Modelling System (HEC-HMS), version 4.6.1, was used to simulate precipitation-runoff. The software is developed by the Hydrologic Engineering Center within the U.S. Army Corps of Engineers and is used widely within New Zealand and internationally. It was applied for the Manakau Stream to SH1 (including sub-catchments for Waiauti / South 1 and Manakau / South 2), the Waikawa Stream (South 3), Kuku Stream (South 4), and Koputaroa Stream (incorporating sub-catchments North 1, and sub-catchment 39 used as a check point for the 2D model). Schematics for each model are provided in Appendix B. An example of the Waikawa (South 3) model is featured in Figure 4-16 below. The North Manakau Road gauge is at the outlet of S_7. The sub-catchment S_1 represents stream id 27.1 which enters the Waikawa downstream of the gauge and is a separate input to the hydraulic model.

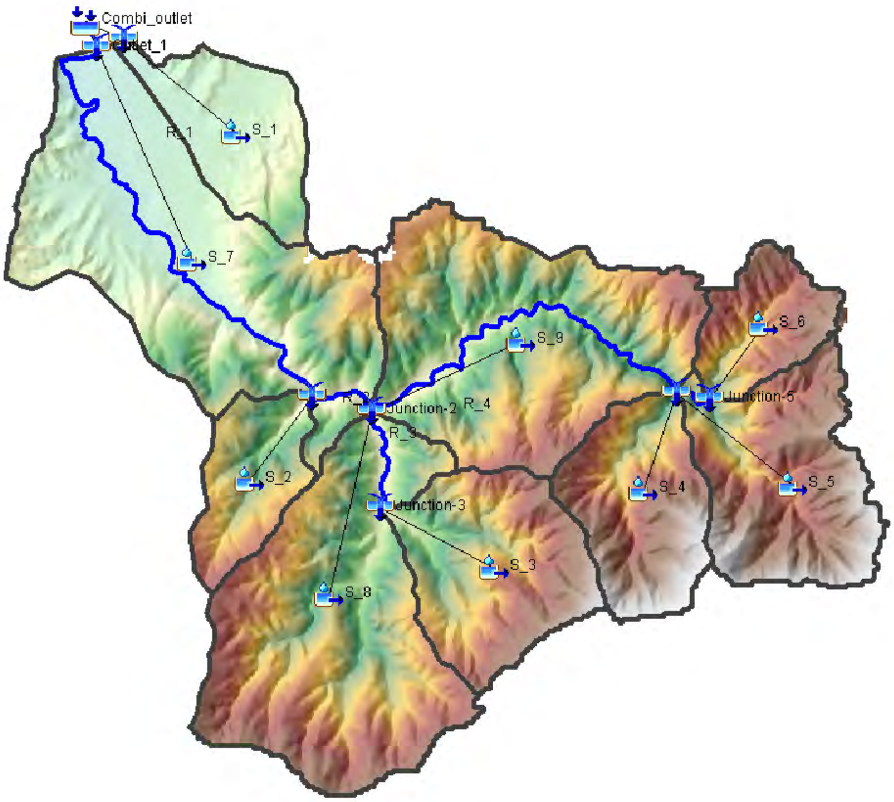


Figure 4-16: HEC-HMS model schematic example of the Waikawa (South 3) catchment

The following is a summary of final hydrological model input parameters after the calibration had been confirmed as acceptable (as discussed in 4.4.3 and Appendix C):

Loss: Initial and Constant

The initial and constant losses were informed by the Fundamental Soil Layer Drainage Class map from Land Resource Information Systems Portal (Appendix D). Whilst there is some variation in drainage class, the calibration and validation is satisfactory with a consistent set of runoff parameters across all hydrological models (refer to Section 4.4.3):

Initial Loss = 7mm

Constant Loss = 5mm/h

(Note that the application of Initial and Constant Losses over the 2D direct rainfall model zones in the HEC-RAS hydraulic model is discussed separately in Section 5.6).

Transform: Clark Unit Hydrograph

Initially, default parameters were used and then adjusted based on a comparison with other methods and calibration, to reach the following:

Time of Concentration = Bransby-Williams

Storage coefficient = Time of Concentration * 3

Routing: Muskingham-Cunge

For the HEC-HMS models used as input boundaries for the hydraulic model, the Muskingham Cunge method was used to calculate the routing up to the point required for the hydraulic model. For the separate models that were solely used for model validation (Koputaroa & Manakau Gauge catchment), a simpler Lag routing method was used for the downstream reaches. This was tested and compared with the Muskingham Cunge method and was not found to make a significant difference. The net effect was also confirmed by comparison with the observed validation event hydrographs.

Temporal rainfall profiles

The temporal profiles mentioned in Section 4.2.5 were used to provide the rainfall hyetograph for the design events, with an override total rainfall depth applied to each sub-catchment as per Table 4-3 (Section 4.2.8).

4.4.2 Critical Storm Duration

Each HEC-HMS modelled catchment was initially run with 1:100 AEP current climate rainfall with various storm event durations from HIRDS data and the critical duration selected that resulted in the greatest peak modelled flow. See Figure 4-17 below for an example of a hydrograph for Waikawa (South 3) showing the critical duration as 4 hours. Once each catchment's critical duration was found, each model was then tested with 1:10 AEP current climate with various durations to confirm that the chosen duration was still applicable. Refer to Table 4-7 in Section 4.5 for final critical durations used in the model.

Figure 4-17 below shows the varying durations used to find the critical storm duration for Waikawa (South 3) catchment.

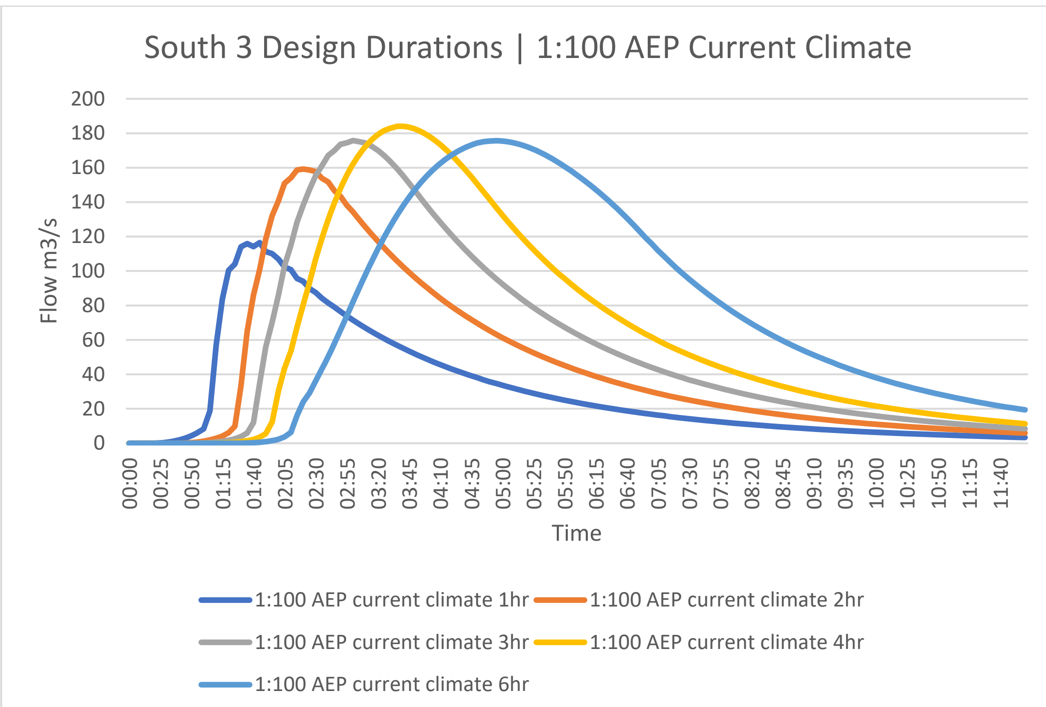


Figure 4-17: Design durations for the Waikawa catchment for 1:100 AEP current climate

Note that it was not required to calculate critical duration for the Ōhau River catchment, since peak flows were based on Flood Frequency Analysis (which uses peak values only). Historical observed flood hydrographs were analysed for the Ōhau and Waikawa gauges. Both were found to have a similar rapid response to short duration rainfall. A comparison of the timing of the Waikawa and Ōhau is shown below for the December 2009 event. A 4h storm hydrograph shape was therefore used for the Ōhau catchment, based on the hydrograph shape generated from the Waikawa HEC-HMS model for a 4h storm and scaled to the Ōhau target peaks derived from statistical flood frequency analysis. The relatively short length of the Ōhau being modelled relative to the large peak flows means that selection of hydrograph shape will have minimal impact on transmission of the hydrograph shape through the modelled reach.

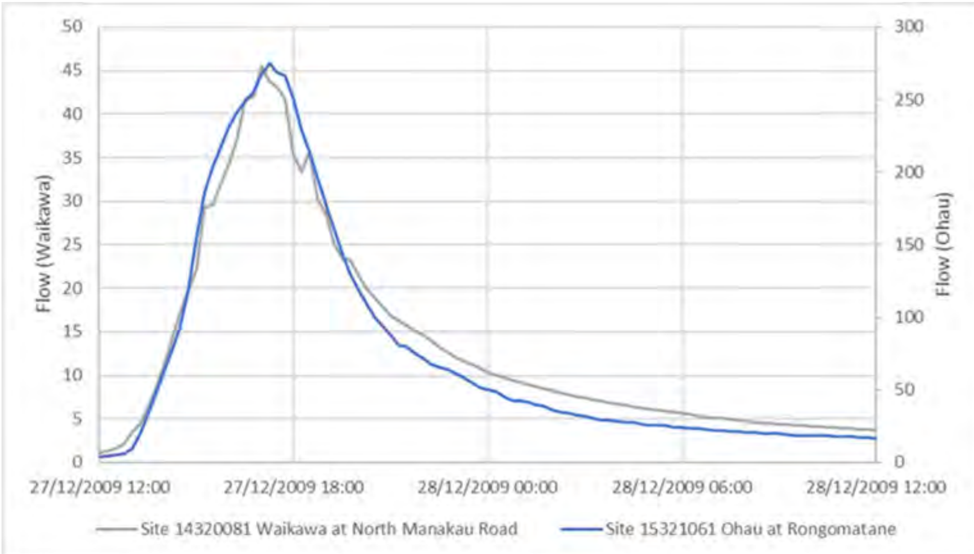


Figure 4-18: Observed hydrograph timing comparison, December 2009 event

For the direct rainfall zones applied in the 2D hydraulic model, the selection of storm duration and their application in the hydraulic model is discussed in Section 5.6).

4.4.3 Model Calibration

As described in Section 4.3 and Figure 4-2, three catchments & their respective flow gauges were used to aid in the validation of the hydrological models. The catchments used for validation are:

- The Koputaroa Stream at Tavistock Rd flow gauge
- Manakau at SH1 flow gauge
- The Waikawa at N Manakau Rd flow gauge

The fact that a consistent set of parameters was found to fit well at three flow gauges added more confidence to the validation process than only regarding a single model in isolation. A full set of results is presented in Appendix C.

An example of recorded and modelled flow for the Waikawa gauge is shown in Figure 4-19 below.

At least four events were selected for each gauge, due to some uncertainties in spatial rainfall coverage. Rainfall gauges were used where data was available for the selected events. Thiessen polygons were created in ArcGIS and were weighted when applied to sub-catchments in the model, as illustrated in Figure 4-6. It may be technically feasible to improve the catchment average rainfall by using rainfall radar and/or by using a terrain-sensitive rainfall surface fitting approach that accounts explicitly for elevation. However, as shown in Appendix C, a reasonable fit between the modelled and observed flows has been achieved, with reasonable explanations for those events with poor fit based on spatial distribution of rainfall. Additional checks were also made on the HEC-HMS peak flows, using the gauged flood frequency analyses (refer section 4.3) and additional independent methods (refer section 4.4.4). The calibration of the HEC-HMS models shown in Appendix C is considered reasonable for historic events but required adjustment for the design events as outlined in section 4.3 mainly on account of shortcomings in the HIRDS v4 design rainfall.

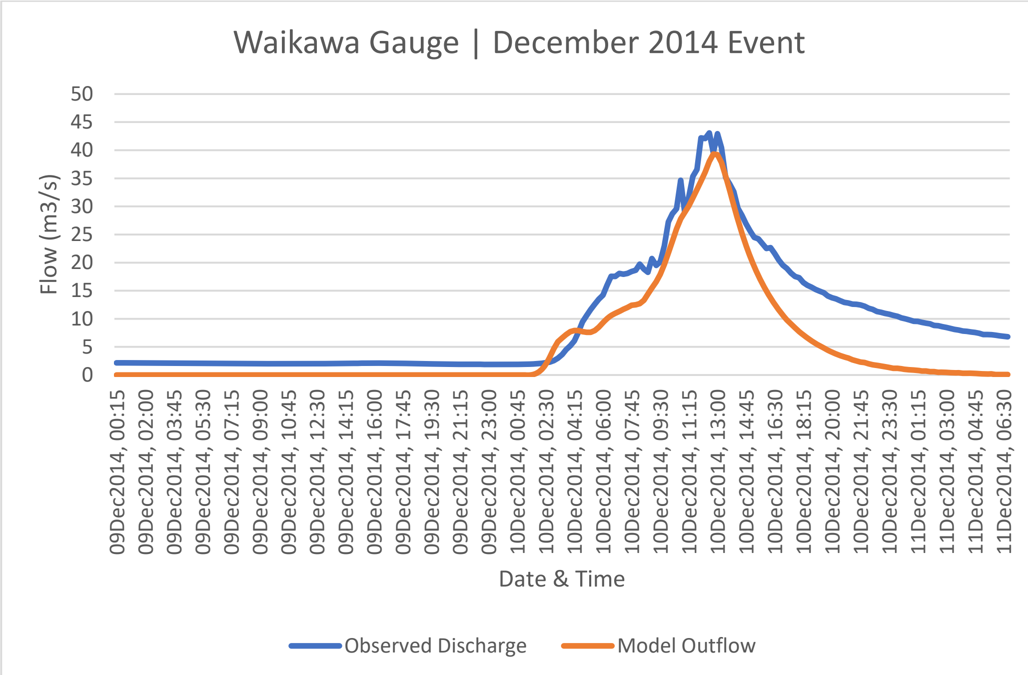


Figure 4-19: Simulated and observed flows at Waikawa gauge

4.4.4 Comparison of Results versus Rational and Regional Estimates

A 1:100 AEP event rational and regional method peak flow was calculated for selected catchments as additional independent checks on the outputs of the FFA and HEC-HMS models. Table 4-6 lists the results for each catchment. The Rational Method calculation is usually the preferred method for catchments less than 10km^2. The Regional Method (McKerchar and Pearson 1989)[3] is usually preferred for catchments over 10km^2. The online NIWA Flood Frequency Tool (Griffiths et al)[4] was also used as another regional calculation approach but was found to give inconsistent results and is therefore not presented.

Rational Method estimates were based on the following formula:

Peak Flow (m^3/s) = C (unitless) I (mm/h) A (m^2)/(3600*1000)

Where C is the runoff coefficient, I is the rainfall intensity for a storm duration corresponding to the catchment time of concentration (ToC) and a given AEP, and A is the catchment area. The runoff coefficient of 0.3 was estimated based on the NZ Building Code guidance – E1 Surface Water.

Table 4-6: Comparison of with rational and regional method (1:100 AEP current climate)

Catchment Name	Area (km^2)	Rational (m^3/s)	Regional (m^3/s)	FFA (m^3/s)	Raw HEC-HMS (m^3/s)	Adj HEC-HMS (m^3/s)
Sth 1 (Waiauti)	7.2	27	19	-	28	39
Sth 2 (Manakau)	7.1	35	20	-	30	42
Sth 3 (Waikawa)	**29**	106	68	126	184	147
Sth 4 (Kuku)	7.5	32	16	-	26	31
North1	7.5	36	20	-	23	23

Regional Method results are significantly lower than the Rational Method which is not unexpected. The significant difference in results from these methods for the Waikawa catchment is thought to be due to the steep rainfall gradient within this catchment, some of which may result from the extremely high (possibly unrealistic) rain gauge records at Oriwa. Regional Method contour resolution in this area is too low to account for the steep change in rainfall across the catchment.

[3] McKerchar, A.I., Pearson, C.P. (1989) Flood Frequency in New Zealand. Publication of the Hydrology Centre, No. 20: 87.
[4] https://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d

A summary of the adopted peak flows is provided in Section 4.5 below.

4.5 Summary of Adopted Peak Model Flows

The HEC-HMS hydrographs scaled where applicable, provided the runoff hydrographs for input to the hydraulic model, with application is discussed in Section 5. The peak flows provided for the hydraulic model are shown in Table 4-7 below. The second part of the table is the specific yield (peak / area^0.9) for each inflow. A map of modelled inflow catchments is presented in Figure 5-1.

Table 4-7: Summary of peak flow results for each catchment

Inflow	Catch Area km²	Critical Duration	1:10 AEP current climate	1:100 AEP RCP 6.0 2130	1:1500 AEP RCP 8.5 2130
			Peak flows (m^3/s)		
Waiauti 14	7.2	3h	21	54	90
Manakau 15	7.1	4h	24	57	92
Waikawa 27	29	4h	91	191	302
Waikawa trib 27.1	1.8	4h	5	11	17
Kuku 32	7.5	4h	18	43	71
Makorokio 33e	11.5	4h	35	74	113
Ōhau 33	120	4h	411	861	1315
North1	7.5	4h	13	32	54
	Method summary		Specific yields (peak/area^0.9)		
Waiauti 14	HEC-HMS(HIRDS)*1.4		3.6	9.2	15.2
Manakau 15	HEC-HMS(HIRDS)*1.4		4.2	9.7	15.8
Waikawa 27	HEC-HMS(HIRDS)*0.8		4.3	9.1	14.4
Waikawa trib 27.1	Above scaled to cumulative catch increase		2.9	6.2	9.8
Kuku 32	HEC-HMS(HIRDS)*1.2		2.9	7.1	11.6
Makorokio 33e	Ohau FFA scaled to cumulative catch increase		3.9	8.2	12.5
Ōhau 33	Ohau FFA scaled to cumulative catch		5.5	11.5	17.6
North1	HEC-HMS(HIRDS)		2.1	5.3	8.8

Several different methods have been compared to inform and derive the above inflows, with a strong weighting applied to gauged flow data. Given the usual residual uncertainties in hydrological probability, it would be prudent to consider the tolerance of design decisions to the accuracy of the hydrology. Testing the possible impacts of exceedance events will be done using the ULS 1:1500 AEP RCP8.5 2130 scenario, which will help to show if/where the proposed design may be more sensitive to hydrological inputs.

5. Hydraulic Modelling and Assessment

5.1 2D Hydraulic Model Approach

HEC-RAS version 5.0.7 is used to model the flood inundation modelling and mapping in this project. The model is a widely used flood modelling tool for hydrodynamic simulation, and it is designed to perform both 1D steady and unsteady flow simulations in addition to 2D unsteady flow simulations for river and floodplain flow analysis. The program was developed by the US Army Corps of Engineers Hydrologic Engineering Centre (HEC). The model is commonly used and widely accepted by industry and has the following advantages that are applicable to this project:

- Can perform 1D, 2D, and combined 1D and 2D modelling, including rain on grid.
- Saint-Venant or Diffusion Wave Equations in 2D.

- Implicit Finite Volume Solution Algorithm.
- Structured or Unstructured Computational Meshes.
- Detailed Hydraulic Table Properties for 2D Computational Cells and Cell Faces derived from fine underlying DEM.
- Detailed Flood Mapping and Flood Animations.

Two-dimensional component of the model allows water to move in both longitudinal and lateral directions, while velocity is assumed to be negligible in the z-direction. However, unlike 1D models, 2D model represents the terrain as a continuous surface through a mesh or grid. To improve the computational time, HEC-RAS uses a sub-grid approach, which uses a relatively coarse computational grid based on finer scale information from the underlying the topography. The fine topographic grid informs the flow calculations between computational mesh cells. Mesh refinements are applied in the areas of the watercourses or other features of interest, to constrain the computational mesh to an appropriate size. Mesh size can be reduced or enlarged by the modeller to suit the terrain and features that influence the hydraulic calculations.

The HEC-RAS suite has geospatial editing tools that allow for full development of geometric data for hydraulics models, including analysis of terrain data, developing geometric data, refining model layout, and visualizing results directly within HEC-RAS. This makes the process of river hydraulic modelling efficient without reliance a standalone GIS pre- and post-processor. Within the software, hydraulic model development process begins with terrain model and continues with an interpretation of the land surface and elevations, establishing hydraulic model elements, and enters a cycle of iterating between model simulation, analysis of results, and model refinements. Tools assist in the process of creating a terrain model and modifying incorrect elevation data. Visualization of the elevation data along with aerial imagery in HEC-RAS then allows for laying out 1D modelling objects (such as culverts or weirs where available) and creating 2D Flow Areas. Mapping of hydraulic results allows quick identification of model deficiencies for improvement. 2D Flow Area mesh refinement tools and terrain modification capabilities let the hydraulic modeler efficiently improve model geometry and simulation results. The software allows for a detailed assessment of the results both globally and locally to points of interest.

Three different models were created as follows.

- South Model. A single 2D model for all watercourse crossings south of the Ōhau River to Taylors Road near Ōtaki (i.e. the northern extent of PP2Ō). Point inflow hydrographs include the Waiauti Stream (South_1), Manakau Stream (South_2), Waikawa Stream (South_3) and Kuku Stream (South_4).
- Ōhau Model. A 2D model of the Ōhau River and adjacent floodplain. A single point inflow hydrograph is applied for the Ōhau River (Ōhau_1).
- North Model. A single 2D model for all watercourses north of the Ōhau River to the intersection of SH1 and Kaputahoa Road, north of Levin. One of the sub-catchments north east of Levin, that drains past near the corridor towards Koputaroa, is represented as a point inflow hydrograph (North_1) to reduce the size of the computational mesh.

Figure 5-1 shows the extents for each model. The models extend approximately 2 km downstream and 1 km upstream of the proposed Project, so that results in the vicinity of the proposed project are not sensitive to boundary effects. For the larger upstream catchments approaching from the east, the model uses point inflows as derived in chapter 4 (Hydrology) of this report. For the 2D domain, additional rainfall is applied directly over the model domain.

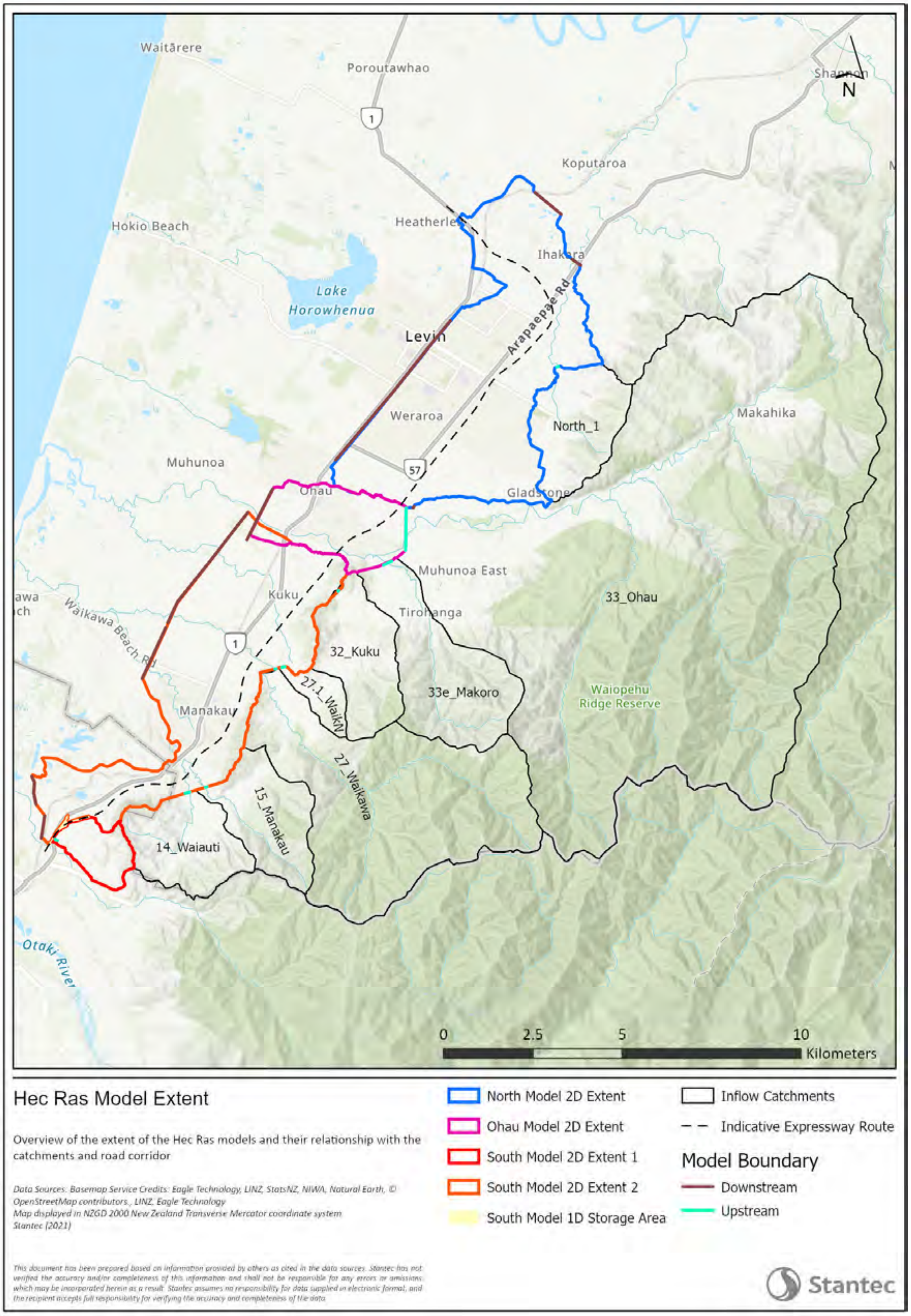


Figure 5-1: HEC-RAS 2D model extent for the three 2D hydraulic models

5.2 Digital Elevation Model Preparation

5.2.1 Reference Digital Elevation Models

Different DEM datasets were evaluated to prepare the terrain model within HEC-RAS. A key requirement was for the DEM domain to provide full coverage of the required 2D zones / catchments where direct rainfall modelling would be applied. As shown in Figure 2-1, the required model coverage extends well beyond the 2020 drone DEM, meaning that the 2020 drone DEM on its own would not be sufficient, and the step changes between datasets would require careful management.

In the areas of overlap, the 2020 drone DEM showed significant differences from the Regional Councils LiDAR DEM, both in terms of moving average or trends (apparent vertical shifts, although not continuous in nature) and in terms of large, localised errors. This is illustrated graphically in Appendix F. The 2020 drone DEM was more recent and higher resolution but being based on photogrammetric techniques appears poorer than the filtered Regional Council LiDAR DEM in vegetated watercourses and floodplains which are key flow paths. This may be because the LiDAR had managed to achieve better penetration of the vegetation. Away from the watercourses, the 2020 drone LiDAR higher resolution data also included many high points, possibly due to trees, fence poles, etc. Even when downsampled to a 1m x1m grid using the minimum elevation in each grid cell, there was still considerable noise or scatter in the terrain which could cause anomalous results in the direct rainfall modelling. It would have required considerable additional editing of the 2020 drone DEM and the step changes on its boundaries before achieving an overall DEM suitable for hydraulic modelling. On balance of these factors, it was therefore decided to use the Regional Council LiDAR DEM for the hydraulic modelling, with the following additional actions taken to mitigate the possible effects on the Ō2NL geometric design process which was being based on the 2020 drone DEM:

- Minor improvements to the 2020 drone DEM where particularly large errors were found relative to the Regional Council LiDAR DEM in watercourses, such as the example shown in Appendix F, to provide a more realistic ground surface to support the design process.
- Extensive minor improvements to the Regional Council LiDAR DEM to reduce or remove obstructions to flow paths, as discussed in Section 5.2.3 below, to reach an overall DEM more suitable for representing the passage of water. Some residual DEM issues remain as outlined in Section 5.2.4 below, although these were determined to be of minimal impact to the results within or near the Ō2NL corridor for calculating water levels and Assessment of Effects.
- Modelled depths (rather than water surface elevations) within the Ō2NL corridor are provided to the geometric design team, to apply above their improved ground surface where water levels are required.
- Proposed culverts created within the geometric design model will be modified in the hydraulic model to meet the HEC-RAS channel inverts when performing the calculation of post-scheme water depths and assessment of effects.

Once the decision had been made to retain primary use of the Regional Council LiDAR datasets, the model DEM preparation for each model extent involved clipping and/or mosaic (merging) of the Regional Council datasets into a single seamless raster file. Each of the model DEM files is 1mx1m horizontal resolution, meaning that there is an elevation value for every 1 metre travelled along the ground surface. The DEM files are all projected to the "NZGD 2000 Transverse Mercator" coordinate reference system. All DEM's and model rasters are in Wellington 1953 datum to provide a consistent set of outputs for the project. Further processing steps are outlined in the following sections.

5.2.2 Model Meshing

For all models, a terrain file was created slightly larger than the proposed model extents. For each model different computational mesh cell spacing criteria were used to create the initial 2D modelling surface. Mesh refinements are applied to limit the cell size around certain features, such as roads, watercourses or structures. The maximum cell size is lower near the project corridor, with additional mesh refinements being applied for spatially sensitive features in the with-scheme model being re-applied within the final baseline model. This ensures that the final baseline and with-scheme models are run with the same computational mesh, to minimise the slight differences that can otherwise be introduced when comparing results from different computational meshes. The values shown on Table 5-1 are the results of iterations to reduce the mesh generation errors whilst achieving a reasonable accuracy and computational time.

Table 5-1: Hydraulic model maximum 2D cell spacing

	Model South	Model Ōhau	Model North
2D Flow Area (maximum spacing in m^2)	20	20	20
Refinement Zone nearer to corridor (m^2)	10	-	10
Break lines Structures (m^2)	5	5	5
Break lines Road (m^2)	8	8	8
Break lines on ditch (in refinement zone) (m^2)	5	-	5
Break lines on ditch (outside refinement zone) (m^2)	15	15	15

The smaller cell spacing in the refinement zone and near hydraulic features allows for more detailed results through critical flows areas. Information from the 1m grid is used to inform the computational mesh calculations, providing a high degree of accuracy. An extract of the model mesh is provided in Figure 5-2 below to illustrate the concept of computational grid refinements on regular mesh and around hydraulic features.

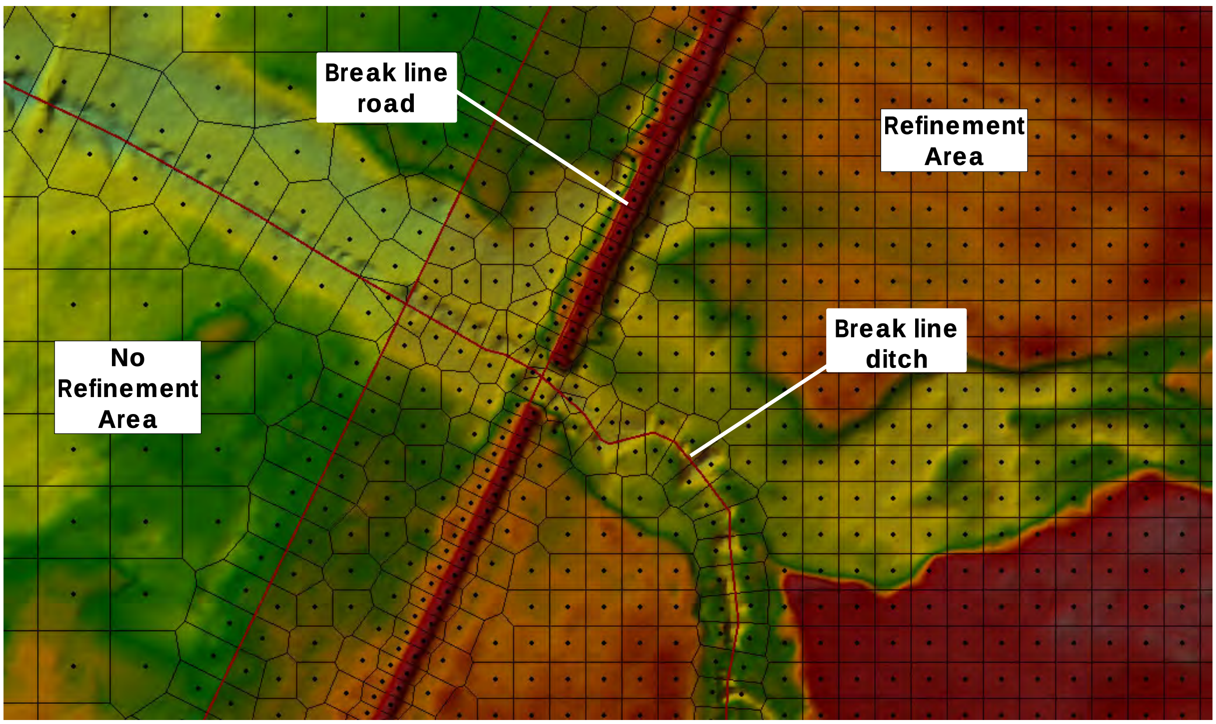
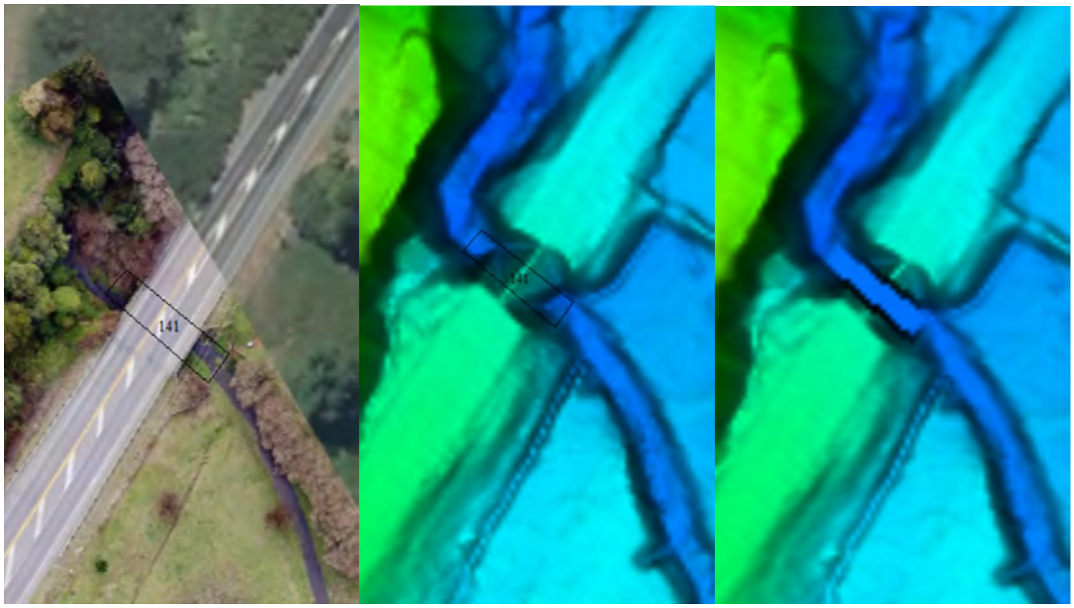


Figure 5-2: Example of model mesh refinements

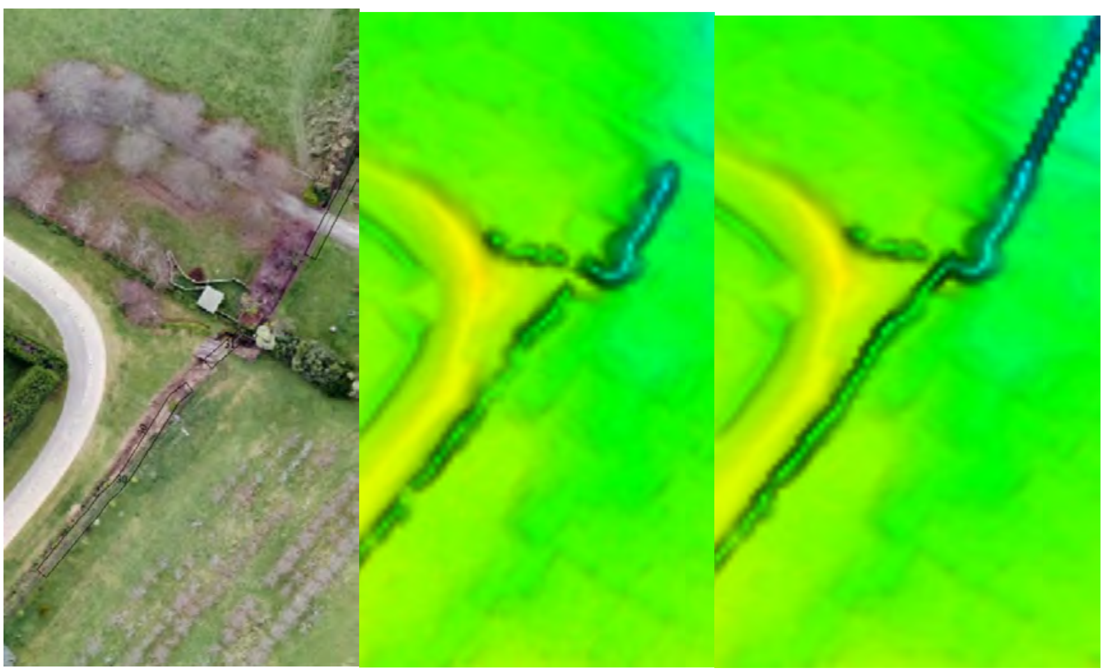
5.2.3 DEM modifications

To provide stream continuity on the flow surface, the terrain model was burnt down mainly at small bridges outside the area of interest or farm access tracks where there is not information available. The burning process was applied using GlobalMapper, by creating a polygon on the intersection between the stream and the road, then the polygon vertices were edited to match with the lowest nearby level in the DEM. The polygons were turned into a raster and stamped over the model DEM. Figure 5-3 below shows an example burning process on Koputaroa bridge (Model North) and Figure 5-4 shows the burning process in a ditch close to Waihou road. Approximately 200 DEM modification polygons were created to improve the three model DEM's.



Aerial Before burning After Burning

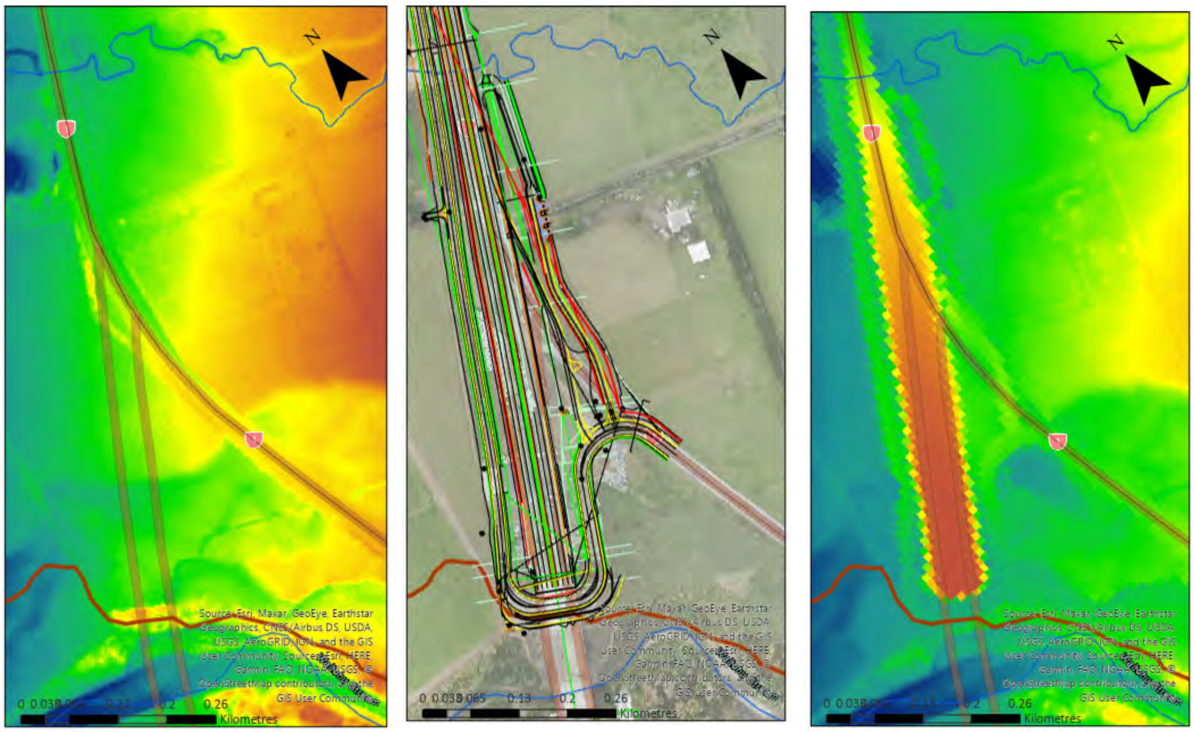
Figure 5-3: Example DEM burning process for a bridge on Koputaroa Stream.



Aerial Before burning After Burning

Figure 5-4: Example burning process for a ditch near Waihou Road

At the southern end of the South model, the northern end of PP2Ō Project is currently under construction. The baseline for the Ō2NL assessment should therefore include the PP2Ō as-built information. Since the PP2Ō was not completed at the time of the regional council LiDAR, it was necessary to stamp the PP2Ō as-built and proposed design information onto the South model domain as shown in Figure 5-5 below. The PP2Ō embankment terrain model was extracted from the PP2Ō hydraulic model files. The unmodified terrain (in flat areas) was consistent with the current DEM, therefore no datum adjustments were made.



Original LiDAR | PP2Ō As Built drawing | Terrain after stamped PP2Ō embankment

Figure 5-5: Adding PP2Ō embankment onto updated baseline terrain

5.2.4 DEM issues

Analysis of the LiDAR DEM provided by the regional councils (and used for the model DEM preparation) showed some additional residual inaccuracies. The HRC DEM contained some significant step discontinuities in data along features of significant length, most likely as a result of HRC merging different datasets. This also affected the SH1 road upgrade near near Gleeson Road Manakau, which was not fully evident at the time of the LiDAR capture but is visible as completed in more recent aerial photographs. Unfortunately, this could not be patched using the 2020 drone DEM as it was beyond the 2020 drone DEM extent. The discontinuities have been left in the hydraulic model build, as they tend to be mostly in parallel with the flow direction or downstream of the Ō2NL area of hydraulic interest or influence. The Ō2NL merged dataset also contains a step discontinuity (varying size) along the boundary between the HRC and GWRC terrain datasets. These are discussed in more detail in Appendix F.

5.3 Surface Friction

For all models, Manning's roughness coefficient values ('n') were applied based on the following key sources:

- Land Cover Database version 5.0 (LCDBv5) polygons, as at January 2020.
- LINZ – NZ -primary-road-parcels, as at November 2020.

The Land Cover Database contained 21 different classification within the model extent. Land cover names were grouped into four roughness categories, over which the road parcels was then applied. The final cover categories and the applied Manning's n coefficient are summarized in Table 5-2 below.

Table 5-2: Manning's n roughness coefficients

CATEGORY	Manning's 'n' Value	FINAL SOURCE
HIGH VEGETATION	0.08	Wellington Specification, Table 4. - Vegetation: forest
URBAN	0.1	Wellington Specification, Table 4. Residential Properties: small fenced backyard.
OPEN SPACE	0.048	Guidelines for Stormwater using MIKE FLOOD, Tauranga City Council, 2017. Table 4.1. - Open vegetation
WATER	0.045	Wellington Specification, Table 4. - River
ROAD	0.014	Guidelines for Stormwater using MIKE FLOOD, Tauranga City Council, 2017. Table 4.1. - Road

A manual refinement process was made to update these classifications in some locations using the DEM and recent aerial photography. This included edits to avoid high vegetation obstructions along streams alignment (particularly on larger streams). Also, some new high vegetation patches and urban area corrections were applied. Appendix E shows an overview of the final roughness used in the modelling.

5.4 Existing Bridges and Culverts

Existing bridges and culverts were analysed using the datasets referenced in Section 2.2, notably:

- KiwiRail bridges and culverts.
- State Highway bridges and drainage assets (culverts included).
- Horowhenua District Council (HDC) bridges and culverts.
- Kapiti Coast District Council (KCDC) stormwater points and pipes (culverts included).
- Inspection of aerial photography, LiDAR DEMs and Street View (by Google).
- The locations of bridges and relative to the proposed Project corridor and watercourses is illustrated in Figure 5-7, Figure 5-8 and Figure 5-9.

Most of the existing significant bridges are relatively far (in terms of hydraulic influence) from the Project area, and many of the datasets did not include bridge soffit heights. Therefore, most bridges were modelled in the 2D domain, without their bridge deck present. This could underestimate local water levels when they are above soffit height, but these bridges are far enough from the Ō2NL Project to not have a significant impact on water levels within the Project corridor.

A small 1D/2D bridge structure was added for the existing South Manakau Rd Bridge as it sits close to the proposed project and thus required more accurate modelling of the bridge deck. This bridge was built by drawing a cross section in Hec RAS, used to set the locations of the linked upstream and downstream cross sections. The bridge cross sections were given elevations based on the underlying terrain. A bridge deck width of 10m and thickness of 0.2m was assumed based on design drawings and confirmed by site photographs. A weir coefficient for overtopping was assumed to be the default 0.92.

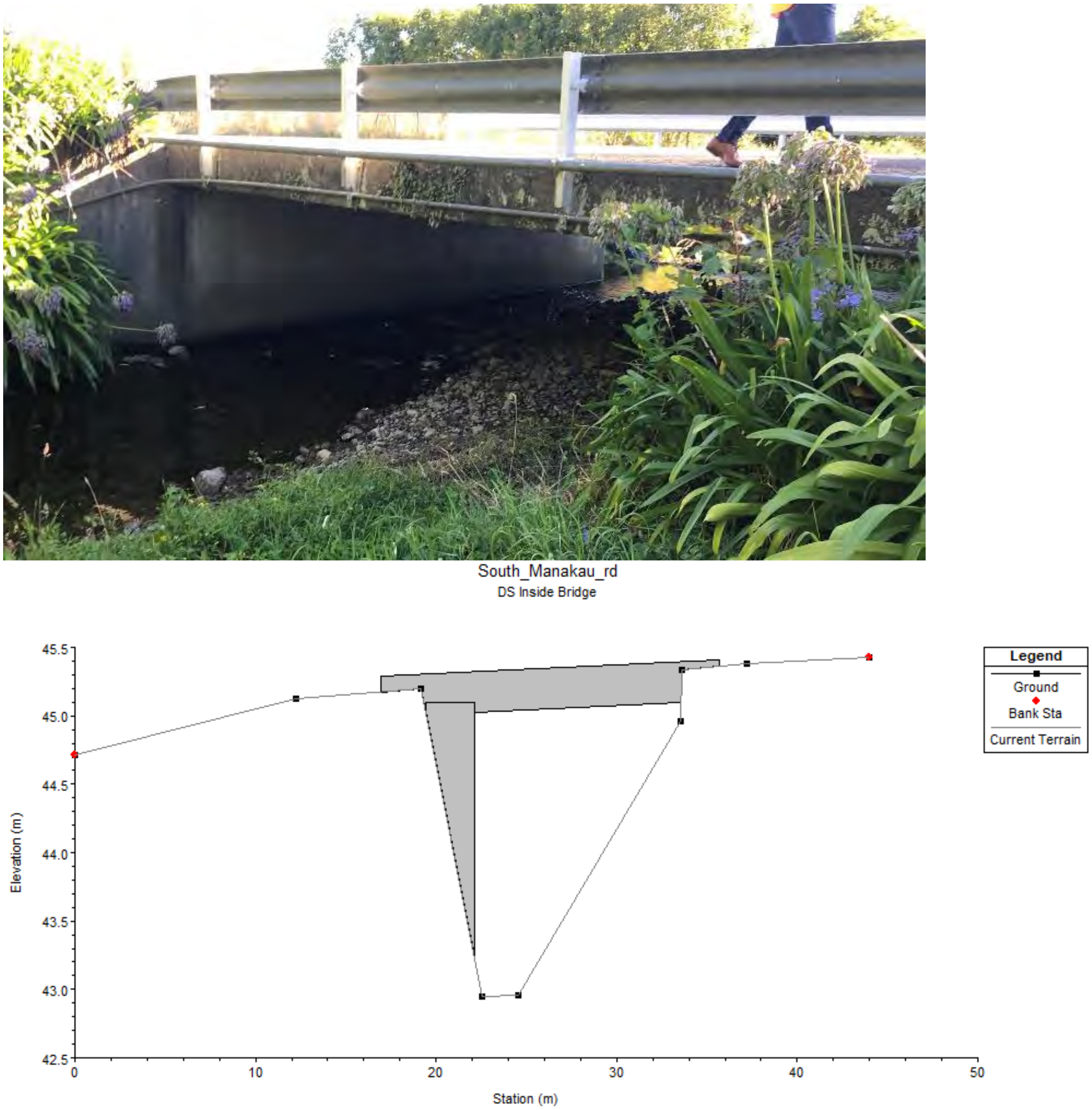


Figure 5-6: Cross section Manakau Stream bridge at South Manakau Road

Culverts that are considered hydraulically significant near (upstream or downstream) to the corridor were built into the model. To include these in the model, internal boundary connections were created in HEC-RAS to allow water to pass from the 2D domain into the 1D feature and back into 2D. The structure embankment is enforced as a 2D break-line to prevent premature overtopping of the structure, as discussed in section 5.2.2. Internal boundary connections were used in the model as needed along existing roads to prevent unrealistic flow through or over the road. Each connection can contain one or more culverts and these were named according the indicative highway crossing number (as an internal reference system), location downstream (DS) or upstream (US) relative to the Ō2NL corridor, and the asset type (railway, highway, or road).

Since the urban built-up area of Levin is significant distance and elevation downstream of the proposed Ō2NL corridor, it was not required to model the urban drainage pipes with Levin.

Culverts with pipe diameter larger or equal to 450 mm and those that affect the flooding near the indicative corridor were applied in the model. A summary of the existing structures represented in the models is included in Table 5-3. This table highlights in red any assumed values that were inferred or estimated (e.g. from LiDAR and assumed cover). It is relevant to mention that there was no level information from all the structure's information sources. Therefore, invert levels on culverts were set considering the lowest nearby 2D surface elevation plus 0.01m. The assumptions used to estimate missing data are summarized in Table 5-4.

Table 5-3: Existing culvert connections

Culvert Name	No Culverts	Total Barrels	Source	Diam (m)	Shape	Length (m)	Invert levels (us/ds, m)
00_DS_HWY	1	1	Highway	2.429	Pipe Arch	17.8	23.9/23.31
00_DS_RD1	2	2	KCDC	1.5	Circular	15.0	17.63/17.63
00_DS_RLW	1	1	KiwiRail	1.2	Circular	14.8	17.28/17.28
00_US_RD1	2	2	ASSUMED	0.6	Circular	15.0	29.29/29.29
00_US_RD2	1	1	KCDC	0.6	Circular	19.5	41.43/41.1
00_US_RD3	1	1	KCDC	0.75	Circular	10.1	51.48/51.3
01_US_RD1	1	1	ASSUMED	0.6	Circular	15.0	22.45/22.41
01-04_DS_HWY	1	1	Highway	1.2	Circular	30.0	15.22/15.95
01-04_DS_RD1	1	1	ASSUMED	1.2	Circular	15.0	15/14.26
01-04_DS_RD2	2	2	ASSUMED	0.6	Circular	15.0	12.76/12.63
01-04_DS_RLW	1	1	KCDC	0.6	Circular	14.0	12.54/10.32
04_DS_RD1	1	1	ASSUMED	0.6	Circular	15.0	23.8/22.26
05-06_DS_HWY	2	2	Highway	1.2	Circular	30.0	16.34/15.7
05-11_DS_RD1	1	1	KCDC	1.2	Circular	21.1	10.14/9.7
05-11_DS_RLW	1	1	KiwiRail	0.91x1.2	Box	43.4	11.98/11.98
11_DS_HWY	1	1	Highway	1.2	Circular	72.3	35.3/33.66
11_DS_RLW	3	3	KiwiRail	0.6	Circular	32.0	37.56/38.7
14-15_DS_HWY	*0*	0	Highway		BRIDGE		
14-15_DS_RD1	*0*	0	HDC		BRIDGE		
14-15_DS_RLW	*0*	0	KiwiRail		BRIDGE		
15_US_RD1	*0*	0	HDC		BRIDGE		
17_DS_HWY	1	1	Highway	0.6	Circular	69.4	34.24/34.24
17_DS_RD1	*0*	0	HDC		BRIDGE		
17_DS_RLW	1	1	KiwiRail	0.6	Circular	28.6	35.83/35.83
17_US_RD1	1	1	HDC	0.6	Circular	15.0	45.78/44.37
17_US_RD2	1	1	HDC	0.6	Circular	14.0	45.78/45.44
18_DS_HWY	1	1	Highway	0.6	Circular	22.3	25.86/25.86
18_DS_HWY2	1	1	Highway	0.45	Circular	22.5	28.9/30.11
18_DS_RLW	1	1	KiwiRail	1.2 x 1.47	Pipe Arch	42.6	34.13/34.84
18_US_HWY	2	2	HDC	1.05	Circular	17.2	42.93/42.57
18_US_RD1	1	1	ASSUMED	0.6	Circular	15.0	49.87/49.87
18_US_RD2	1	1	HDC	0.6	Circular	15.0	52.92/52.92
19_DS_RD1	1	1	HDC	0.6	Circular	15.0	43.04/42.98
19-25_DS_HWY	1	2	Highway	1.05	Circular	18.1	27.38/27.38
19-25_DS_RLW	1	1	KiwiRail	1.2	Pipe Arch	21.5	27.36/27.36
27_DS_HWY	*0*	0	Highway		BRIDGE		
27_DS_RLW	*0*	0	KiwiRail		BRIDGE		
27_US_RD1	1	1	HDC	0.6	Circular	15.0	66.2/66.93
28_DS_HWY	1	1	Highway	0.38	Circular	24.0	44.71/44.19
28_DS_RLW	1	1	KiwiRail	0.45	Circular	10.0	39.72/39.32
29-30_DS_HWY	1	1	Highway	1.05	Circular	20.9	37.9/38.9
29-30_DS_RLW	1	1	KiwiRail	1.5	Pipe Arch	10.0	24.34/23.93
31-32_DS_HWY	1	2	Highway	0.6	Box		25.71/25.71
31-32_DS_RD1	*0*	0	HDC		BRIDGE		
31-32_DS_RD2	*0*	0	HDC		BRIDGE		
31-32_DS_RLW	*0*	0	KiwiRail		BRIDGE		
32_DS_RD1	1	1	ASSUMED	0.6	Circular	15.0	33.15/33.15
33_DS_HWY	*0*	0	Highway		BRIDGE		
33_DS_RLW	*0*	0	KiwiRail		BRIDGE		
33_US_RD1	*0*	0	HDC		BRIDGE		
34_US_RD1	*1*	2	HDC	0.3	Circular	9.0	48.87/48.67
34_US_RD2	*1*	1	HDC	0.6	Circular	20.0	49.29/49.12
34_US_RD3	*1*	1	HDC	0.6	Circular	20.0	46.42/46.1
34_US_RD4	*1*	1	ASSUMED	3.42x2	Box	12.0	45.02/44.94
36_DS_RD1	*1*	1	HDC	0.75	Circular	11.9	41.5/41.29
36_DS_RD2	*1*	2	HDC	0.45	Circular	10.0	35.27/35.02
36_DS_RD3	*1*	1	HDC	0.45	Circular	10.0	33.13/33.13
36_US_RD1	*1*	*1*	HDC	0.6	Circular	10.0	63.83/63.6
37_DS_HWY	*2*	2	HDC	0.525	Circular	31.0	48.75/48.1
39_DS_HWY	*1*	2	Highway	0.375	Circular	17.1	19.27/1
39_US_HWY	*1*	1	Highway	0.85	Circular	31.0	30.81/30.81
41-42_DS_RD1	*3*	3	HDC	0.6	Circular	15.0	11.36/10.66

Culvert Name	No Culverts	Total Barrels	Source	Diam (m)	Shape	Length (m)	Invert levels (us/ds, m)
42_DS_RD1	*1*	1	ASSUMED	0.6	Circular	15.0	31.34/31.75
42_DS_RD2	*2*	2	HDC	0.6	Circular	15.0	29.57/27.4
42_DS_RD3	*1*	1	ASSUMED	0.6	Circular	15.0	30.84/30.24
42_DS_RD4	*1*	1	ASSUMED	0.6	Circular	15.0	34.46/33.26
42_DS_RD5	*1*	1	HDC	0.6	Circular	15.0	23.6/21.73
42_DS_RLW	*4*	4	KiwiRail	0.45	Circular	10.0	40.8/39.1
42_DS_RLW2	*1*	1	KiwiRail	0.45	Circular	10.0	38.83/39.41
43_DS_RD2	*0*	0	HDC		BRIDGE		
48_DS_RD1	*1*	1	HDC	0.6	Circular	15.0	62.4/62.3
48_DS_RD2	*1*	1	HDC	0.6	Circular	10.0	60.3/61.2

Table 5-4: Assumptions used to infill missing structure data

Assumptions for Weirs	
Width	Weir on railway: 4m Weir on local road (no highway): 6m Weir on highway: 10m
Coefficient (Cd)	0.92 (see HEC-RAS Hydraulic Reference for SI units also ref[4])
Weir Crest Shape	Broad crest
Overflow Computational Method	Normal 2D Equation
Assumption for Culverts	
Type	Circular
Diameter	600mm, or nearest known existing culvert diameter if larger
Invert Levels	The lowest upstream level from DEM
Chart /Type	1-3. Concrete pipe culvert. No headwall.
In / Out Loss coefficient	0.5 and 0.1 respectively
Length	If there is not information from source the following lengths were applied: On railway: 10m On highway: 20m On local road (no highway): 15m
Roughness	• Concrete 0.013 • Corrugated arch pipe 0.024

[4] https://engineerpaige.com/lateral-structure-weir-coefficients-in-hec-ras/

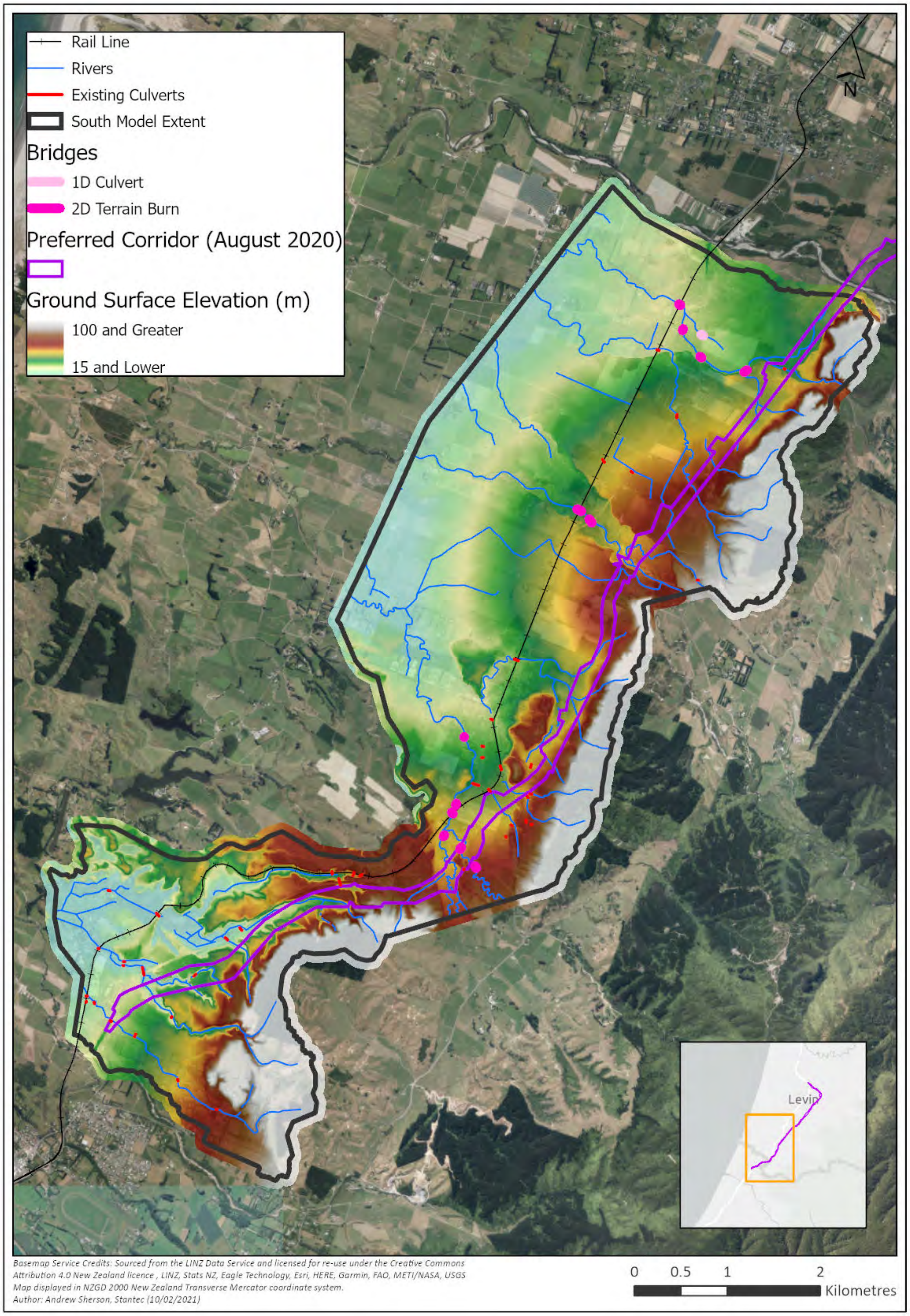


Figure 5-7: Map of modelled existing bridges and culverts in South model

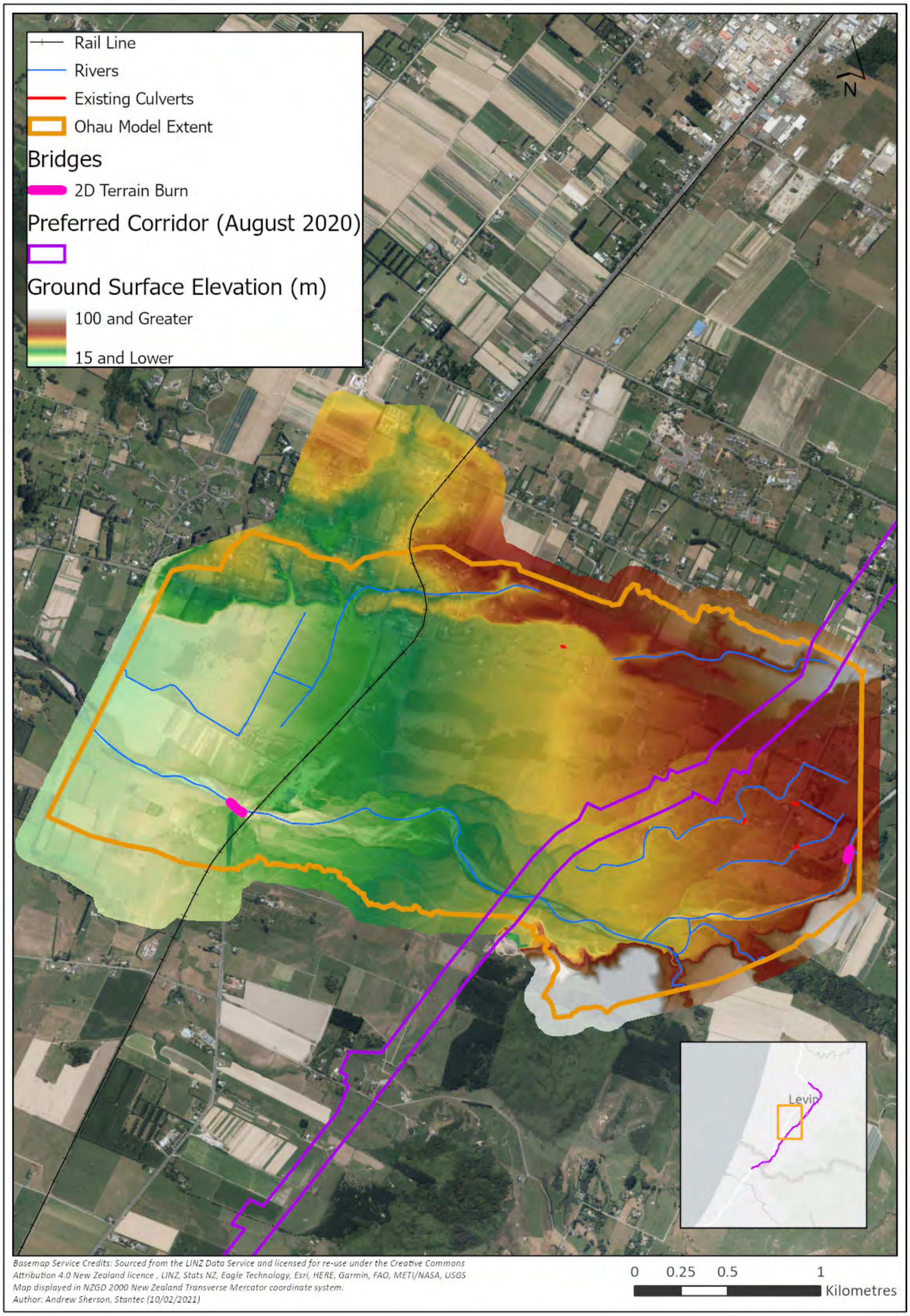


Figure 5-8: Map of modelled existing bridges and culverts in Ōhau model

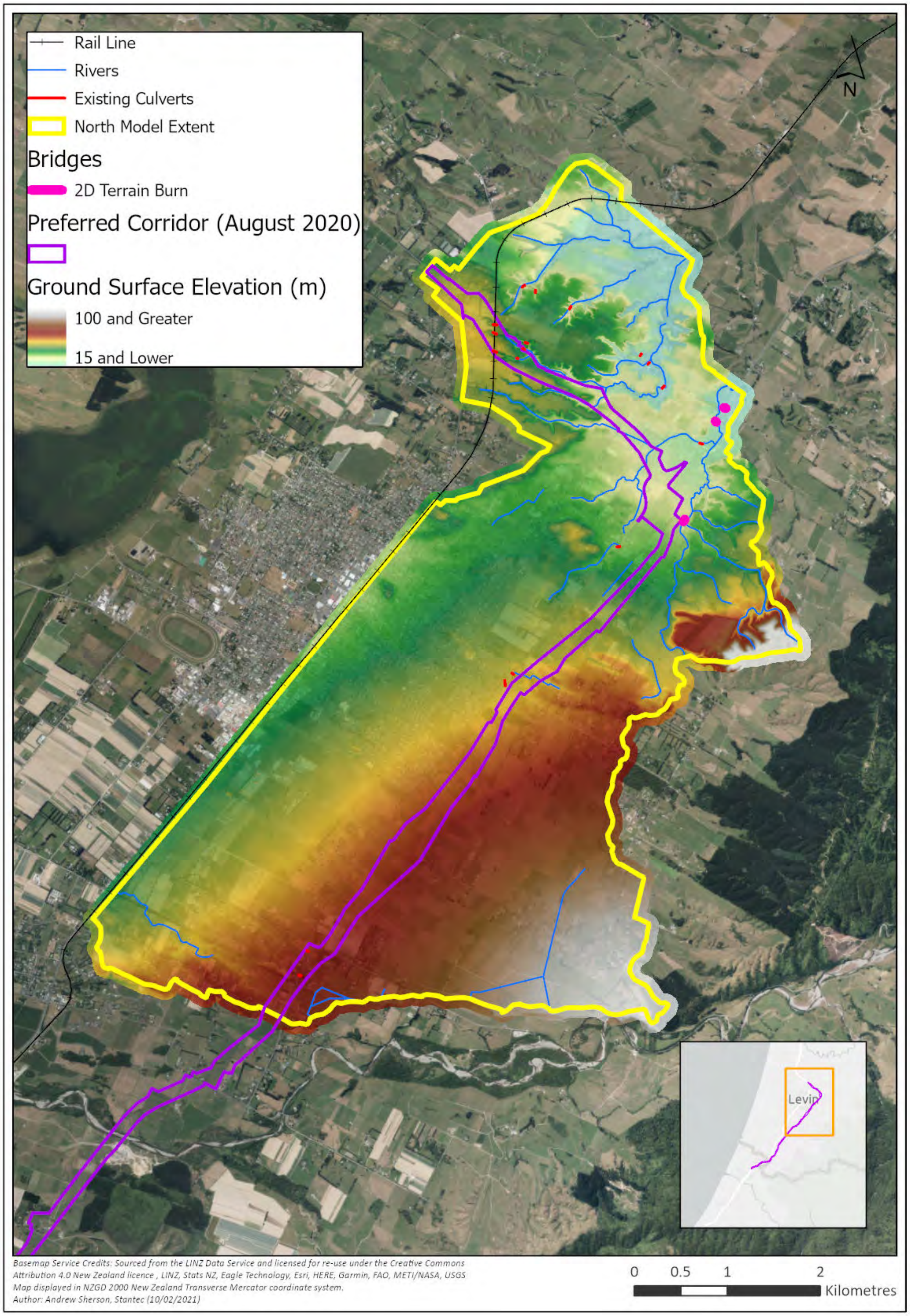


Figure 5-9: Map of modelled existing bridges and culverts in North model

5.5 Boundary Conditions and Scenarios

Downstream boundaries of the 2D models were set using the normal slope of the streams at these locations, derived from the DEM. Normal slopes were chosen for the downstream boundary conditions as no existing water levels at these points was known for different AEP events. By using the normal slope of the stream, the model calculates a water level at the boundary condition based on flow area including the floodplain, Manning's 'n' and the normal slope. A summary of the upstream and downstream boundary conditions is provided in Table 5-5.

Table 5-5: Model boundary conditions summary

Model	Boundary Condition Name	Boundary Type	Normal Depth Slope
South Model	US_14 (South_1)	Flow Hydrograph	
	US_15 (South_2)	Flow Hydrograph	
	US_27 (South_3)	Flow Hydrograph	
	US_27.1	Flow Hydrograph	
	US_32 (South_4)	Flow Hydrograph	
	South_Mesh	Precipitation	
	DS_1-11	Normal Depth	0.0034
	DS_13-22	Normal Depth	0.0023
	DS_27	Normal Depth	0.0053
	DS_32	Normal Depth	0.0026
	DS_44	Normal Depth	0.0092
	DS_31	Normal Depth	0.0035
Ōhau Model	US_33 (Ōhau_1)	Flow Hydrograph	
	US_33e	Flow Hydrograph	
	Ōhau_East_Mesh	Precipitation	
	DS_33	Normal Depth	0.0028
North Model	US_ North (North_1)	Flow Hydrograph	
	North_Mesh	Precipitation	
	DS_41-42	Normal Depth	0.0032
	DS_39-40	Normal Depth	0.0029
	DS_37-38	Normal Depth	0.0082

Upstream boundary conditions were defined using point inflow hydrographs derived in Section 4 plus distributed direct rainfall for the smaller catchments near and downstream of the Ō2NL corridor as discussed in Section 5.6 below.

5.6 Direct Rainfall

The rainfall totals (prior to applying losses) and sample temporal profiles for different storm durations were prepared for the 2D direct rainfall modelling zones, using the methods outlined in Sections 4.2.2 to 4.2.8. Direct rainfall was the preferred approach to produce a map of flooding 'everywhere' (as opposed to just within known watercourses at known crossing locations). This approach allows the effects of downstream tributary backwater effects and is independent of final road alignment.

Based on the range of indicative 2D catchment sizes draining towards and near the corridor, initial testing commenced with 20 minute and 1h storm durations with their respective total rainfall amounts and temporal profiles applied. The Initial and Constant loss values were adopted initially from the HEC-HMS models described in 4.4, namely 7mm and 5mm/hr respectively, and applied to the respective rainfall profiles. Despite the higher total rainfall intensities, the 20 minute storm was smaller than a 1h storm once run through the distributed hydraulic model with appropriate initial losses applied. Further testing therefore focussed on a 1h and 4h storm.

A subset of catchment outflows from the HEC-RAS 2D model were compared against HEC-HMS and Rational Method peak flows as the sample locations. As anticipated, the initial set of losses via the HEC-RAS produced unrealistically high peaks compared to the HEC-HMS model. This is expected to be mainly associated with the HEC-RAS model translating flow too quickly to the outlet of the catchment, even if high roughness values are applied, because the HEC-RAS model does not capture many local depressions and initial or continuing storage (in which ongoing infiltration can occur after rain has ceased falling, reducing surface flow volume at the catchment 'outlet'). By contrast, the HEC-HMS represents these processes differently via selection of unit hydrographs, time of concentration and storage coefficients. It was found that the HEC-RAS model was calculating flows (and hence associated levels) far greater than the calibrated flows from the HEC-HMS models.

The Initial and Constant loss parameters for the HEC-RAS applied rainfall were therefore increased from 7mm and 5mm/hr to 16mm and 7mm/h respectively. The resulting effective rainfall depths are presented in Table 5-6. The reduced peak sub-catchment outflows from the HEC-RAS model compared graphically to independent peak flow estimates (HEC-HMS, Rational Method, Flood Frequency Analysis) in Figure 5-10. The specific yield (peak flow divided by catchment area raised to the power of 0.9) is plotted against catchment area. The spread in the cloud of 2D data points is attributable mainly to variations in catchment steepness and storage features (ponds/depressions). It is worth reiterating that the FFA for the Koputaroa at Tavistock Rd is considered unreliable. In general, there appears to be a good correlation between the trends in the data clouds from the respective methods, which supports the newly adopted loss values (previous 2D clouds were unrealistically high). There is also a good correlation with the PP2Ō data point at Greenwood Stream (PP2Ō Culvert 1, based on a peak of 9.46m^3/s extracted from Waitohu model inflow boundary). Additional sensibility checks on the losses and percentage runoff are discussed below.

Table 5-6: Direct rainfall adopted values and losses for 1h storm

	Total rainfall	Effective rainfall with I/C 7/5		Effective rainfall with I/C 16/7 (adopted)	
Event	**Depth (mm)**	**Depth (mm)**	**%**	**Depth (mm)**	**%**
1:10 AEP current climate	26.1	16.0	61.1%	6.9	26.6%
1:100 AEP RCP6 2130	56.1	44.4	79.0%	33.7	60.0%
1:1500 AEP RCP8.5 2130	84.4	72.5	85.8%	61.5	72.9%

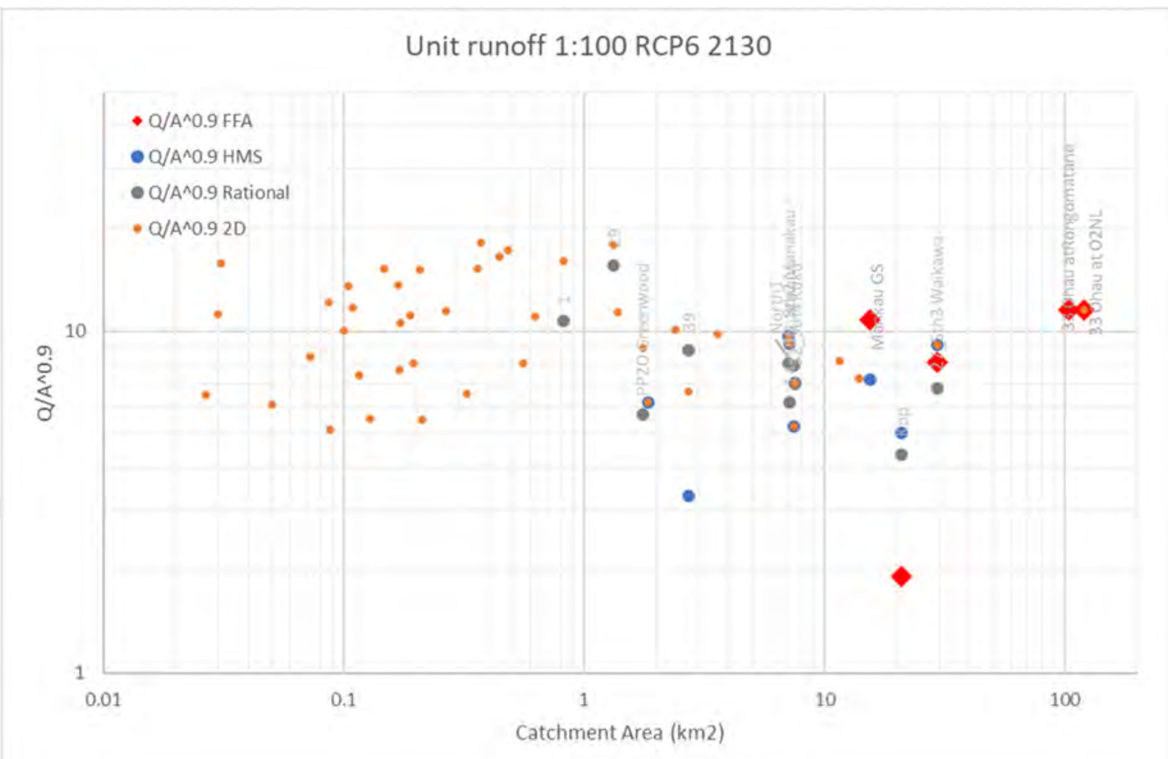


Figure 5-10: Comparison of unit runoff per km^2 (1:100 AEP RCP6 2130)

The range in % runoff presented in Table 5-6 for the updated Initial and Constant losses appears quite large (i.e. the difference between 1:10 current climate and 1:1500 with climate change). It is desirable to confirm that the resulting range of % runoff values was not being unduly influenced by the rapid response in the HEC-RAS model (compared to calibrated HEC-HMS). Therefore, the infiltration rates were compared qualitatively against design reference curves and tables for rural catchments in Figure 5-11 below (reproduced from NZ Geological Society paper "Soil Infiltration Rates" by John Hawley, June 2016). Table 5-6 is for a 1h storm, and the depths are therefore indicative of the average rainfall intensity over the 1h period. Taking the smallest total rainfall value of 26mm (1:10 AEP current climate) and the largest 84mm (1:1500 AEP RCP8.5 2130), the % runoff in the table appear to correlate reasonably to either a medium soil with forest cover or sandy soil with open crop, which provides additional confidence that the values are not unrealistic. Additional qualitative checks were also made against ultimate infiltration rates for application in the Horton method, reproduced in Figure 5-12 (from Christchurch City Council Waterways Wetlands and Drainage Guide: Part B - Chapter 21 – Updated June 2020).

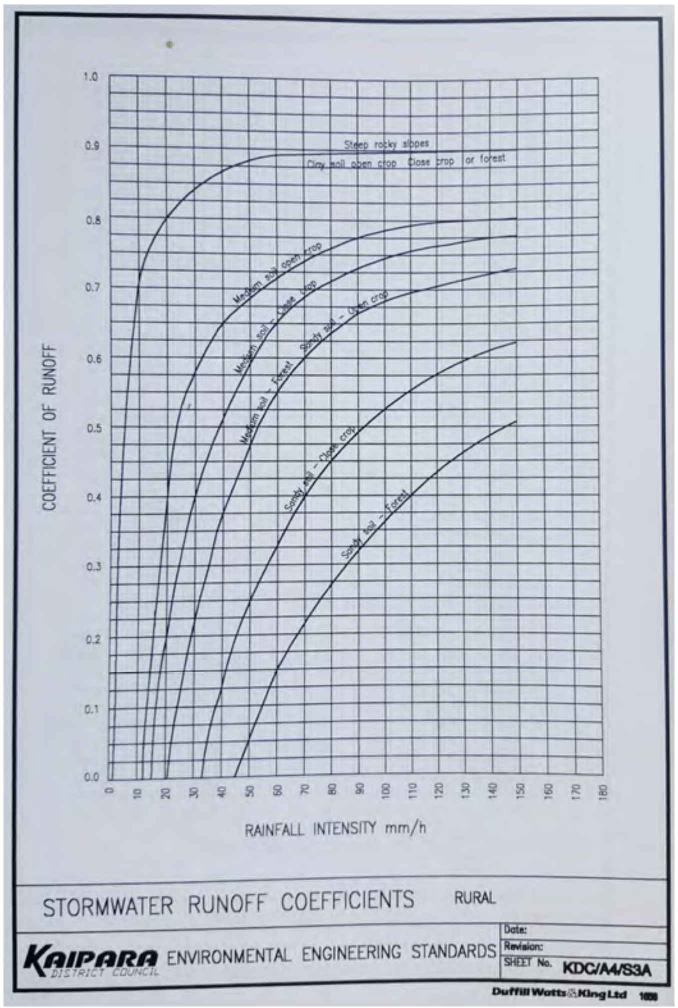


Figure 5-11: Stormwater runoff coefficients for rural catchments (Kaipara District Council)

Table 21-11: Soil type ultimate infiltration rates.

USDA Soil Texture Classification	Ultimate infiltration rate (mm/hr)	Infiltration Type
Sand	230	Free
Loamy Sand	60	
Sandy Loam	22	
Loam	13	Moderate
Silt Loam	6.8	
Sandy Clay Loam	3.0	Poor
Clay Loam	2.0	
Silty Clay Loam	2.0	
Sandy Clay	1.2	
Silty Clay	1.0	
Clay	0.6	

Figure 5-12: Ultimate soil infiltration rates (Christchurch City Council)

With the selected losses of 16mm and 7mm/h, the HEC-RAS model confirmed that the 1h storm is larger than a 20-minute storm for all sites of interest near the proposed Ō2NL corridor (due to the initial losses having a more profound effect of lowering the 20-minute total effective rainfall). Therefore, in subsequent simulations, the 20-minute storm is not used. The maximum of the 1h and 4h storm durations is used.

The timing of the 1h storm was lagged by 90 minutes so that the peak rainfall intensity for the 1h direct rainfall storm coincided with the peak rainfall intensity applied to the HEC-HMS models to derive the 4h critical duration storm point inflow hydrographs. This hybrid storm approach with coincident critical spatial intensities is more accurate and representative of reality than a nested temporal storm profile applied to the whole system.

Visual comparisons were made of the HEC-RAS model results against Regional Council flood mapping where available for the larger rivers (Waiauti, Manakau, Waikawa and Ōhau). There was generally good correlation in shape and extent, although the provenance (source, date and modelling approach or flows applied) for the Regional Council flooding layers were not known, and they appeared to include some unrealistic extents relative to ground topography. In Levin, existing HDC urban flood modelling is focussed around representing the impervious areas and pipe network capacity, with shorter duration storms and/or that drain away from the Ō2NL corridor, and therefore were of less relevance for direct comparison. The drainage network and flow paths through Levin do not have an impact on water levels within the proposed project corridor.

In-situ testing of infiltration rates as part of Detail Design could potentially be used to further refine the adopted infiltration / loss values, potentially along with additional rainfall and streamflow data collection and analysis. Consideration could also be given to applying the Horton loss model approach, depending on the outcomes or issues identified during the assessment of effects or factors shown to influence the Detailed Design.

5.7 Run Parameters and Model Stability

The model used an adaptive time step based on courant formula with a maximum value of 2 and a minimum value of 0.5. The equation set used in all models was 'Full Momentum'.

The three models were simulated successfully across all AEP events, with the model balance results summarised in Table 5-7.

Table 5-7: Model balance results (volume accounting in 1,000 m^3)

Model	Plan Name	Ending Vol (1000m^3)	Cum Inflow	Cum Outflow	Error in 1000m^3	% Error
South	P24_0.07%AEP_USv06 Gv09 Tv07	1606	8515	6911	1.768	0.02076
	P22_1%AEP_USv06 Gv09 Tv07	1096	5136	4042	1.331	0.02591
	P21_10%AEP_USv06 Gv09 Tv07	514.2	1873	1360	0.407	0.02173
Ōhau	P39 - 0.07% AEP UsV06 Gv07 Tv03	65.92	11427	11363	1.548	0.01354
	P36 - 1% AEP UsV06 Gv07 Tv03	61.82	7305	7245	1.887	0.02583
	P37 - 10% AEP UsV06 Gv07 Tv03	46.32	3141	3095	0.586	0.01866

Model	Plan Name	Ending Vol (1000m³)	Cum Inflow	Cum Outflow	Error in 1000m³	% Error
North	P32_North_1500yr_Geo v8 TerV6.0	399.4	2746	2346	0.0971	0.00354
	P29_North_100yr_Geo v8 TerV6.0	307.5	1501	1194	0.0404	0.00269
	P30_North_10yr_Geo v8 TerV6.0	182.2	369.6	189	1.53	0.4138

5.8 Baseline Model Results

The various AEP design event scenarios were applied to the models and run for 6 hours of simulation time to allow the peak value to pass the downstream boundary. Maximum results from the entire simulation are then available as flood extent overview maps in Appendix G.

5.9 Limitations and Residual Uncertainties

The modelling outputs are a reasonable representation of peak flow rates and depths, to allow representation of baseline flood risk near the proposed Ō2NL corridor, and to allow an Assessment of Environmental Effects suitable for Resource Consent. The source data and the hydrological and hydraulic modelling processes have followed industry best practice but still naturally contain some uncertainties as normally anticipated. Depending on the effects or issues that arise during assessment of effects, or if greater precision is required during detailed design (for example if seeking to reduce standard design tolerances or freeboard), consideration could be given to reducing some of the residual uncertainties. Potential limitations and uncertainties to consider include:

- Limitations in the availability of accurate spatial catchment average rainfall and flow gauge data on some streams for hydrological calibration purposes, and the hydrological methods to represent both calibration events and design (hypothetical) events at a variety of scales, including losses (evaporation, canopy/interception and infiltration losses). Some of these uncertainties could be reduced through additional data collection and analysis, for historic and new flood events, in addition to field testing of infiltration losses. Consideration could be given to improving catchment average rainfall using orographic or altitude-aware methods and applying a Horton loss-model approach for the direct-rainfall model zones.

- Limitations in the Regional Council ground model (LiDAR data) on which the modelling was primarily based. This was discussed in Section 5.2 and Appendix F, including the methods currently used to mitigate these effects. Additional improvements may be feasible depending on the level of accuracy required, for example by improving the quality of the 2020 drone DEM, and/or adding new LiDAR coverage for the model extent or performing additional ground-control survey within and beyond the 2020 drone DEM extent to allow semi-automated adjustments to be applied to the 2020 drone DEM and the Regional Council LiDAR to reduce the step changes within and between the datasets. The onus will rest on the Detailed Design project stage to confirm suitability of the ground model and any associated hydraulic modelling for their final design and construction purposes.

- Limited information on existing hydraulic assets such as bridges and culverts, which necessitated some parameters to be estimated. Most of these are relatively far from the proposed corridor so the impact on results is expected to be small. Again, the tolerance of design decisions can be used to inform what additional data could be collected. For example, the closest existing bridge to the proposed corridor is the Manakau Stream at Manakau Road, where the proposed bridge is likely to have ample vertical clearance dominated by existing road clearance requirements rather than by flood level requirements. This will be discussed further in the post-scheme modelling report and Assessment of Effects.

- The model is focussed on estimating flood depths in the vicinity of the proposed Ō2NL corridor, and therefore the model DEM and results have been more closely scrutinised where they can influence the corridor. Levels elsewhere in the model domain, as well as modelled velocities and total flow volumes for different storm durations may not be fully representative of all flood scenarios.

- The representation of climate change is based on the science from IPCC 5th assessment global climate model predictions downscaled to New Zealand by NIWA (2018). Some aspects or effects of future climate change remain uncertain. Part of the testing of climate change uncertainty is achieved through the ULS resilience case 1:1500 AEP RCP8.5 2130 which represents a conservative climate case. However, there is still minor uncertainty in other aspects of climate change and knock-on impacts such as on vegetation and sediment mobility and their effects on watercourse morphology.

- The baseline modelling presented in this report, including for future climate assessments, is based on current topography, drainage assets and estimated infiltration rates. These may change in future through natural morphological change (including earthquakes and associated debris loads, in addition to gradual erosion and aggradation processes), plus anthropological changes in land-use and its impacts on infiltration rates. Future growth in impervious areas is expected notably in the proposed Tara-Ika development east of Levin, although the HDC draft stormwater strategy for Tara-Ika indicates a design philosophy to mimic natural green-field runoff rates by storing and infiltrating roof runoff, and taking road runoff to treatment, storage and infiltration areas. The sensitivity of Ō2NL designs to the effectiveness of Tara-Ika designs and exceedance runoff rates will be tested in the post-scheme modelling and/or through the detailed design stage.

6. Conclusion

The data collection, baseline hydrology and hydraulic modelling have been completed to a standard suitable for Assessment of Environmental Effects (baseline) in preparation for Resource Consent and Notice of Requirements Application.

Example baseline floodmaps are prepared and shown in Appendix G.

This baseline report will be read alongside the with-scheme modelling report that explains the hydraulic elements of the scheme and its effects, to underpin the AEE.

Appendices

Appendix A Map Figures Data Source

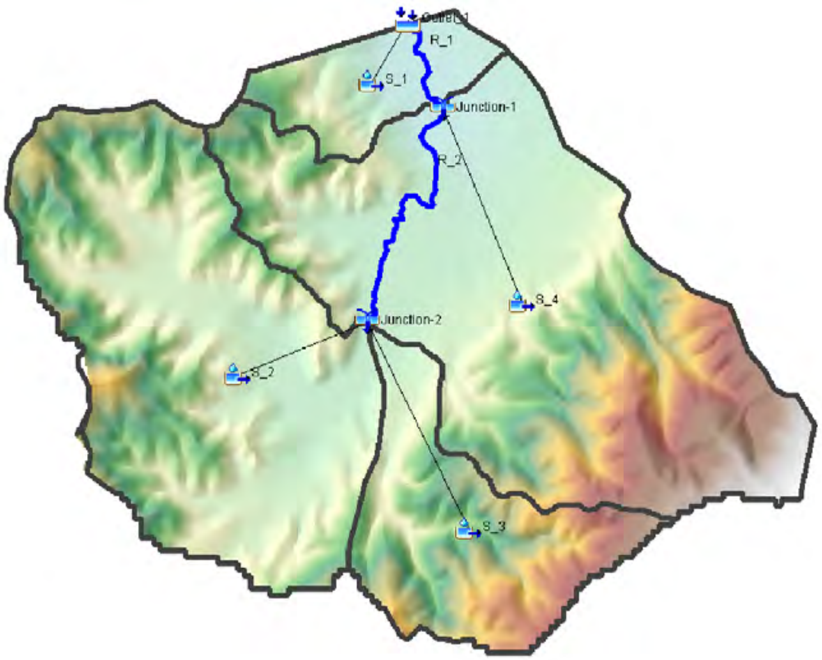
Data Sources: LINZ, GWRC, HRC, KCDC, HDC, KiwiRail and Stantec NZ.

Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors, LINZ, Eagle Technology, Esri, HERE, Garmin, FAO, NOAA, USGS

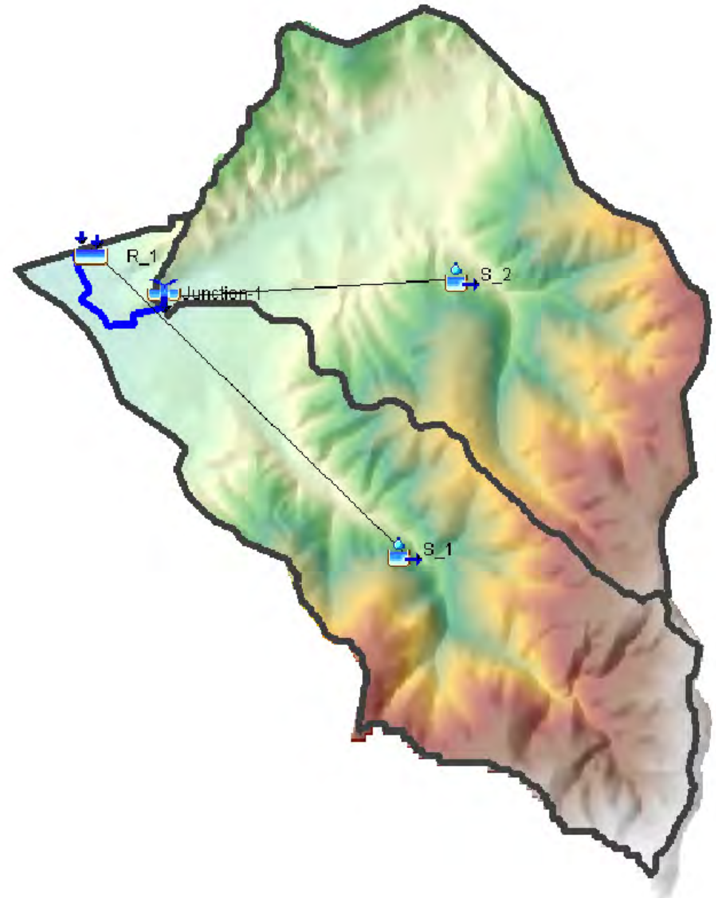
All maps displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system unless otherwise specified.

Appendix B HEC-HMS Model Schematics

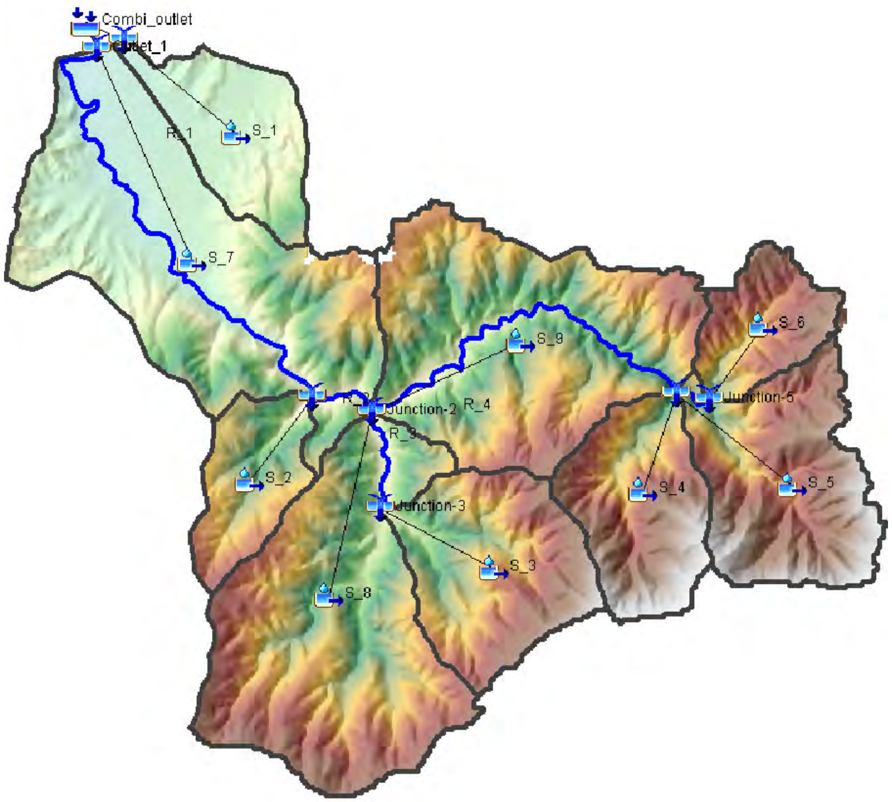
South 1 (Waiauti)



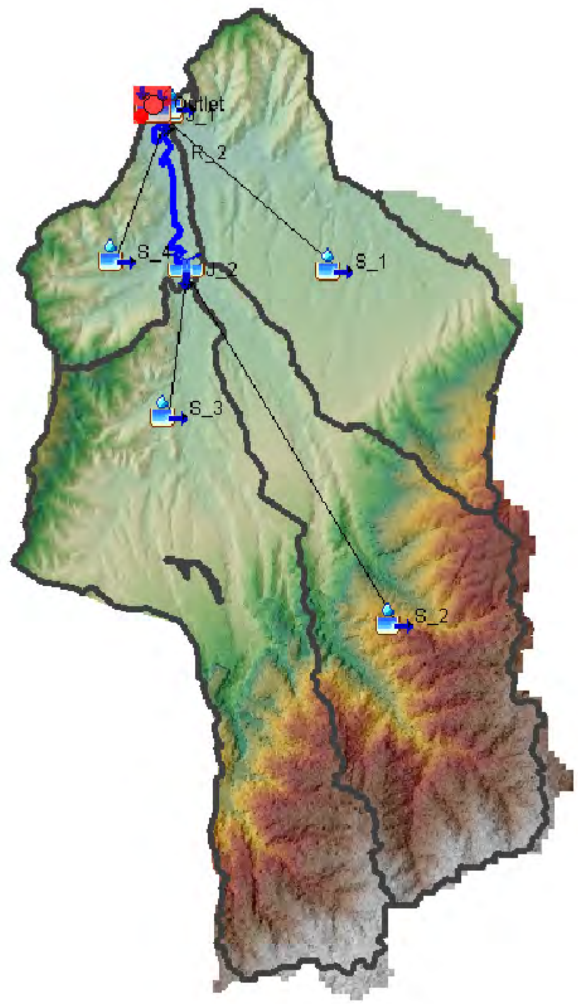
South 2 (Manakau)



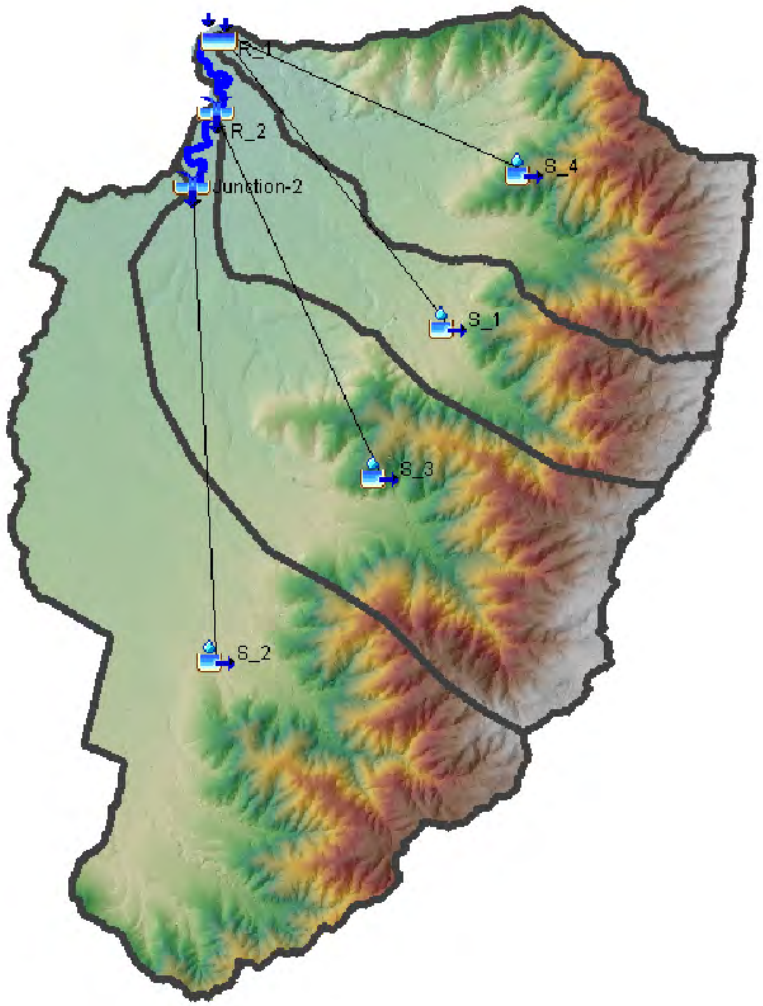
South 3 (Waikawa)



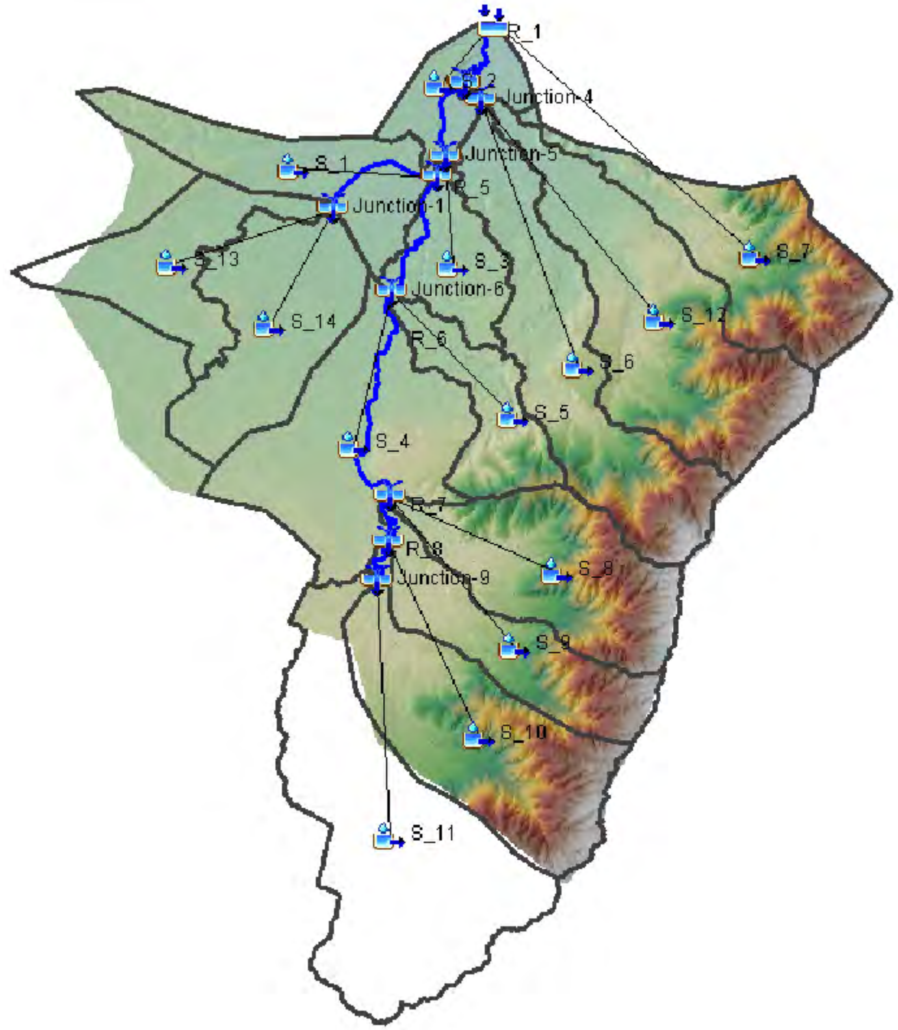
South 4 (Kuku)



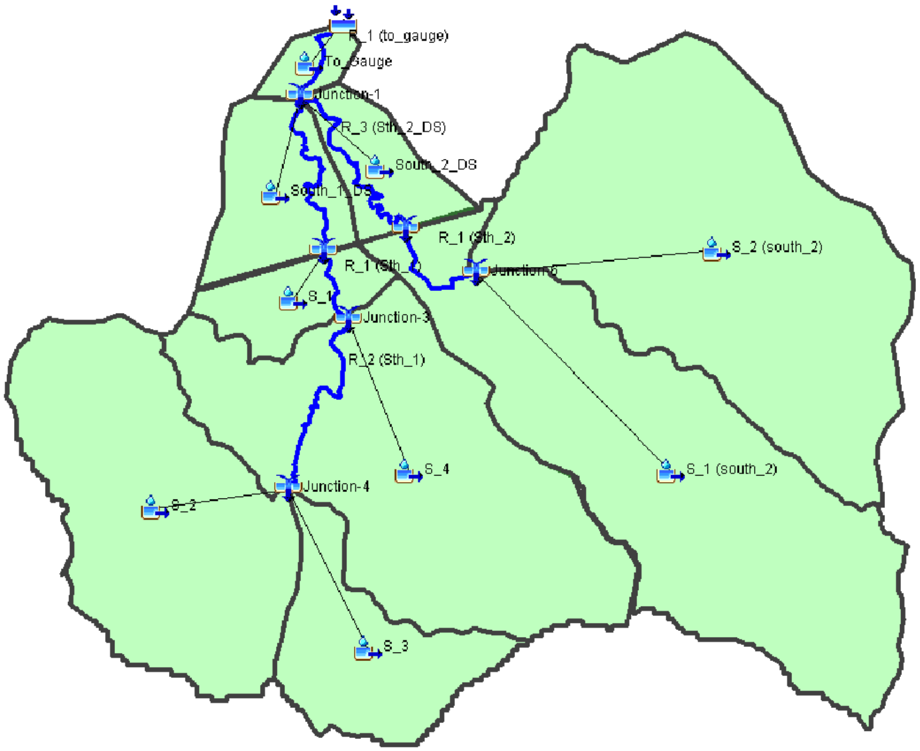
North 1



Koputaroa



Manakau at SH1 Gauge Catchment

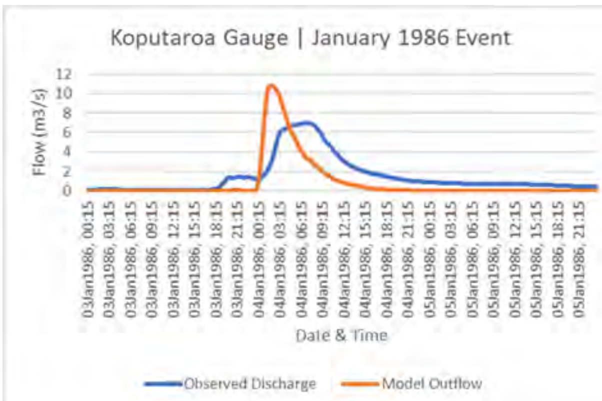


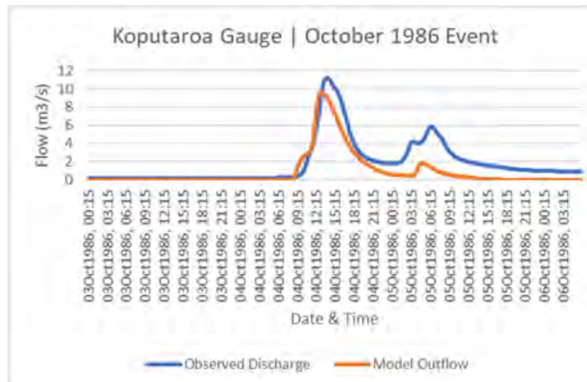
Appendix C HEC-HMS Validation Graphs

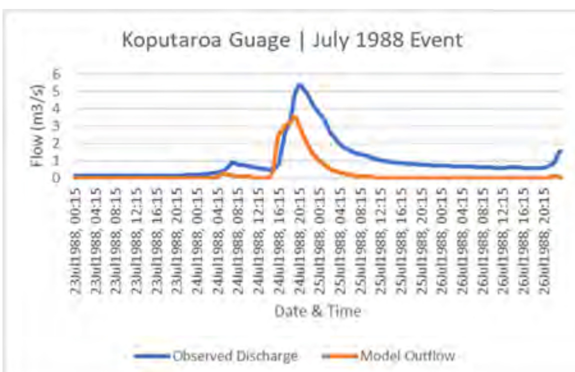
Refer to discussion in Section 4.4.3.

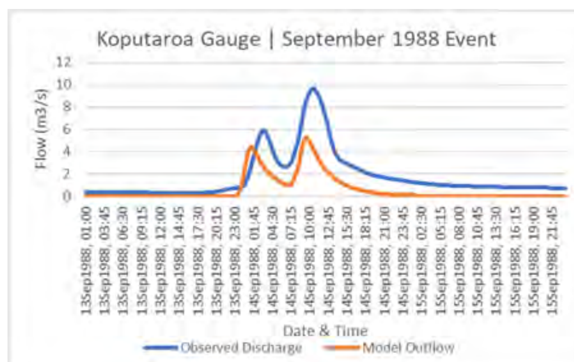
The first table below contains four separate events simulated on the Koputaroa gauge at Tavistock Rd (which had s shorter record from 1974-1989).

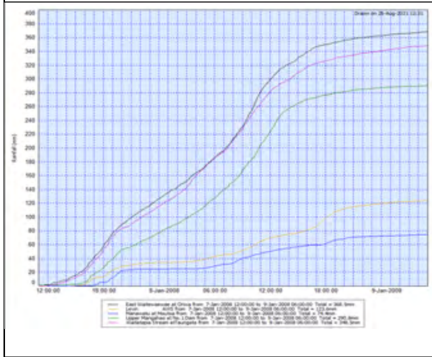
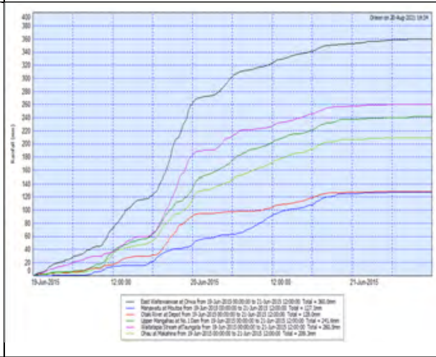
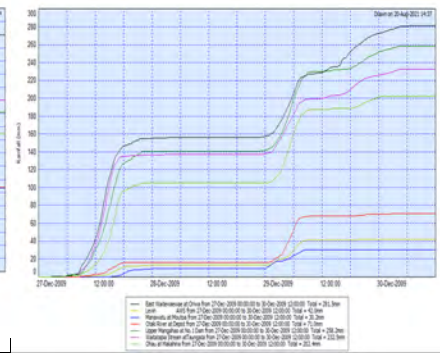
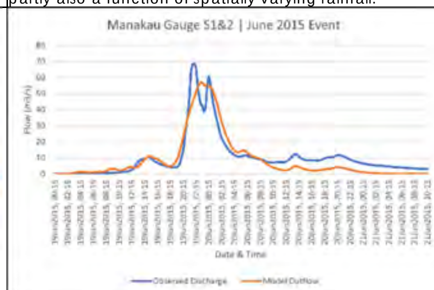
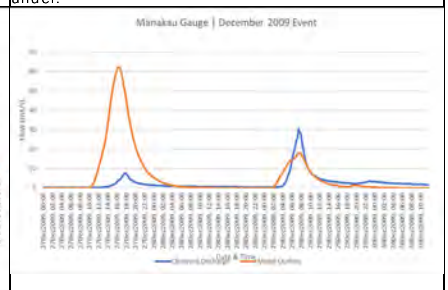
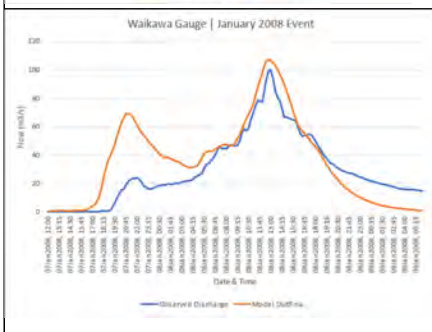
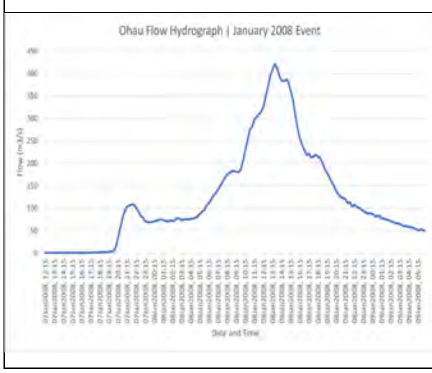
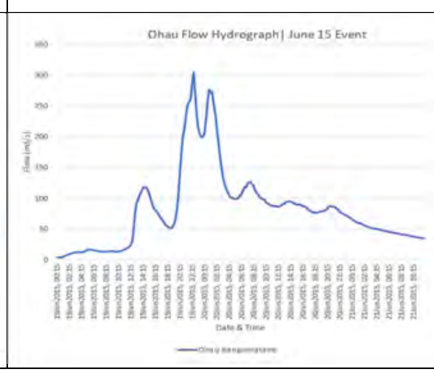
The first table is followed by a more detailed assessment for Manakau and Waikawa hydrological models. A very small layout is used deliberately to highlight patterns across rainfall plus Manakau and Waikawa on the same screen. Zooming in allows more detail to be seen. Ōhau hydrographs also shown to support discussion on hydrograph shape for some events.

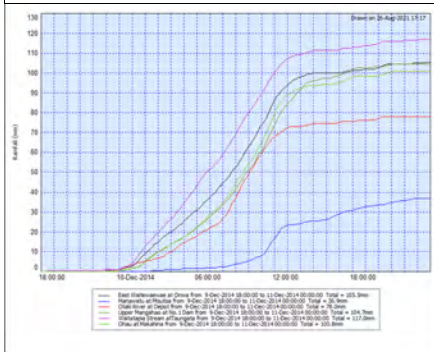
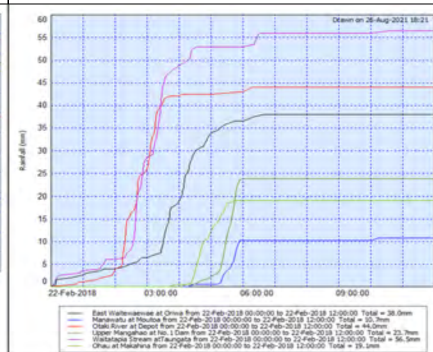
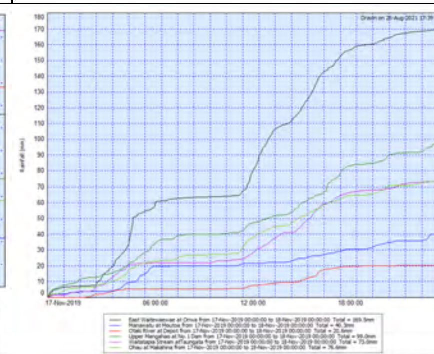
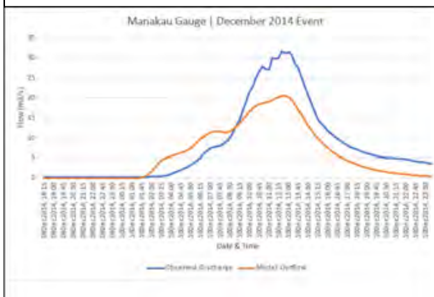
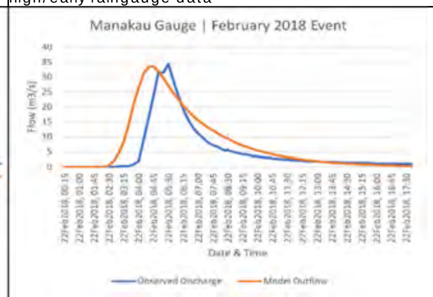
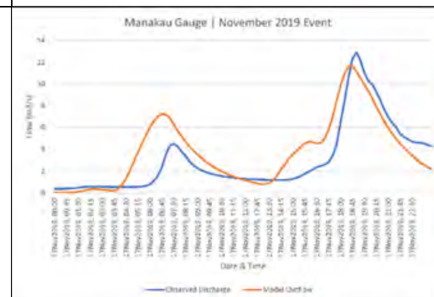
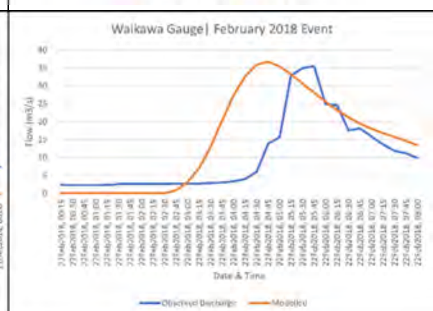
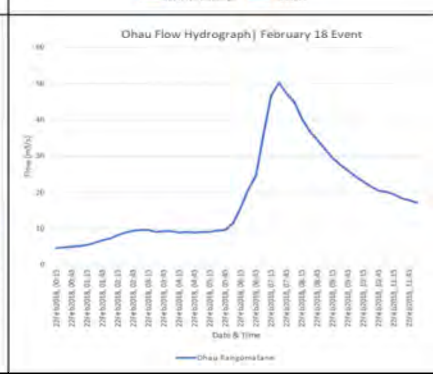




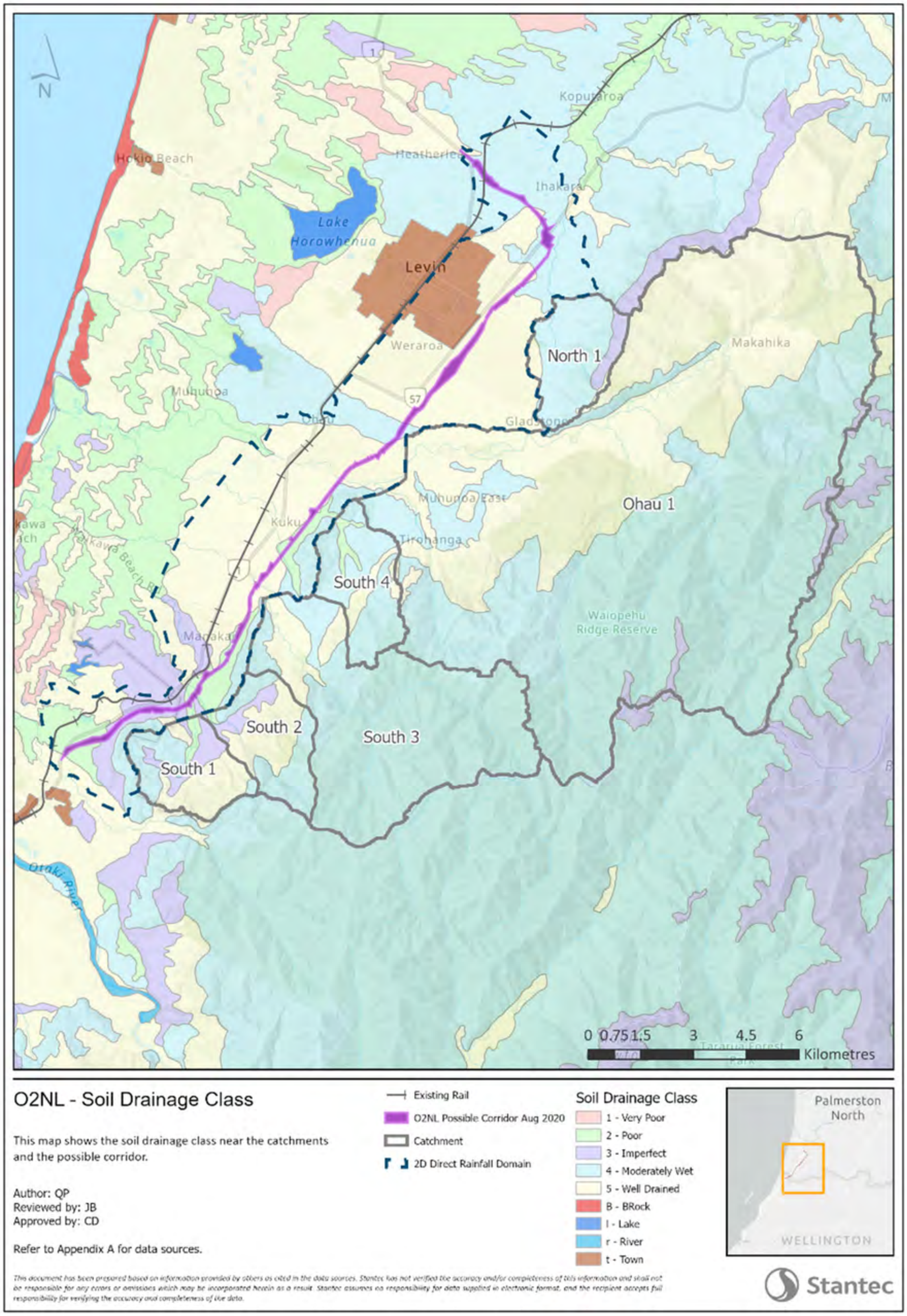




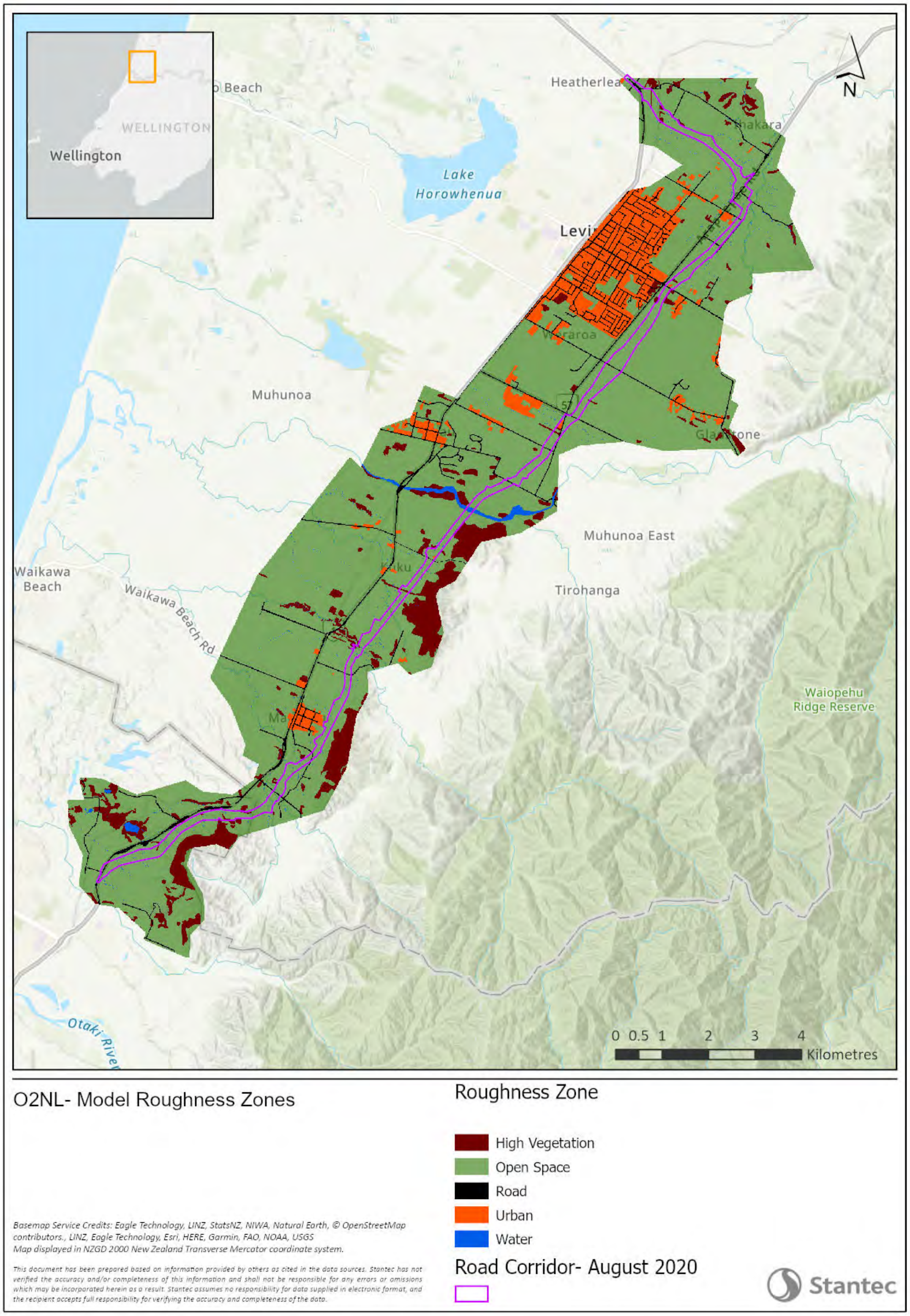
Jan 2008	Jun 2015	Dec 2009
		
Large event circa 1:10, rain spatially variable 1st peak over predicted at both sites, 2nd peak over at Manakau but **good at Waikawa**, 3rd peak observed at Mankau but not observed at Waikawa or Ōhau or most raingauges, hence would be difficult to match in model. Note Otaki rainfall no event data.	**Large event circa 1:10**, rain spatially variable and two peaks close together. 2nd peak observed at Manakau and Ōhau but hardly visible at Waikawa. Overall fit of peak magnitude at both sites is good, although model attenuation results in the two peaks mixing together, partly also a function of spatially varying rainfall.	Small double event, rain spatially variable, 1st peak way over at both Mankau & Waikawa although note the very high first hit of rainfall in the hills so would be difficult to get better model with such high rainfall. 2nd peak fits better at both sites although Manakau under.
		
		
		

Dec 2014	Feb 2018	Nov 2019
		
Small event, rain spatially variable, low at Manakau, good fit at Waikawa	Small event, **rain TIMING VERY variable**, peak values are good at both sites although early due to the use of some high/early raingauge data	Small event, rain variable, fit reasonable (mix of over and under)
		
		
		

Appendix D FSL Drainage Class

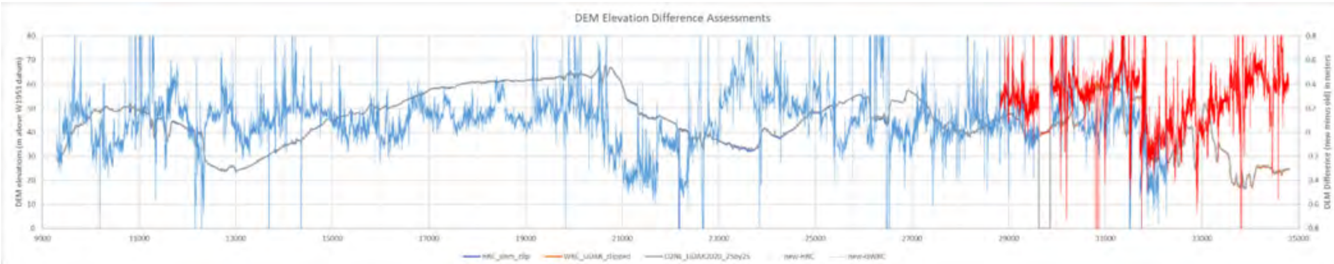


Appendix E Roughness Map

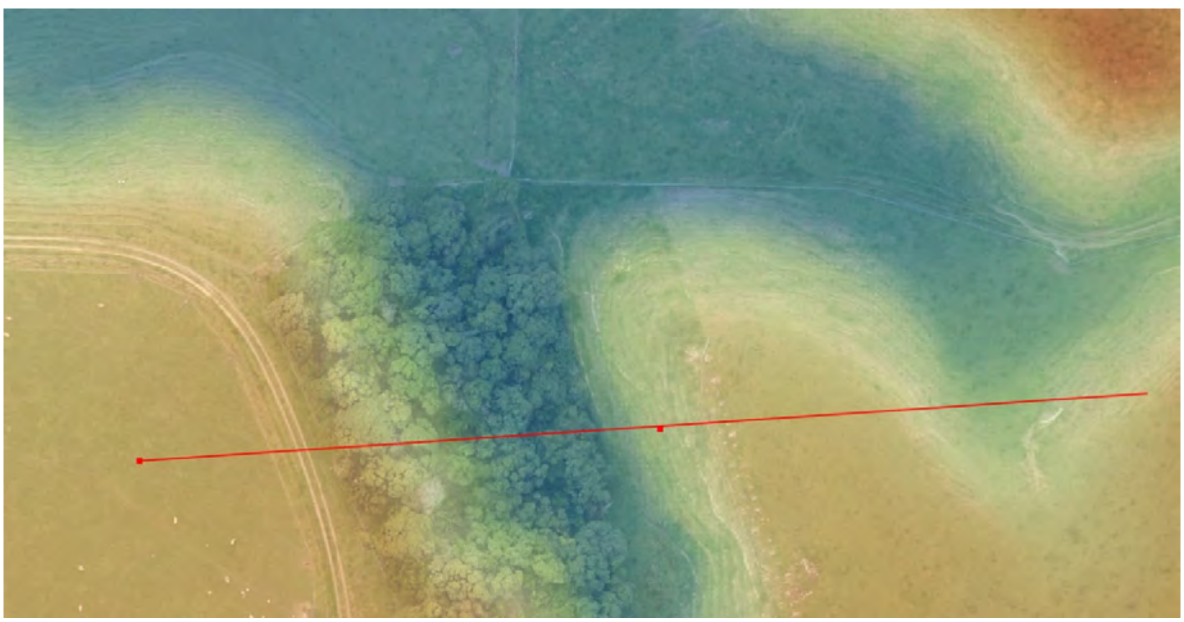


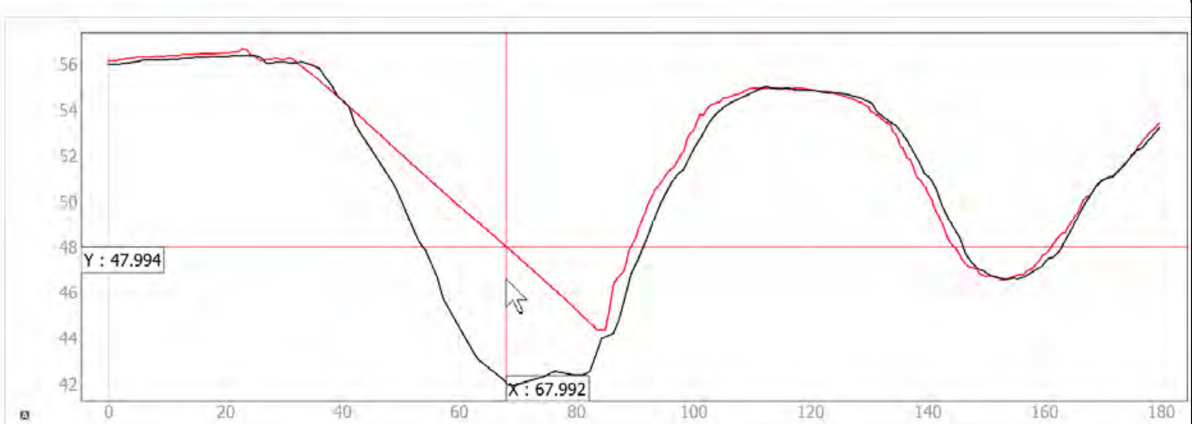
Appendix F DEM Issues

DEM differences assessment (see Section 5.2.1). The three thicker lines show the extents and elevations from the key datasets along a draft Ō2NL route, although the errors cannot be visually assessed at this scale. Therefore, the thin lines show the differences between the datasets, plotted on the right hand (secondary) axis. This shows moving average differences vary from +0.6 to -0.4, with localised noise and many localised deviations of much larger magnitude. The choices and mitigation measures to deal with these differences are discussed in Section 5.2.1.

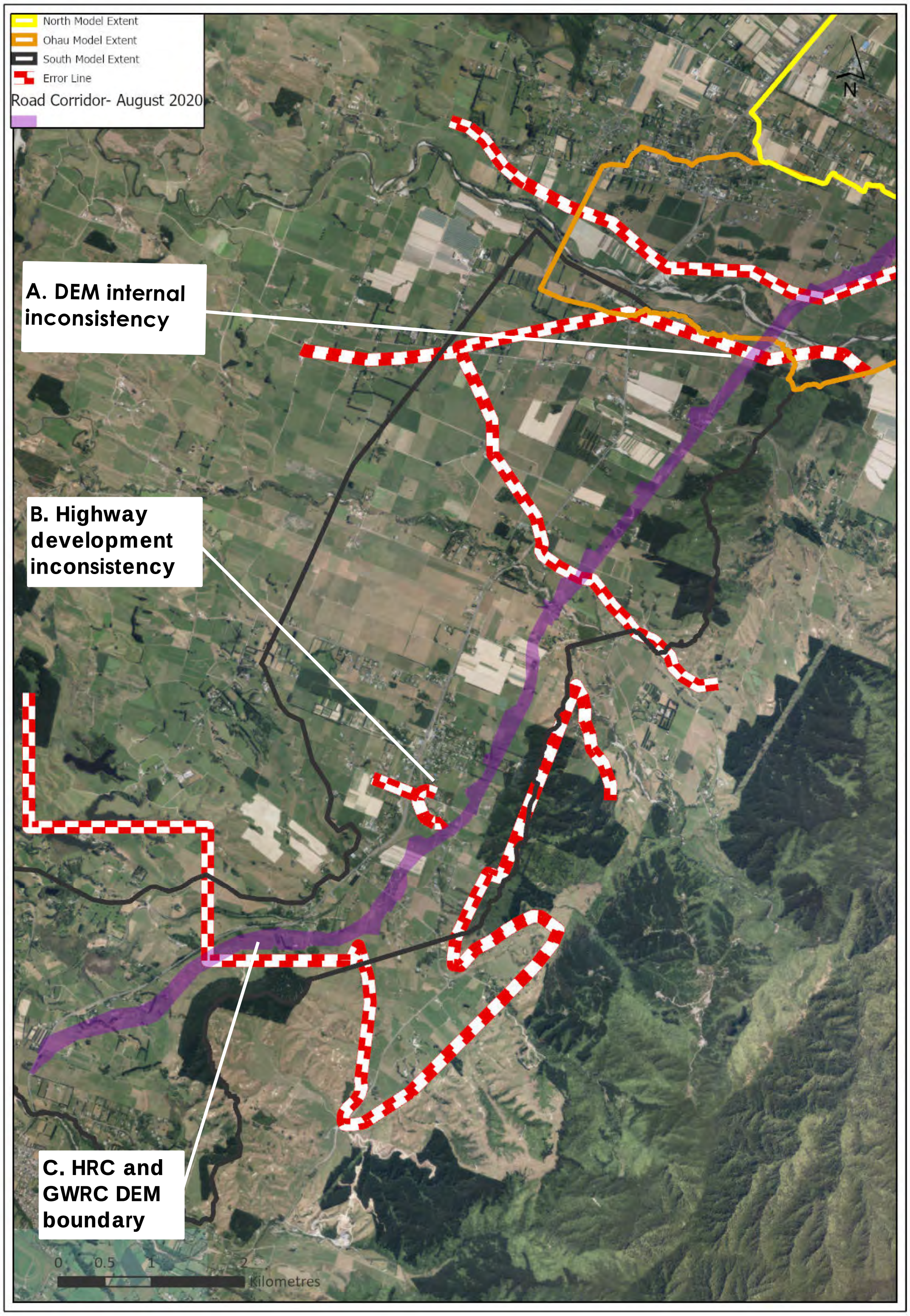


Example of missing data in 2020 drone DEM causing poor vertical interpolation in a flow path due to heavy vegetation. This area in the 2020 drone DEM (red line in cross section) will be patched using the Regional Council DEM (black line in cross section), as discussed in Section 5.2.1.

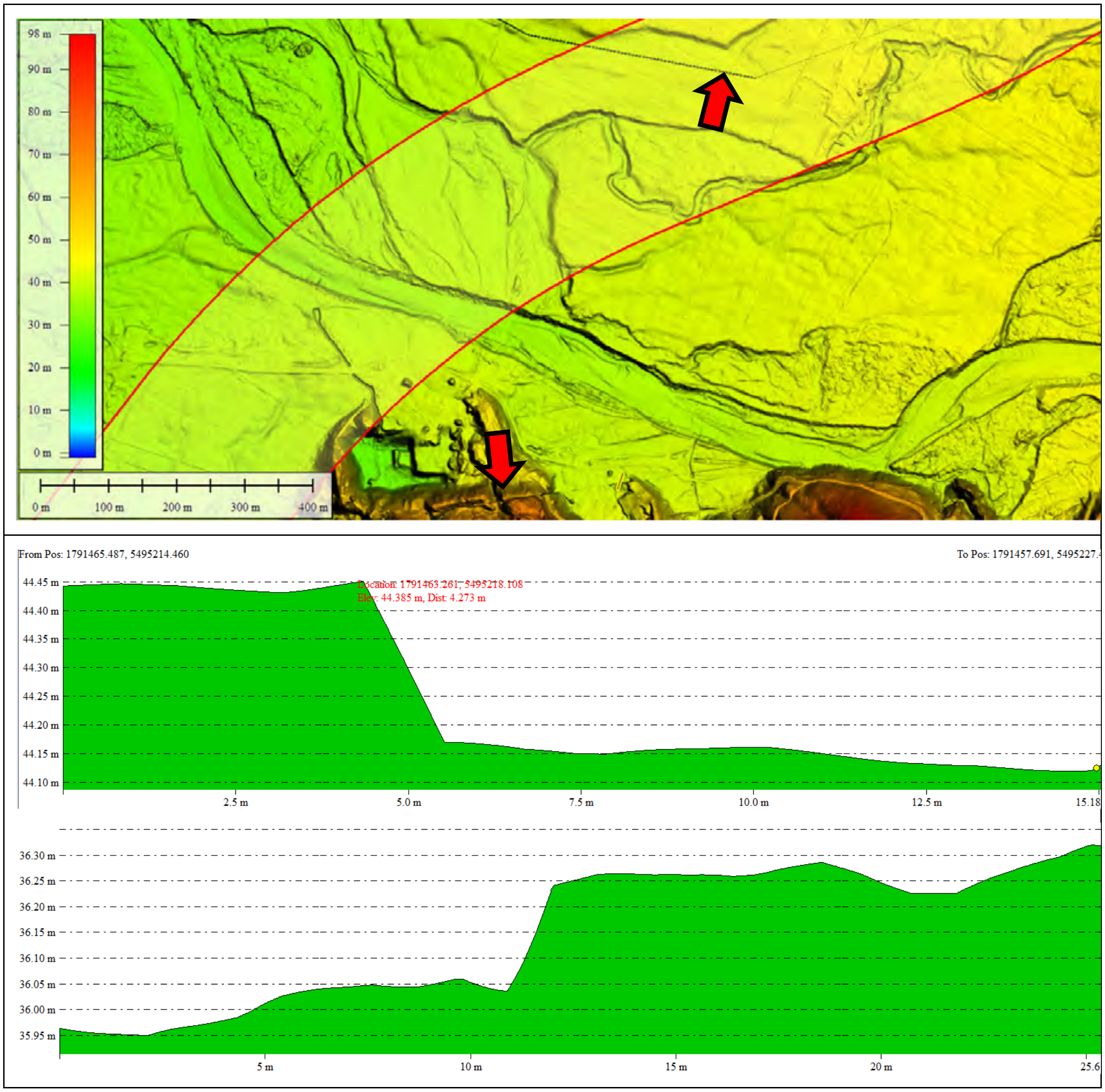




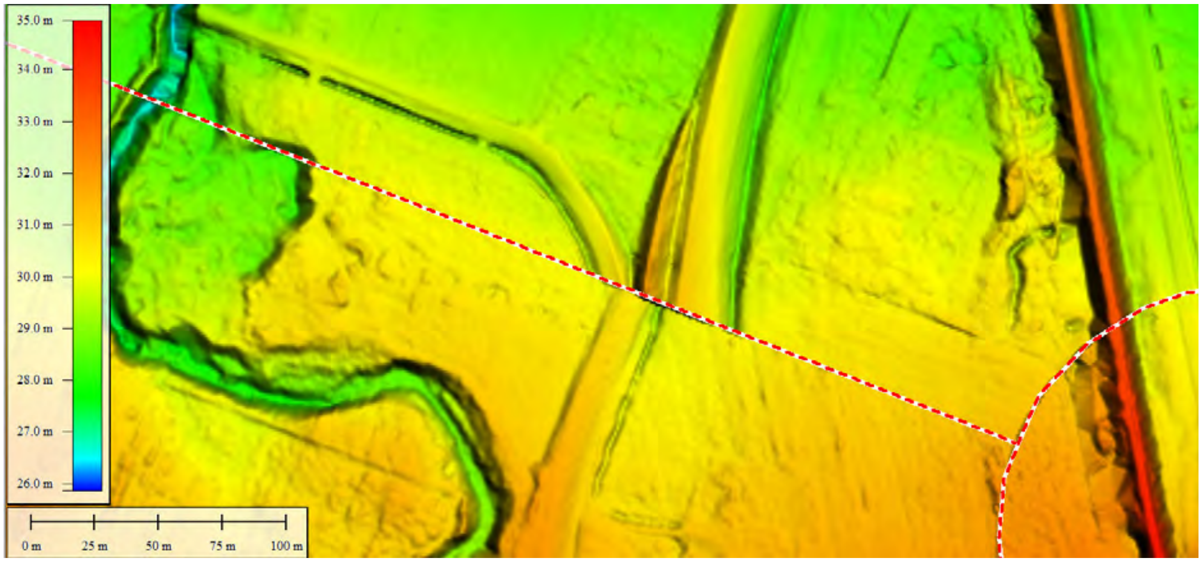
The figure below highlights some long error lines containing significant step discontinuities that are not associated with real features, as mentioned in 5.2.4. Some further description is provided below the figure.



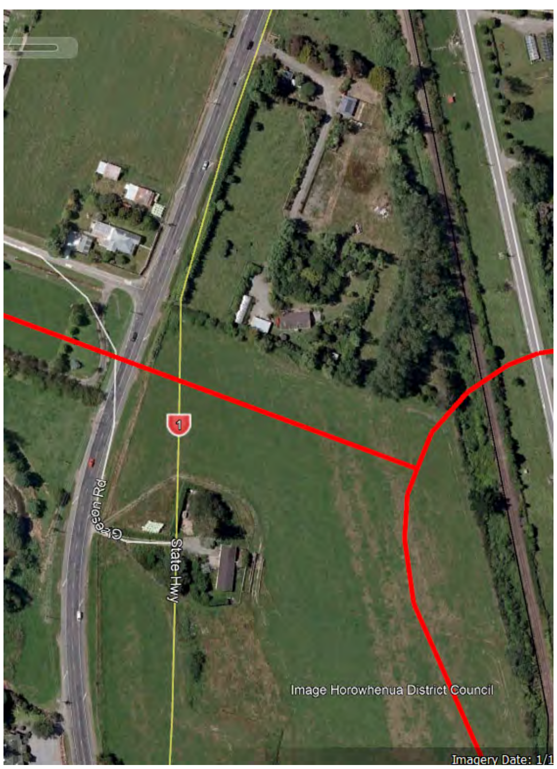
The issue A in the figure above is an internal inaccuracy in the HRC DEM. These differences in terrain appear to be due tile merging of LiDAR data datasets. A profile along this line is shown belowAppendix F. The differences between tiles range between 0.2m and 0.3m.



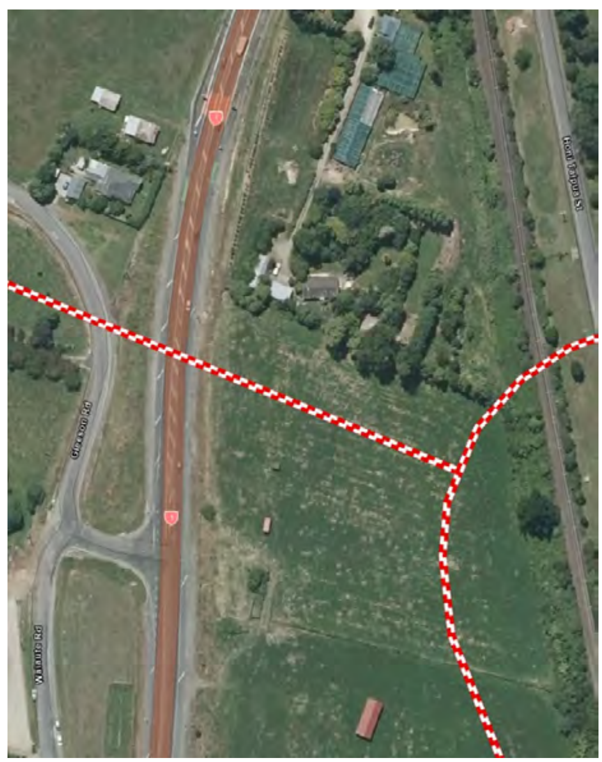
The inconsistency at location B was due to SH1 modifications since the LiDAR was captured, and the LiDAR contains some discontinuities, most notably on the new SH1 alignment although this is downstream of the Ō2NL corridor and downstream of the railway embankment (a major hydraulic impediment) therefore the results in this location will not have any influence on results in Ō2NL corridor.



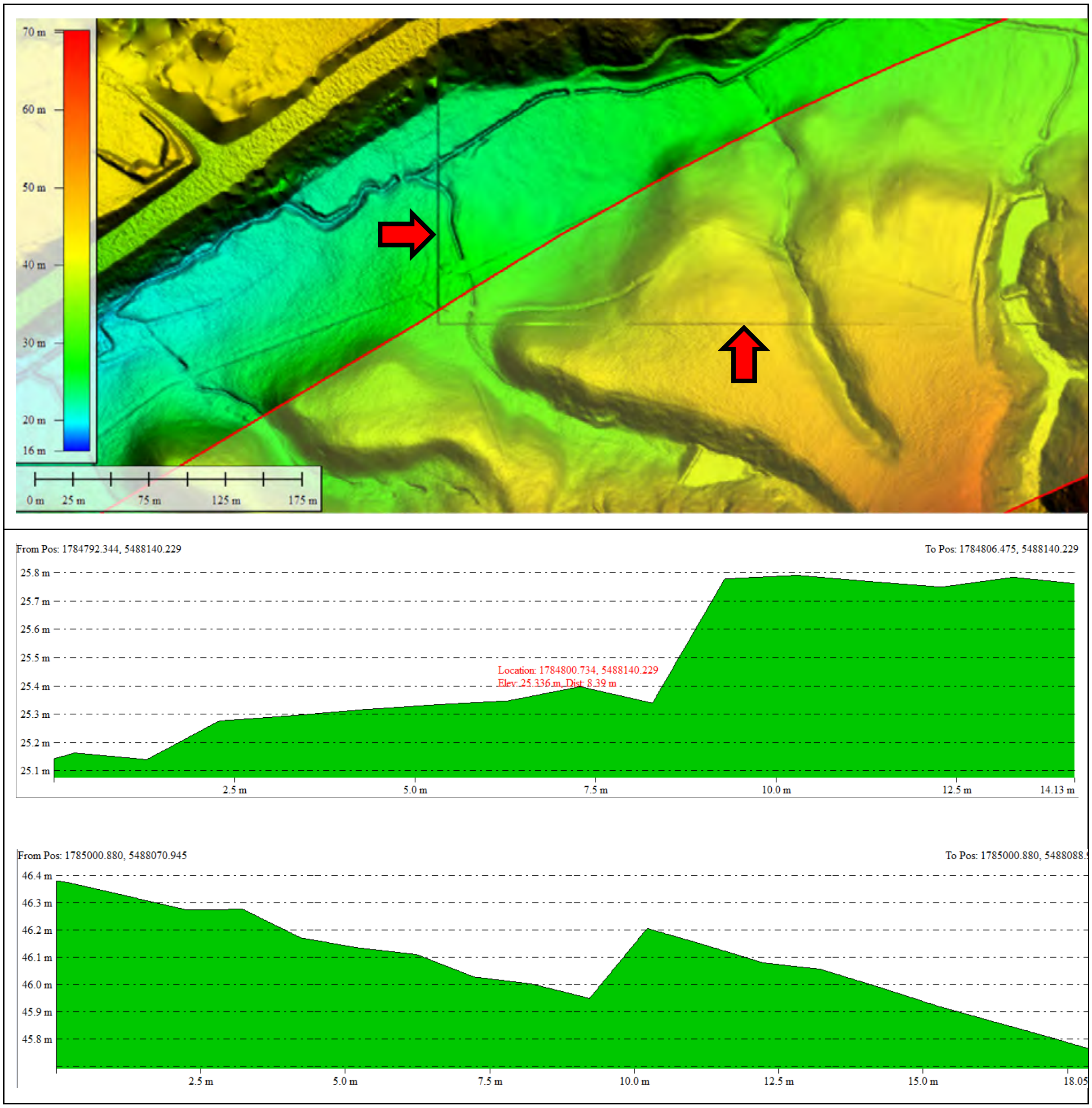
Aerial 2010



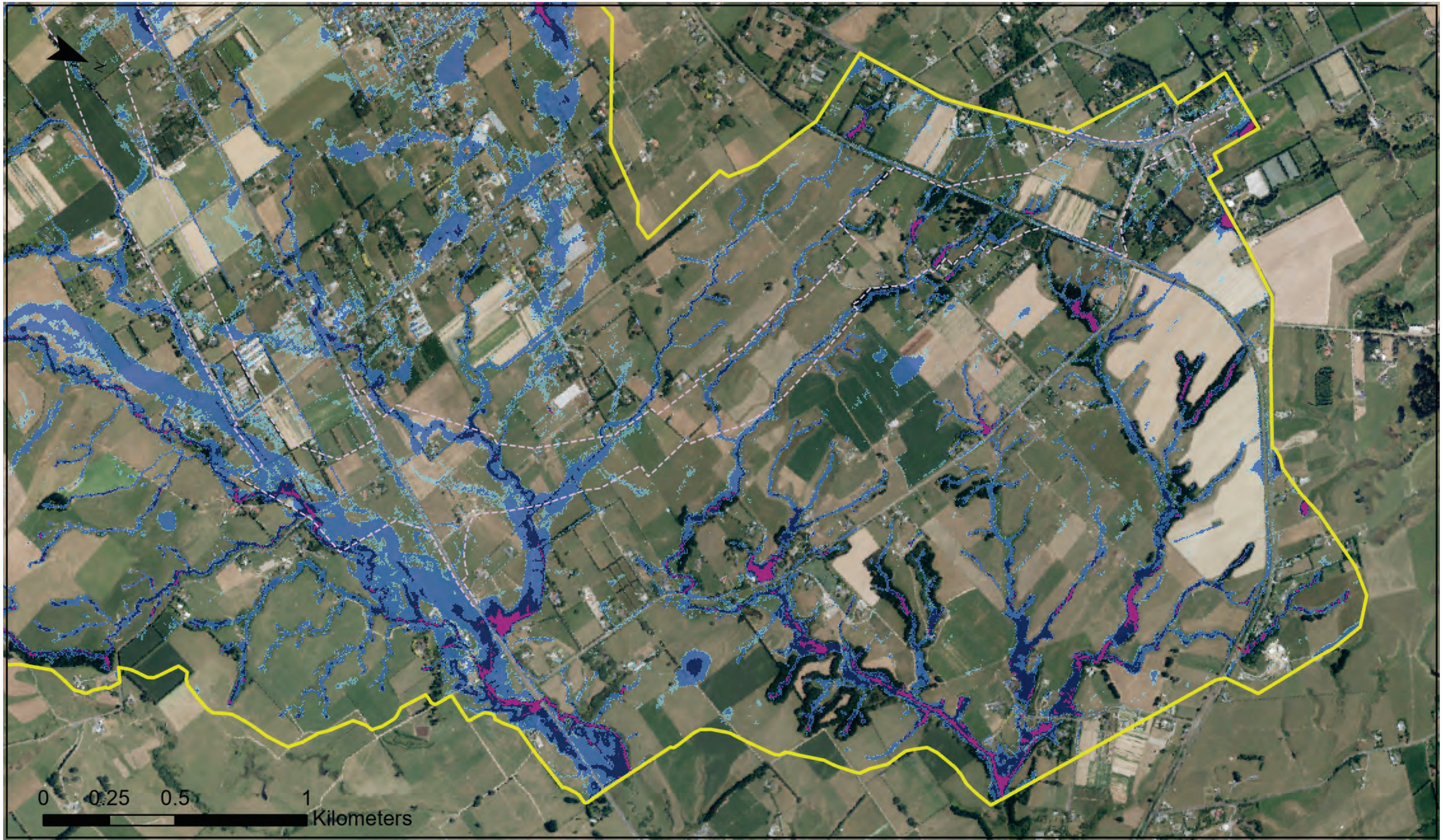
Aerial 2019



Issue C relates to the merge between the HRC and the GWRC terrain models, where the two datasets contain differences in the order of 0.2m to 0.3m.



Appendix G Baseline Results



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

South Model Extent

Ohau Model Extent

North Model Extent

Proposed Designation July 2022

Max. Water Depth (m)

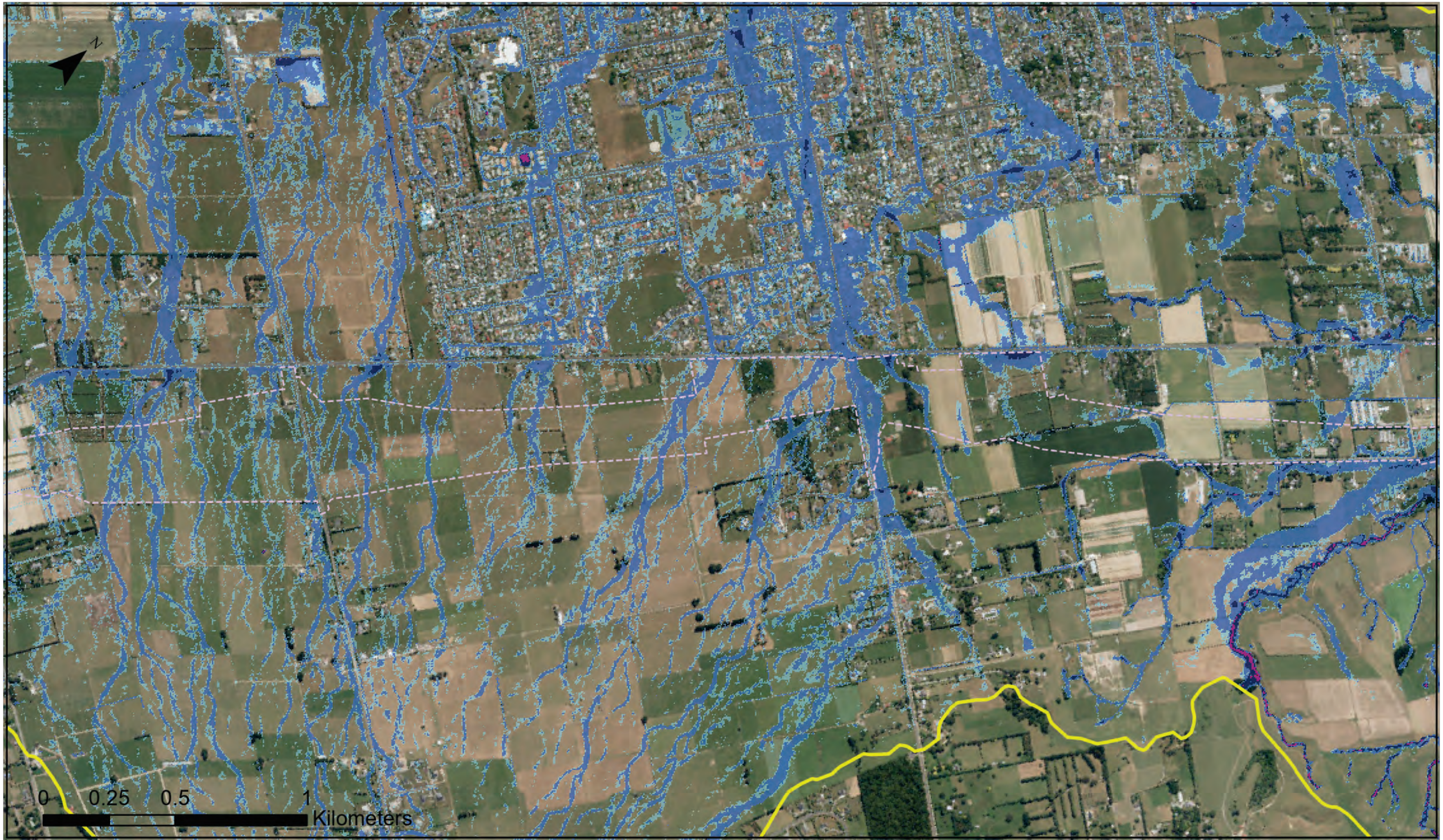
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1
- 1.0 to 3.0
- Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.

Author: Stantec (2022)

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

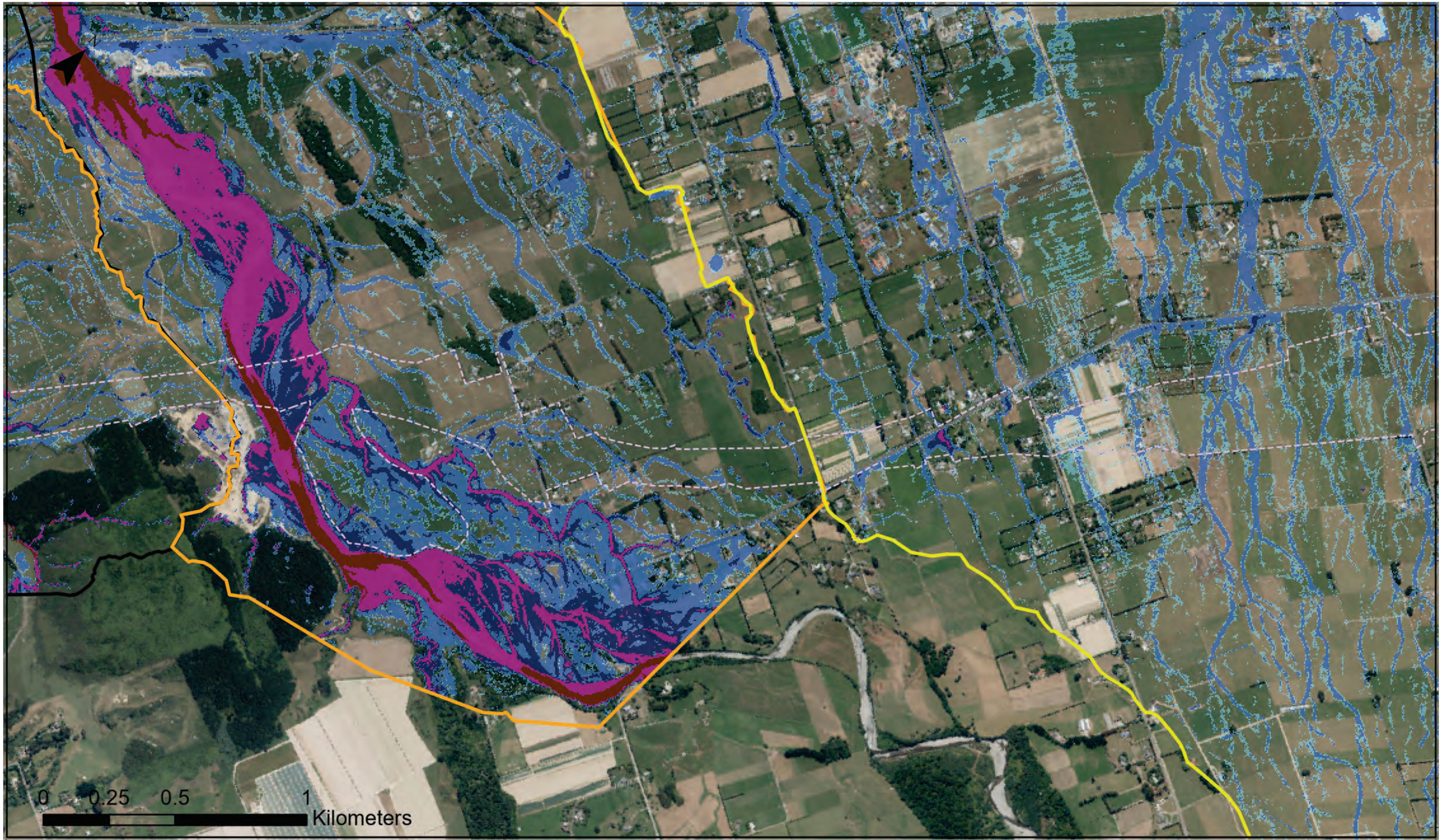
South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022

Max. Water Depth (m)

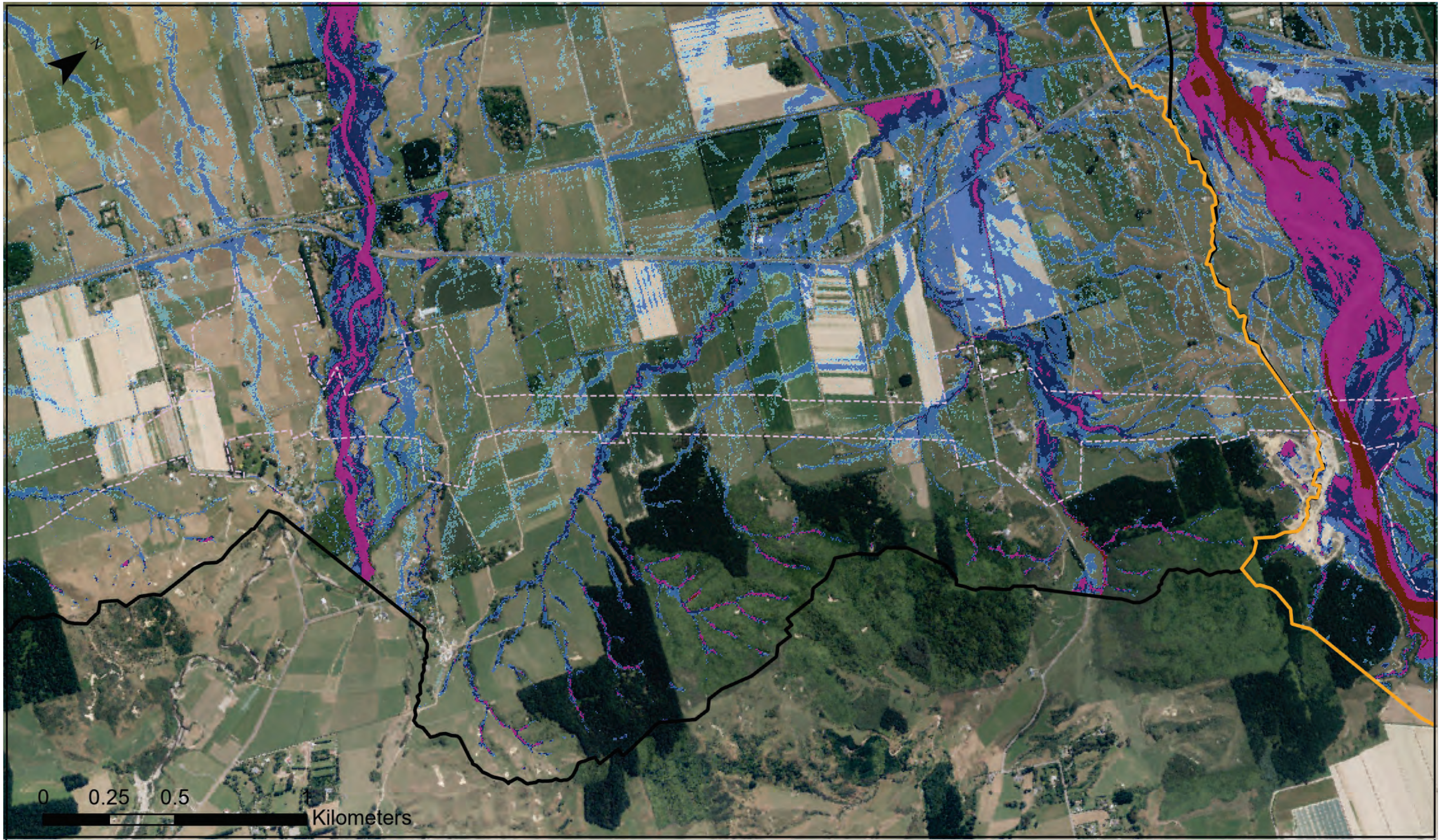
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1
- 1.0 to 3.0
- Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.

Author: Stantec (2022)

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

South Model Extent

Ohau Model Extent

North Model Extent

Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1

0.1 to 0.5

0.5 to 1

1.0 to 3.0

Greater than 3

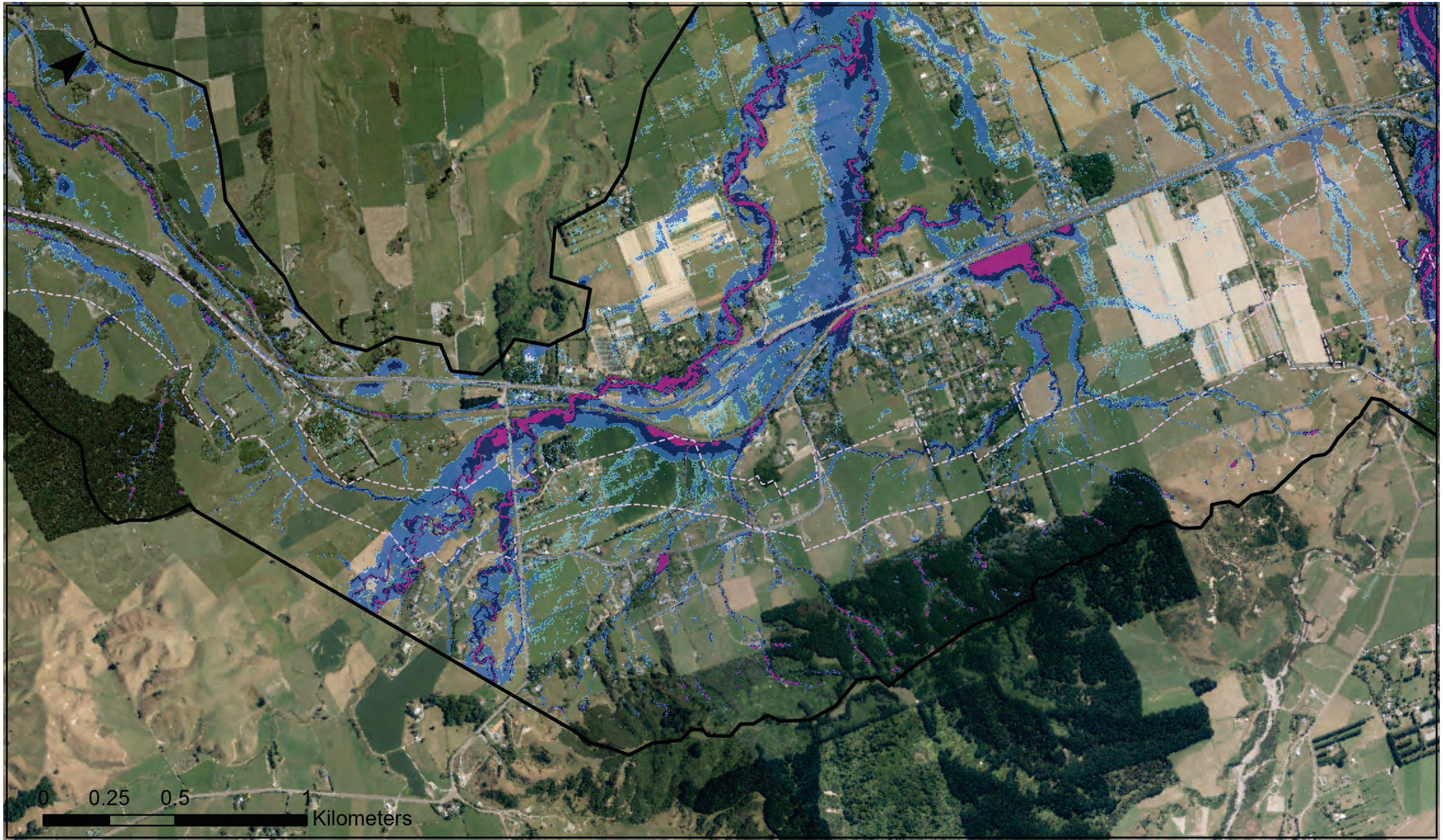
Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.

Author: Stantec (2022)

This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

South Model Extent

Ohau Model Extent

North Model Extent

Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1

0.1 to 0.5

0.5 to 1

1.0 to 3.0

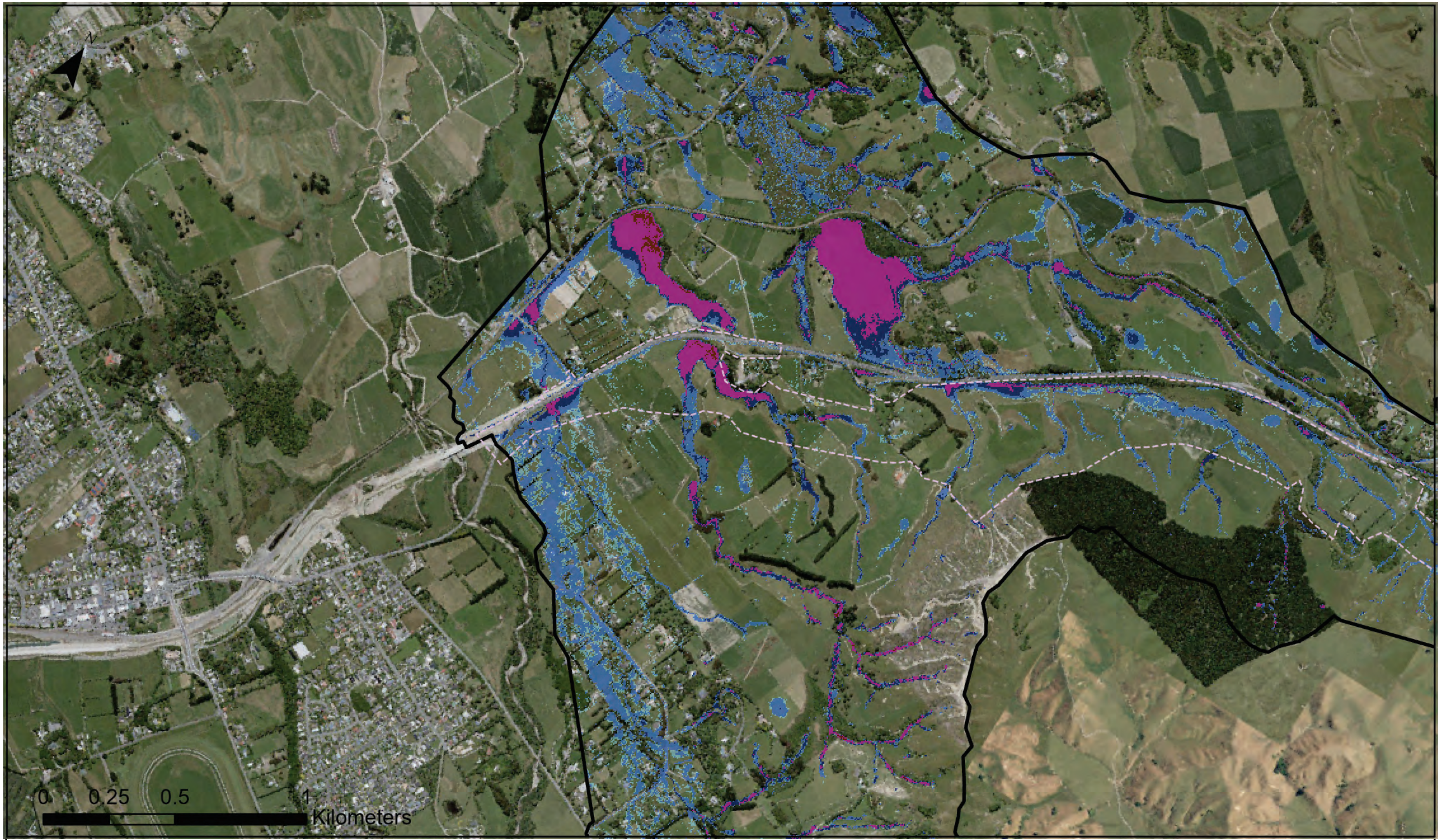
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.

Author: Stantec (2022)

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

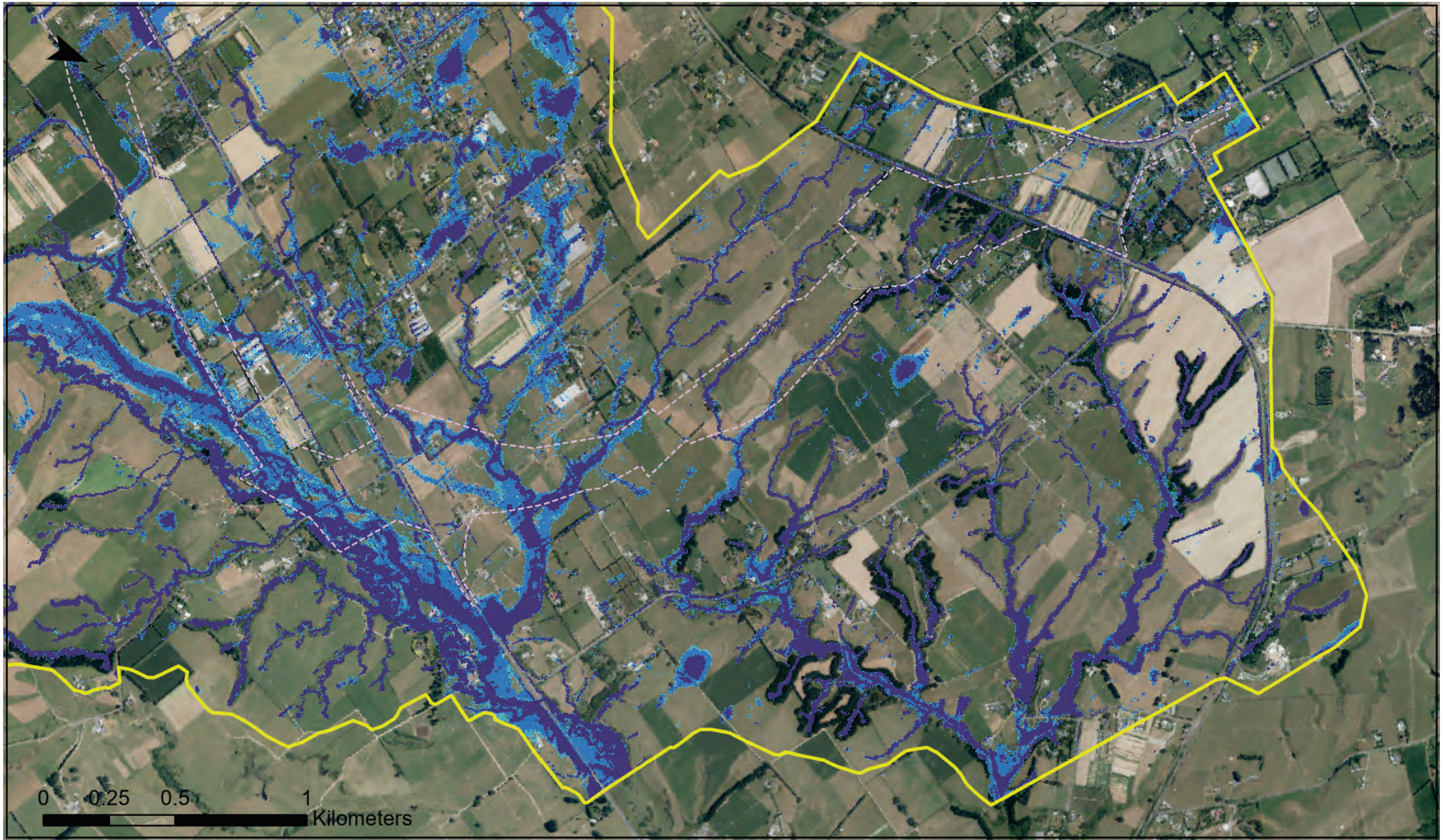
South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



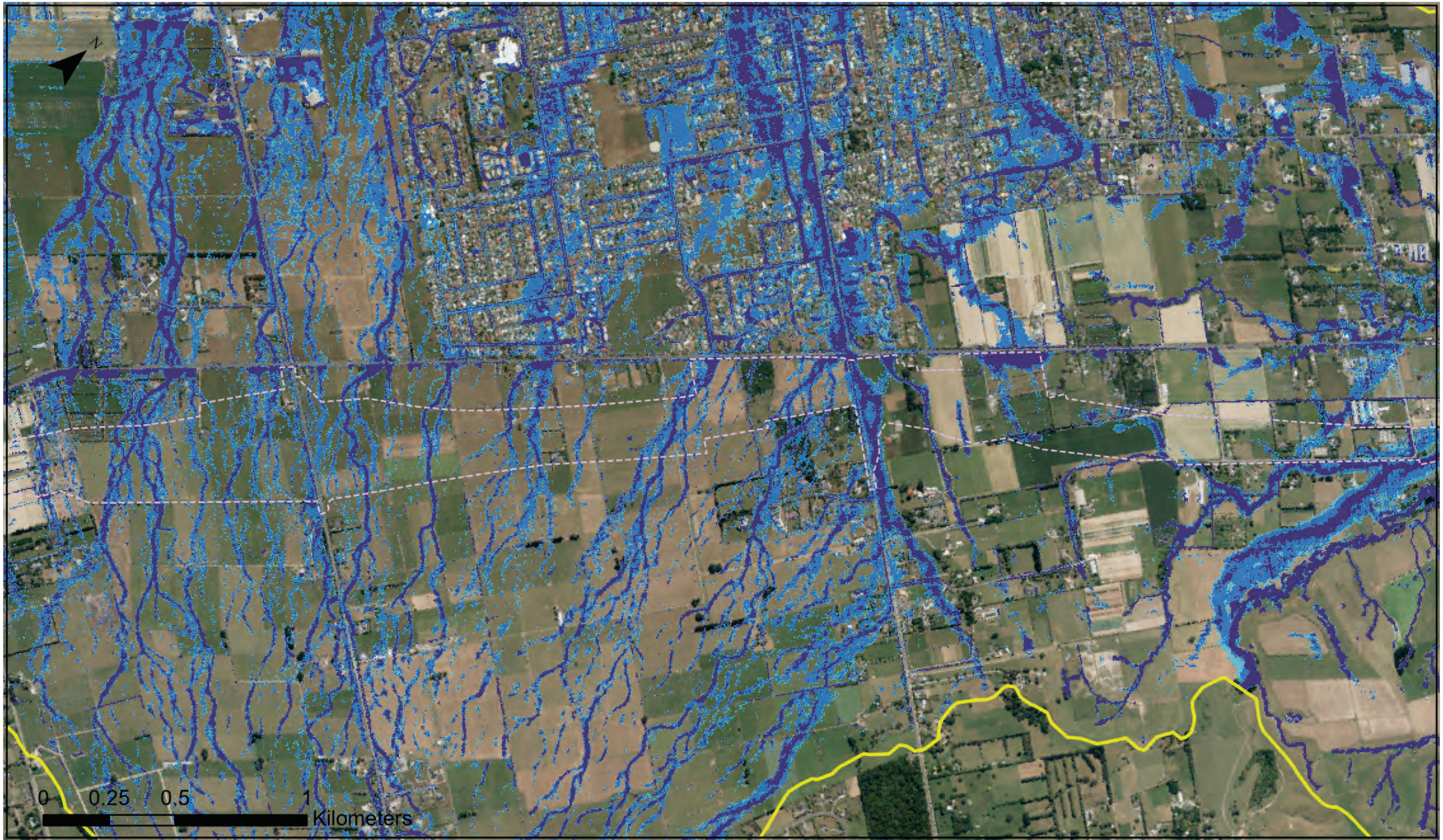
Model Results, Baseline Maximum Extents

This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- 1:10 AEP Current Climate
- 1:100 AEP RCP 6.0 2130
- 1:1500 AEP RCP 8.5 2130

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



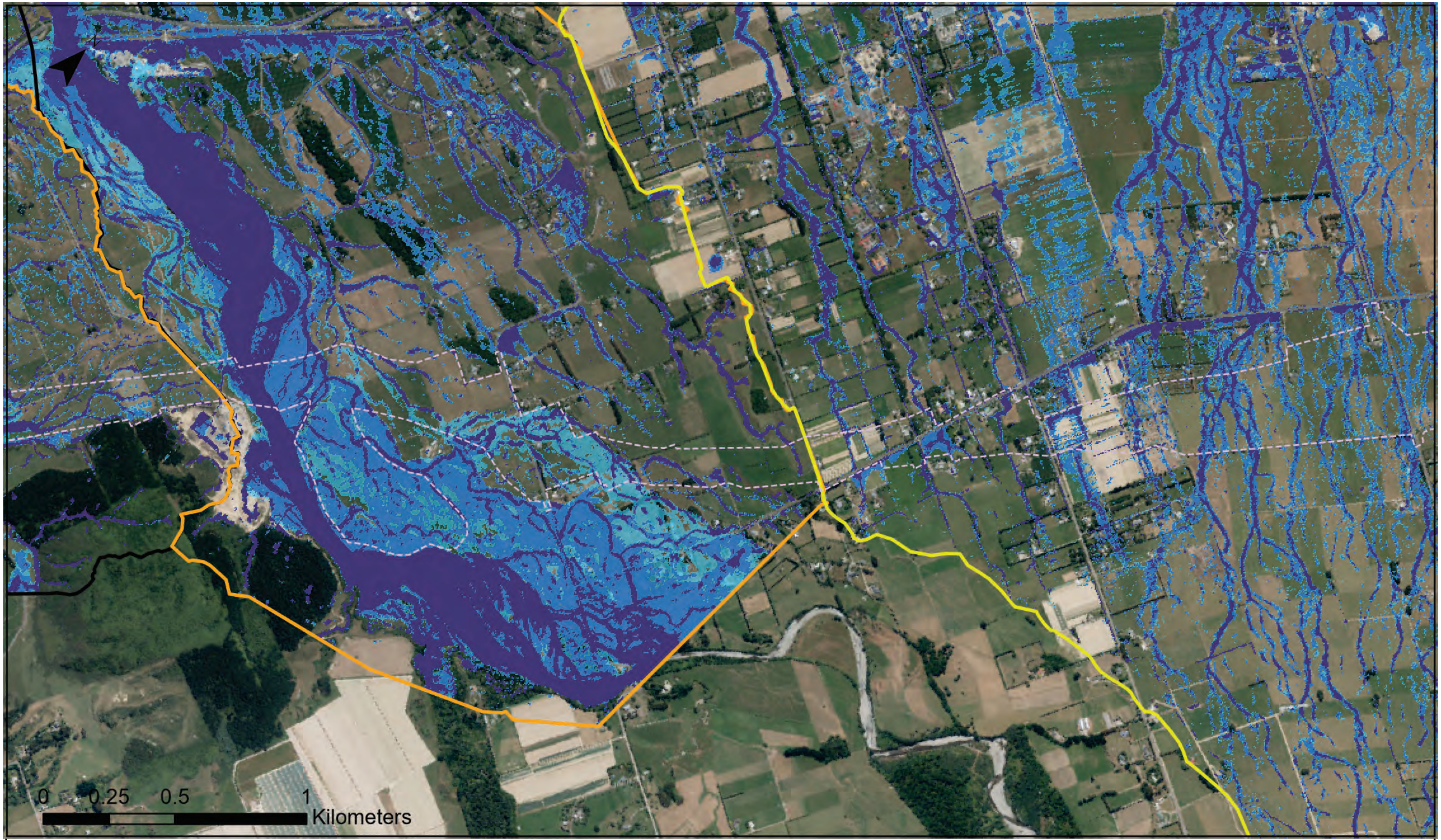
Model Results, Baseline Maximum Extents

This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

Stantec

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- 1:10 AEP Current Climate
- 1:100 AEP RCP 6.0 2130
- 1:1500 AEP RCP 8.5 2130

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



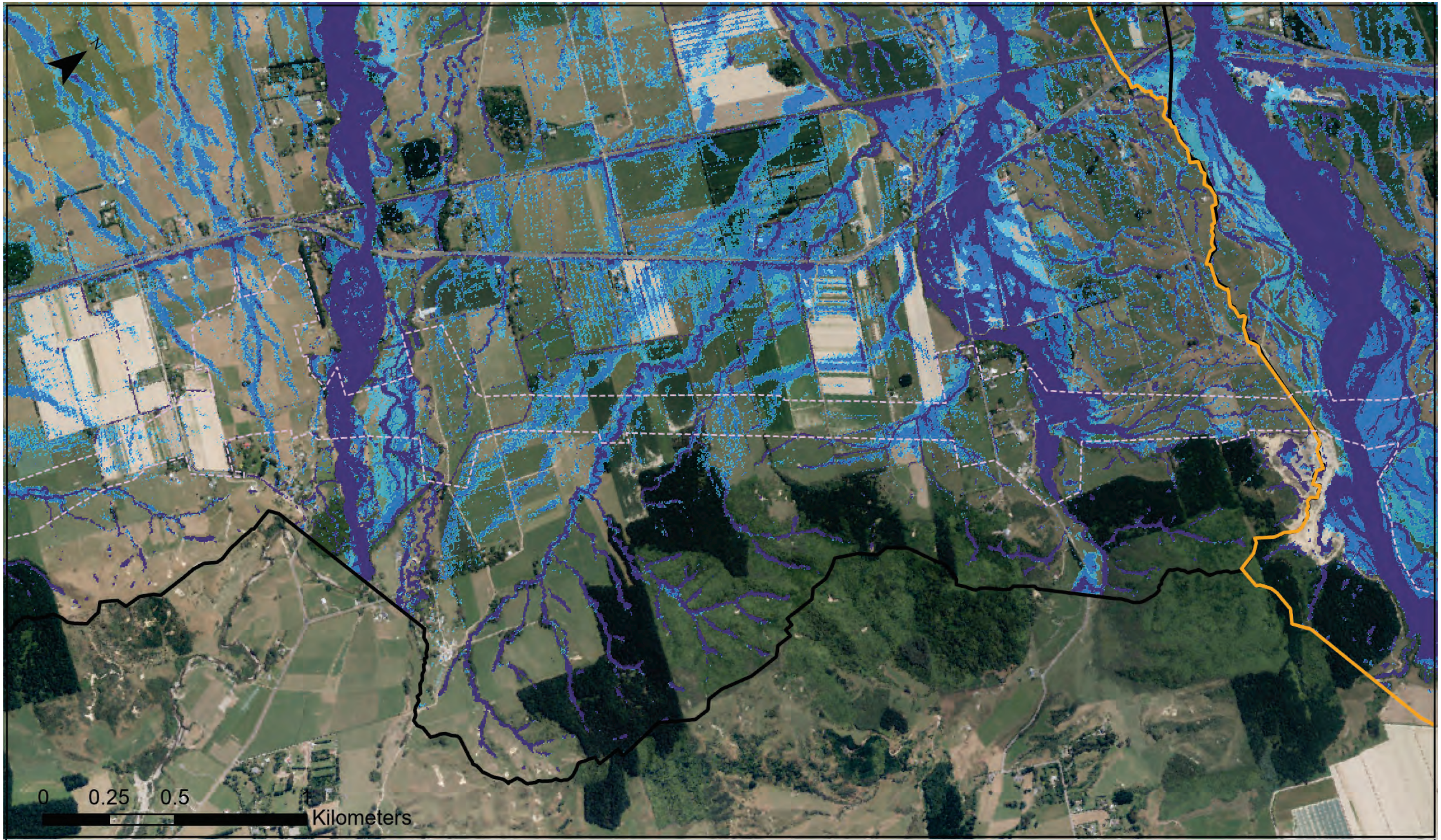
Model Results, Baseline Maximum Extents

This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- 1:10 AEP Current Climate
- 1:100 AEP RCP 6.0 2130
- 1:1500 AEP RCP 8.5 2130

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



Model Results, Baseline Maximum Extents

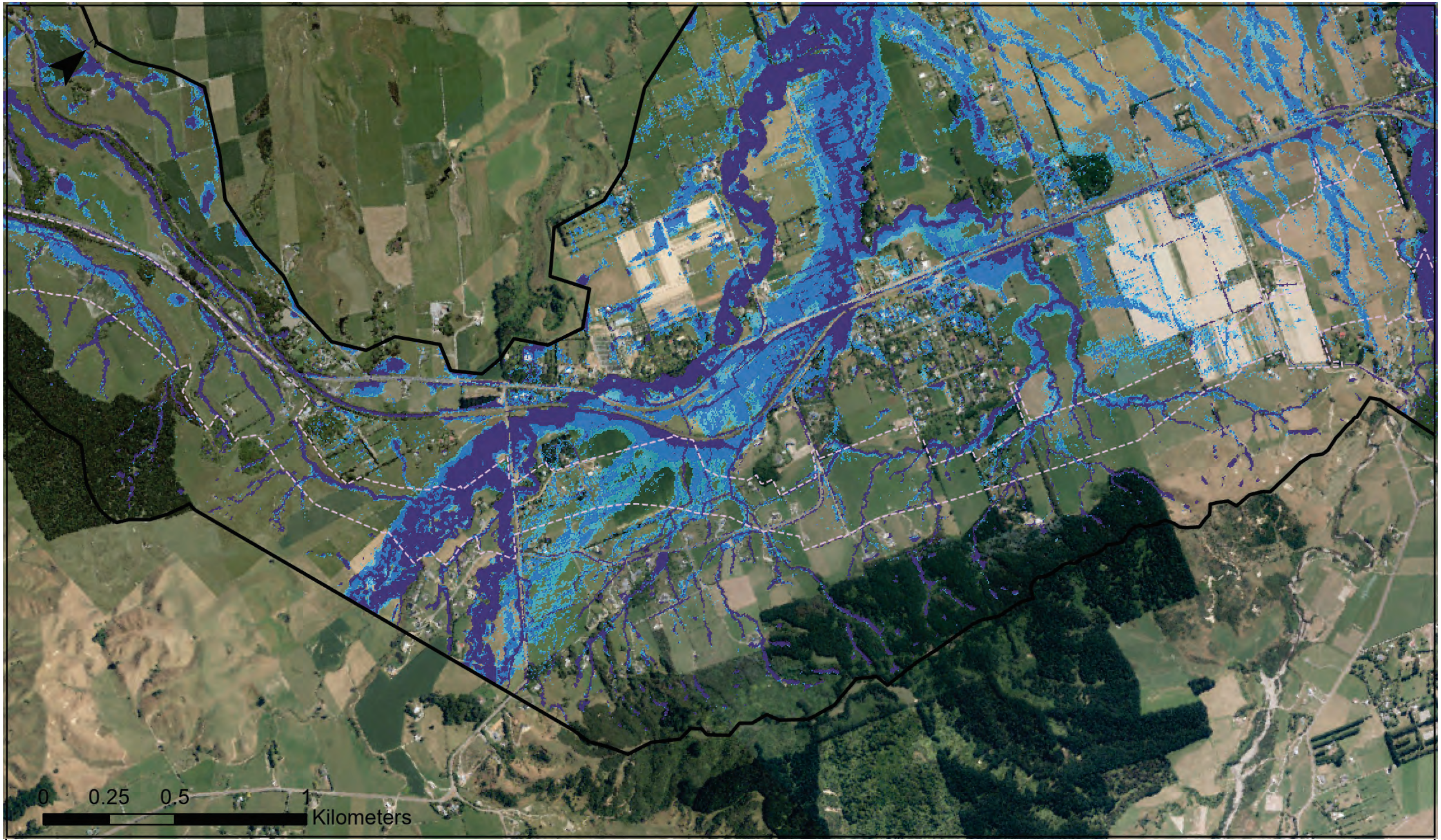
This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

1:10 AEP Current Climate
1:100 AEP RCP 6.0 2130
1:1500 AEP RCP 8.5 2130

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



Model Results, Baseline Maximum Extents

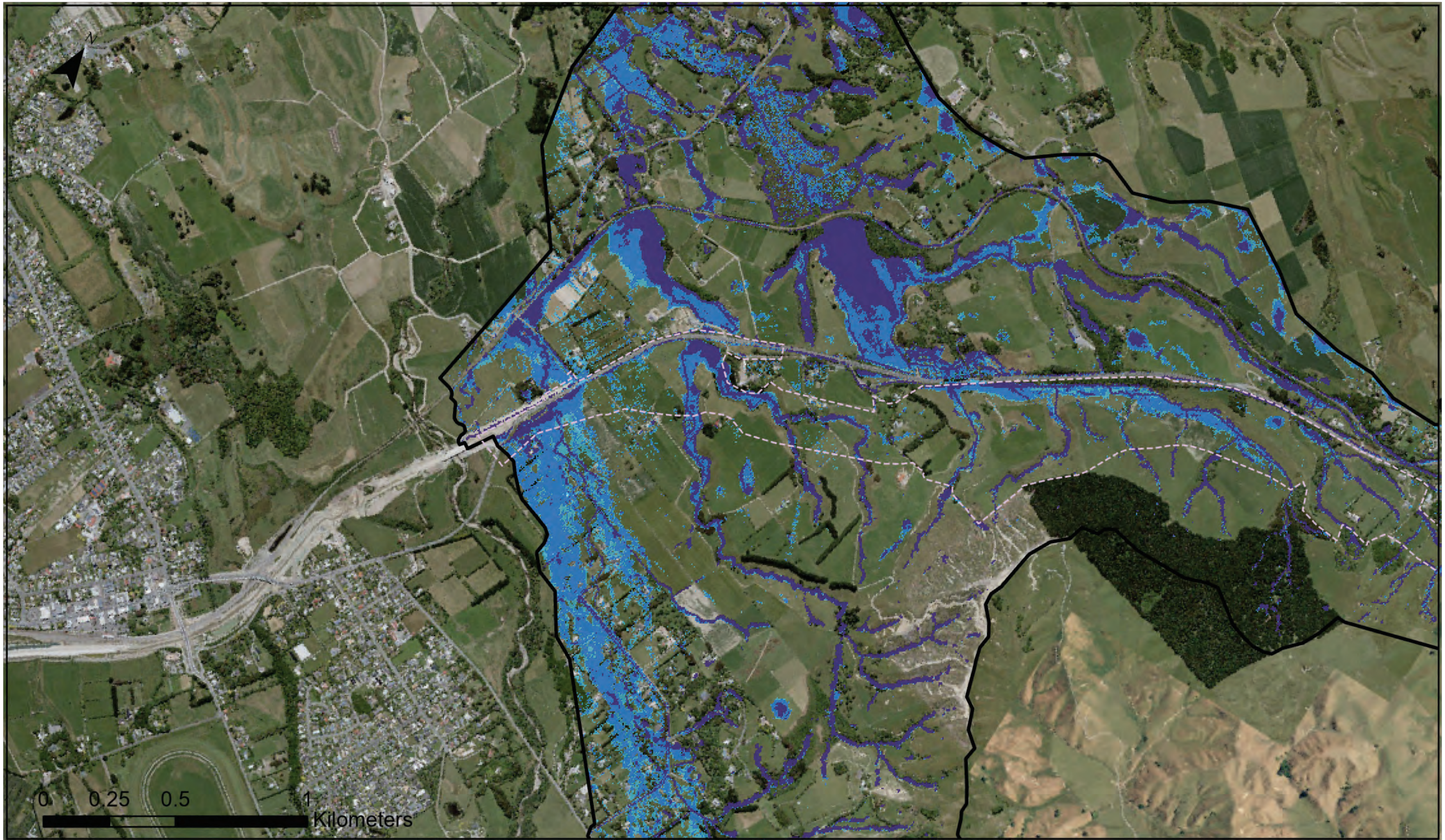
This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

1:10 AEP Current Climate
1:100 AEP RCP 6.0 2130
1:1500 AEP RCP 8.5 2130

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



Model Results, Baseline Maximum Extents

This map shows maximum flood extents for various annual exceedance probabilities. No flood depths less than 0.05m are shown

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

1:10 AEP Current Climate
1:100 AEP RCP 6.0 2130
1:1500 AEP RCP 8.5 2130

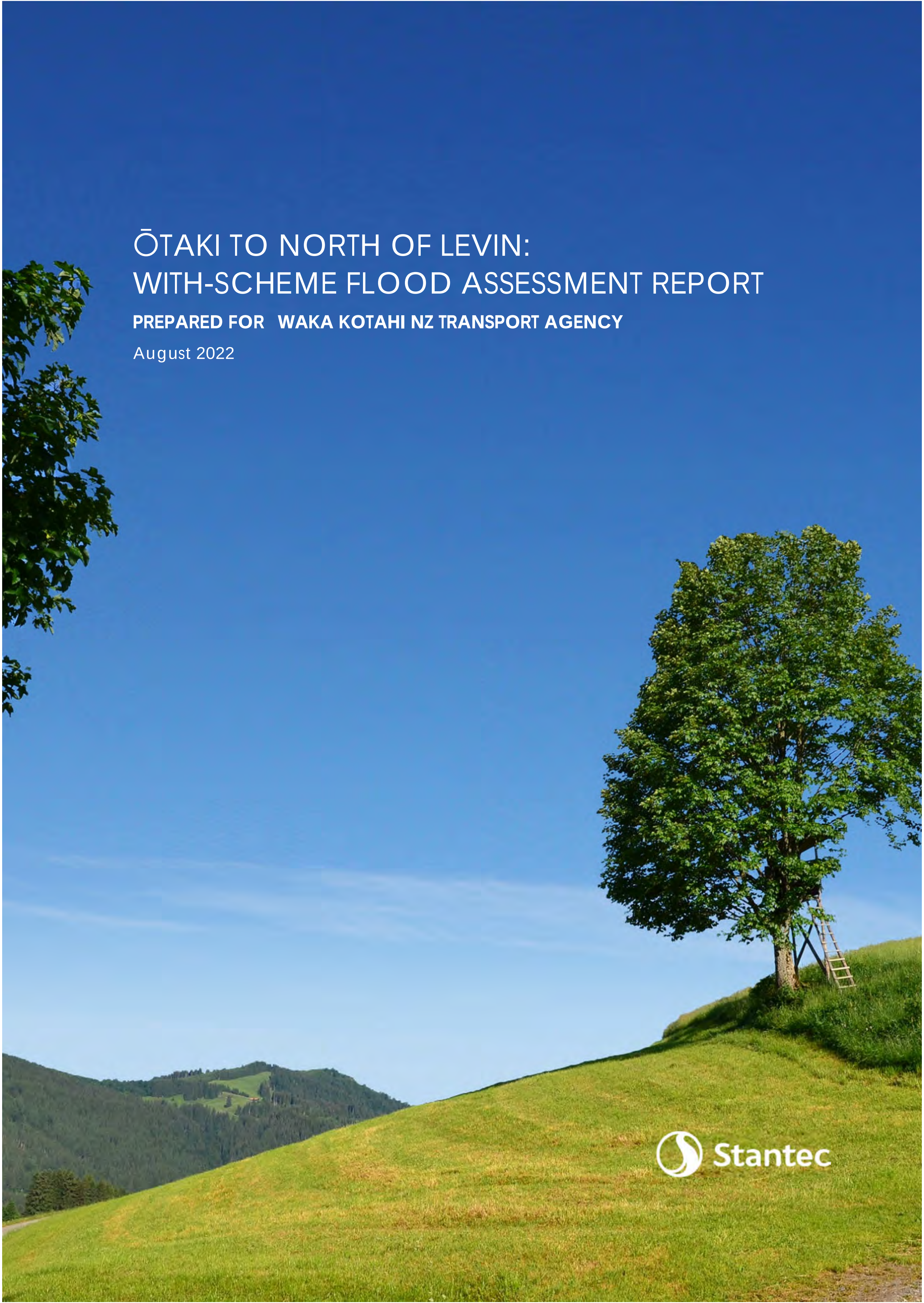
Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec

Wellington

Stantec House
Level 15, 10 Brandon Street
Wellington 6011
PO Box 13-052, Armagh
Christchurch 8141
Tel +64 4 381 6700

APPENDIX F.2: WITH-SCHEME MODELLING REPORT



ŌTAKI TO NORTH OF LEVIN: WITH-SCHEME FLOOD ASSESSMENT REPORT

PREPARED FOR WAKA KOTAHI NZ TRANSPORT AGENCY

August 2022

Stantec

QUALITY STATEMENT

PROJECT MANAGER	PROJECT TECHNICAL LEAD
Jon England	Phil Peet

PREPARED BY		
Andrew Sherson / Andrew Craig	………………………………............	18/08/2022
CHECKED BY		
Andrew Craig	………………………………............	08/03/2022
REVIEWED BY		
Jamie Povall	………………………………............	18/03/2022
APPROVED FOR ISSUE BY		
Jamie Povall	………………………………............	18/03/2022

WELLINGTON
Level 15, 10 Brandon Street, Wellington 6011
PO Box 13-052, Armagh, Christchurch 8141
TEL +64 4 381 6700,

REVISION SCHEDULE

Rev No.	Date	Status	Signature or Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
1	11/10/2021	DRAFT	AC, AS	AC		
1.1	18/03/2022	Draft Final	AS	AC	JP	JP
1.2	18/08/2022	Final	AS	AC	JP	JP

Abbreviations

Abbreviation	Full Name
AEE	Assessment of Environmental Effects
ARF	Aerial Reduction Factor
AEP	Annual Exceedance Probability
DBC	Detailed Business Case
DEM	Digital Elevation Model
FFA	Flood Frequency Analysis
FSL	Fundamental Soil Layer
GWRC	Great Wellington Regional Council
HDC	Horowhenua District Council
HIRDS	High Intensity Rainfall Dataset
HRC	Horizons (Manawatū-Whanganui) Regional Council
h	Hour(s)
IPCC	International Panel on Climate Change
KCDC	Kapiti Coast District Council
LiDAR	Light Detection and Ranging (airborne survey to prepare DEM)
LINZ	Land Information New Zealand
NES-F	Resource Management (National Environmental Standard for Freshwater) Regulations 2020
MfE	Ministry for the Environment
Ō2NL	Ōtaki to North of Levin Project
PMP	Probable Maximum Precipitation
PP2Ō	Peka Peka to Ōtaki Expressway
RCP	Representative Concentration Pathway (IPCC climate scenario)
SLS	Serviceability Limit State
SH1	State Highway 1
SUP	Shared Use Path
ULS	Ultimate Limit State
Waka Kotahi	Waka Kotahi New Zealand Transport Agency

WAKA KOTAHI NZ Transport Agency

Ōtaki to North of Levin:
With-scheme Flood Assessment Report

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1. Introduction

1.1 Background to the Project

Waka Kotahi NZ Transport Agency (Waka Kotahi) is planning a new 24km offline highway from Ōtaki to north of Levin (Ō2NL). The Project extends from the existing SH1 / Koputaroa Road intersection north of Levin, to south of Taylors Road near Ōtaki where it links with the Peka Peka to Ōtaki (PP2Ō) Expressway.

The with scheme hydraulic model has developed over time in parallel with the design process through 2020 and 2021. This report is written to present the latest hydraulic model that aligns with the consent design as at July 2022. Whilst some details are included in this report where they are pertinent to the hydraulic modelling, this report does not seek to present the full detail or drawings of the design. It is intended that this report be read in conjunction with the RMA consent application pack notably the Project Description (Volume II) and the Design and Construction Report (Volume II Appendices) plus the Drawings (Volume III). It is worth reiterating that the stage of design is intermediate, i.e., it is not as far advanced as a Specimen Design or Detailed Design for construction.

The Baseline Flood Assessment Report (Stantec, completed March 2022, selected figures updated August 2022) presents the latest understanding of the baseline flood risk near the Ō2NL Project corridor. All the work in this with-scheme report relates to the changes made to the hydraulic model relative to the baseline model presented in the baseline report. Similarly, the model results differences presented in this report are the differences between the with-scheme models and the pre-scheme baseline.

Similar to the baseline models, the with-scheme models receive the same hydrology, boundary conditions, rainfall scenarios, and is also split into the same three domains, namely: the North, Ōhau, and South models, as shown in Figure 1-1. The split of rainfall domains in the South model is explained later in this report.

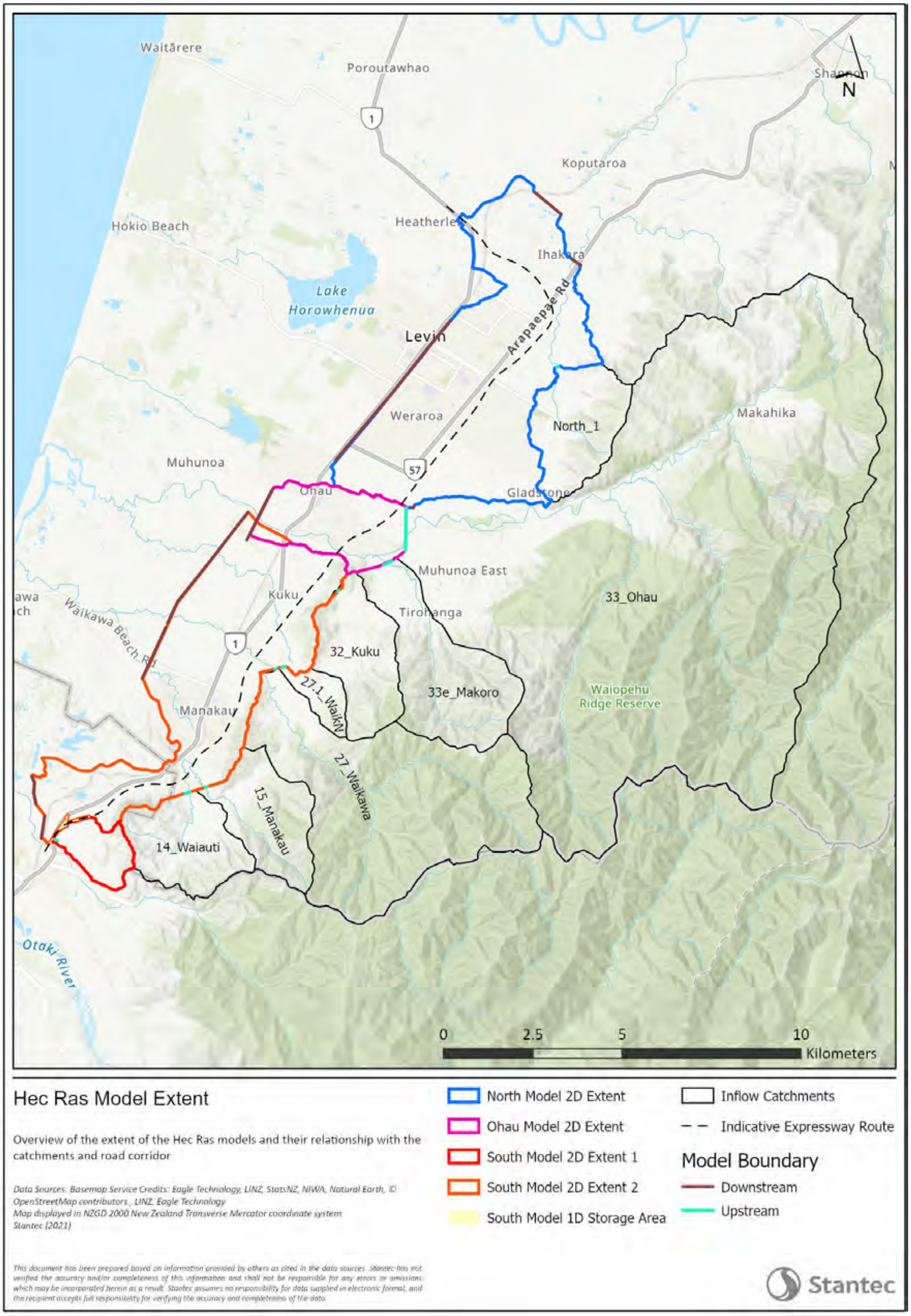


Figure 1-1: HEC-RAS 2D model extent for the three 2D hydraulic models

1.2 Purpose and Scope of this Assessment

It was required to prepare a model representation of the scheme to assess potential hydraulic effects of the Ō2NL Project. The schematisation choices and structure of the baseline model was designed to allow this outcome to be achieved by applying the infrastructure design into a copy of the baseline model.

A sample Consent design of the Ō2NL Project (as at July 2022) has been applied in the with-scheme hydraulic model, to test potential effects. The scheme will later go through detail design and the eventual scheme when built may differ from the sample Consent Design used for this assessment.

There will necessarily be some assumptions and limitations, due to information gaps or modelling processes and the stage of design. These have been captured through the baseline report and within this document where they relate to the scheme representation. Aspects of both the baseline and scheme representation and their uncertainties should be evaluated by the Detailed Design team to test whether the assumptions or limitations have bearing on the final design and whether any updates may be warranted.

1.3 Selection of Design Scenarios

The model scenarios are intended to inform key design decisions and/or assessment of effects. For design purposes, the highway classification (under the Waka Kotahi One Network Road Classification) has been selected as "IL3+ National (High Volume)". The associated serviceability and ultimate limit state design scenarios are provided in Table 2.1 of the NZ Bridge Manual, reproduced below:

Table 1-1: Design scenarios (reproduced from NZ Bridge Manual Table 2.1)

Bridge categorization	Importance level (as per AS/NZS 1170.0(4))	Bridge permanence*	Annual probability of exceedance for the ultimate limit state		Annual probability of exceedance for the serviceability limit state	
			ULS for wind, snow and floodwater actions	DCLS for earthquake actions	SLS 1 for wind, snow and floodwater actions	SLS 2 for floodwater actions
Bridges of high importance to post-disaster recovery (eg bridges in major urban areas providing direct access to hospitals and emergency services or to a major port or airport from within a 10km radius). Bridges with a construction cost (including associated ground improvements) exceeding $16 million (as at June 2018).	4	Permanent	1/2500	1/2500	1/25	1/100
		Temporary	1/1000	1/1000	1/25	1/100
Bridges on highways classified as National (High Volume in the One Network Road Classification (ONRC).	3+	Permanent	1/1500	1/1500	1/25	1/100
		Temporary	1/700	1/700	1/25	-
Bridges on highways classified as National, Regional, Arterial, Primary Collector or Secondary Collector in the ONRC.	3	Permanent	1/1000	1/1000	1/25	1/100
		Temporary	1/500	1/500	1/25	-

In accordance with the Bridge Manual, the design life (planning horizon) will be 100 years, from 2030 (estimated start of operation) to 2130. The design life is particularly relevant for climate change.

The Bridge Manual sets the IL3+ main traffic Serviceability Limit State SLS2 design scenario for flooding at 1:100 AEP with climate change. However, the Bridge Manual is not prescriptive on details of climate change allowances (e.g., epoch or emissions scenario). The climate scenario selected is RCP 6.0 extrapolated to 2130, is applied for the SLS2 1:100 AEP. This is a moderately conservative (medium-high) climate projection, which is considered suitable for the Ō2NL Project. Given the long design life and high cost to upgrade culverts or bridges during operational life, it would be impractical to follow a lower climate change scenario with the option to upgrade infrastructure at a later epoch if higher climate change transpires. The RCP 6.0 scenario was also applied for the recent Te Ahu a Turanga; Manawatū Tararua Highway Project, which further supports the decision to use this scenario.

The potential impacts of higher climate outcomes will be tested through the ULS case, namely the 1:1500 AEP with a more conservative RCP8.5 extrapolated to 2130. In summary, the following key scenarios will be used:

Table 1-2: Selected key scenarios

Annual Exceedance Probability		Climate Scenario	Description
1:10	10%	Current climate	Easier to relate to floods in recent history (or construction phase)
1:100	1%	RCP6.0 2130	SLS2, operationally functional
1:1500	0.067%	RCP8.5 2130	ULS, resilience case (damage limitation, avoiding collapse, quick recovery)

As discussed in the baseline flood report, a 4h storm duration is used for the fluvial (large stream) inflows for all model runs. For the North and Ōhau models, a 4h storm duration is also used for the direct rainfall zone, i.e., the same storm that generated the fluvial inflows. For the South model, the water level is taken from the maximum of a 4h storm across the whole model, and a hybrid 1h/4h storm (4h critical duration fluvial inflows and 1h high intensity rainfall with coincident rainfall centroid timing). The latter hybrid storm allows the critical peak flow to be captured in some of the small catchments toward the southern extent of the project. Taking the maximum of the 4h and hybrid 1h/4h storm for the south model was particularly important for the 1:100 AEP event with climate change, for assessment of effects.

The calculation of climate change growth factors for rainfall and river flow are discussed in the baseline flood report.

Outside of the Project area, the modelling for future epochs is based on current topography, drainage assets and estimated infiltration rates. These may change slightly in future through natural morphological change (including earthquakes and associated debris load in addition to gradual erosion and aggradation processes), and/or anthropological changes in land-use with associated impacts on infiltration/runoff. For the purposes of the modelling, it is assumed that hydrological catchment net response to any depth-duration rainfall event will remain similar to historic performance to up 1:100 AEP with climate change, despite future anthropological or morphological change. This is considered a reasonable assumption because plans submitted under the RMA seek to ensure hydraulic neutrality to avoid or minimise potential adverse effects.

2. Representation of Project in Hydraulic Model

The same HEC-RAS models used in the baseline modelling were used in this project, with modifications to represent the relevant features of the Project.

2.1 Hydrology

The same hydrological boundaries (inflows and direct rainfall for each respective AEP and storm duration) are applied to the with-scheme model as described in the baseline flood report and reflected in Figure 1-1.

Minor changes in the approach were the addition of infiltration regions and corresponding direct inflows to some stormwater ponds near the southern extent of the Project. These changes were added to represent key areas where the highway design utilises grey (piped) drainage infrastructure to convey road runoff to stormwater ponds, rather than open swales. As HEC-RAS is not well suited to model pipe networks, infiltration zones were added over the respective paved areas to remove the rainfall from the model surface. A HEC-HMS hydrological 1D catchment model for each paved area is used to provide direct inflows into the corresponding SW pond, see Figure 2-1. Summary details on the catchment parameters and culverts are shown below in Table 2-1.

Table 2-1: HEC-HMS 1D model catchment parameters

	Expressway Section 1	Expressway Section 2	Expressway Section 3	Expressway Section 4
Area (m2)	35,000	29,000	11,000	24000
Max Elevation (m)	33	33	25	60
Min Elevation (m)	21	27	21	52
Time of Concentration (min)	36	37	11	35

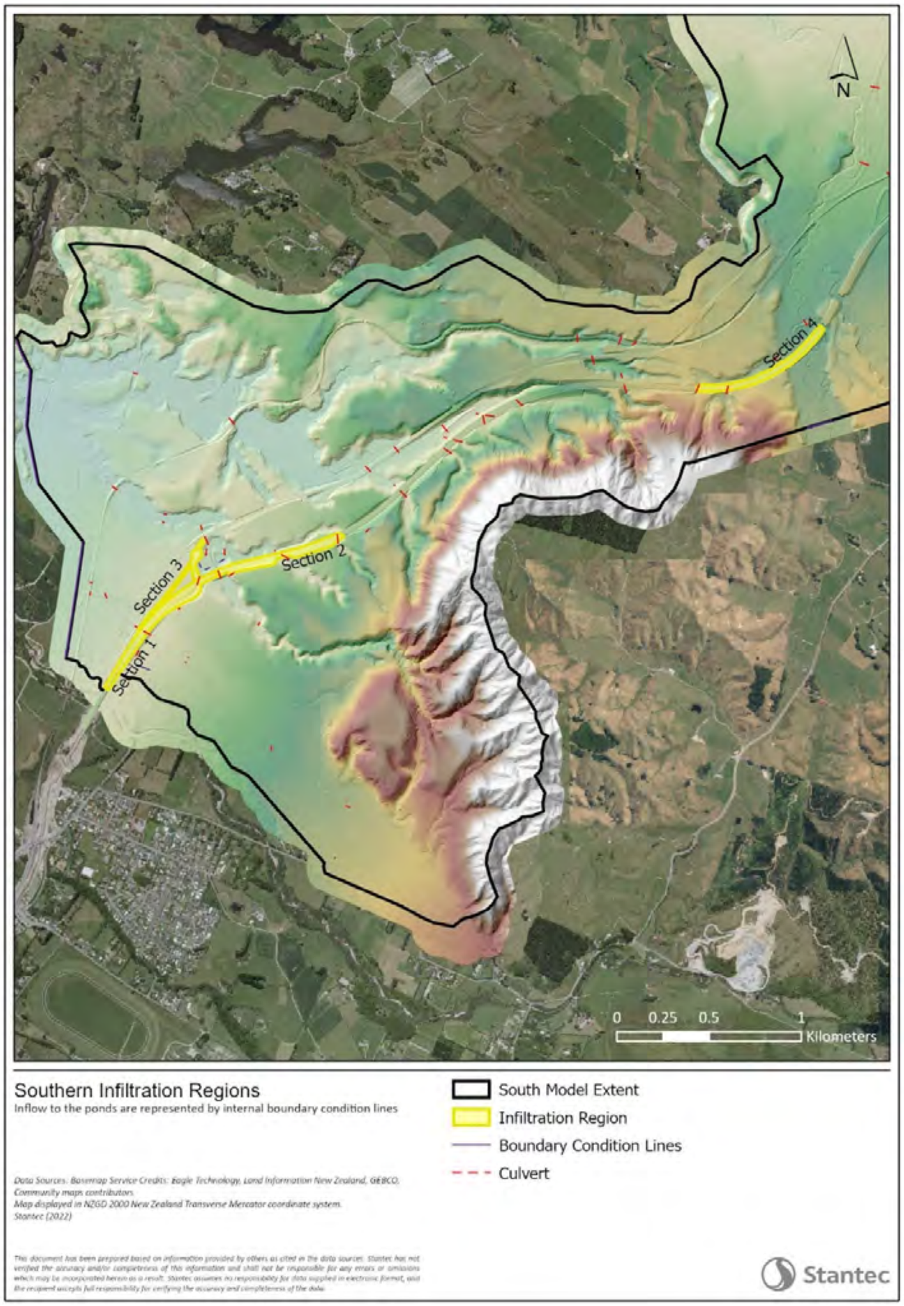


Figure 2-1: Southern grey highway infrastructure - 1D hydrology areas

2.2 Project Earthworks Design Surface

2.2.1 Model surface

The project design surfaces were obtained as OpenRoads 3D exports. These surfaces included finished highway levels, swales, cuts and fills, bridges, local roads (where modified in the design), and the SUP.

The decks of proposed bridges were de-selected from model preparation. This is because the openings through the bridges are modelled in HEC-RAS 2D without the soffit in place, since the soffits are designed to be well clear of the water surface (at least 0.6m in line with the Bridge Manual). The soffits also remain above the modelled water surface for the 1:1500 AEP event with climate change (RCP8.5 2130).

The selected design surface triangle files were imported into GlobalMapper software and converted to a raster grid (TIF) at 1m x 1m cell size to match the HEC-RAS model DEM resolution. This design surface was then superimposed onto the baseline model DEM to create a with-scheme DEM for use in the hydraulic model. The merging of the existing and proposed surfaces in GlobalMapper resulted in a slight horizontal shift of cell co-ordinates, which was corrected to ensure precise alignment with the cells in the baseline model. Otherwise, mis-aligned DEM's can detract from the water level comparison between the two models.

The exact volumes and final form of the material supply and spoil sites were not known at time of modelling and will remain somewhat uncertain until detailed design has occurred, and construction commences, because of potential material variability on site. The potential hydraulic behaviour and effects of the full development of these sites and their consequent rehabilitation (as show in the CEDF) will be inferred from the model results without representing their form in the hydraulic model.

2.2.2 Introduction to feature modifications and mesh refinements

Further modifications to the merged with-scheme DEM were conducted within the HRC-RAS model using the terrain modifications toolbox. This allows for changes to be made without having to create a separate full model surface each time. These use of terrain modifications when representing different features is discussed under each feature type below (first management of streams and overland flows, then longitudinal stormwater management).

Additional mesh refinements were required to allow the model to represent the Project and its hydraulic effect more accurately. Pertinent aspects of mesh refinements are discussed under each feature type below. The mesh refinements were then also copied back to the baseline model and re-run using the same computational mesh as the with-scheme model, to minimise the slight differences that can occur between models on account of different computational mesh, so that only the hydraulic effects of the Project are identified.

The modelling team worked closely with key members of the multi-disciplinary design team to ensure that modelling modifications and assumptions closely matched the design intent.

2.3 Proposed Bridges

2.3.1 Overview

Table 2-2 below lists the waterway bridges, which were modelled in the 2D domain without a bridge deck. This allows the model to include the natural stream bed and detect changes in velocities and depths through the structure due to the lateral constriction of flow. Details of the bridge structures and their hydraulic openings are provided in the design drawing pack (notably 310203848-400 set). Site specific commentary on the model approach is provided in the sub-sections that follow the table.

Where the drawing set indicated scour protection, these polygons were added as roughness patches with a new surface roughness of 0.055.

Breaklines and mesh refinement regions were added around the top edge of bridge abutments to reduce instabilities and improve model performance at the boundary of the road edge and the underlying ground level, see Figure 2-2.

Table 2-2: Proposed watercourse bridge information

Chainage (m)	Flow path ID	Location Name	Model Regime	Soffit clear of 1:1500 AEP (RCP8.5 2130)
22420	34	Ōhau floodplain	2D opening, no deck	Yes
22658	33	Ōhau River	2D opening, with piers, no deck	Yes
23808	32	Kuku Stream	2D opening, no deck	Yes
26440	27	Waikawa Stream	2D opening, with piers, no deck	Yes
30190	15	Manakau Stream	2D opening, no deck	Yes
30350	14	Waiauti Stream	2D opening, no deck	Yes

Figure 2-2: Example (Waikawa) 2D bridge with mesh and breaklines

2.3.2 Piers (Ōhau and Waikawa only)

Piers for the larger the Ōhau and Waikawa multi-span bridges were added as circular terrain modifications. A larger 4m diameter was used in the model preparation (as opposed to the 2m design diameter) to allow for reasonable size mesh cells around the pier and a dry hexagonal cell within the circle. This may result in slight over-estimation of energy losses and water levels and would be resolved more finely during detail design. The pier heights were set based on the approximate height of the bridge deck, which remains above the water surface in all model simulations. An infiltration surface was set on top of the pier to prevent rainfall ponding on top of the pier which can create appearance of curved water surfaces in nearby cells when interpolating results. The surface was brought in as raster cells with a 1m resolution and were drawn so they fell within the hexagon cell to prevent infiltration being applied to cells adjacent to the pier.

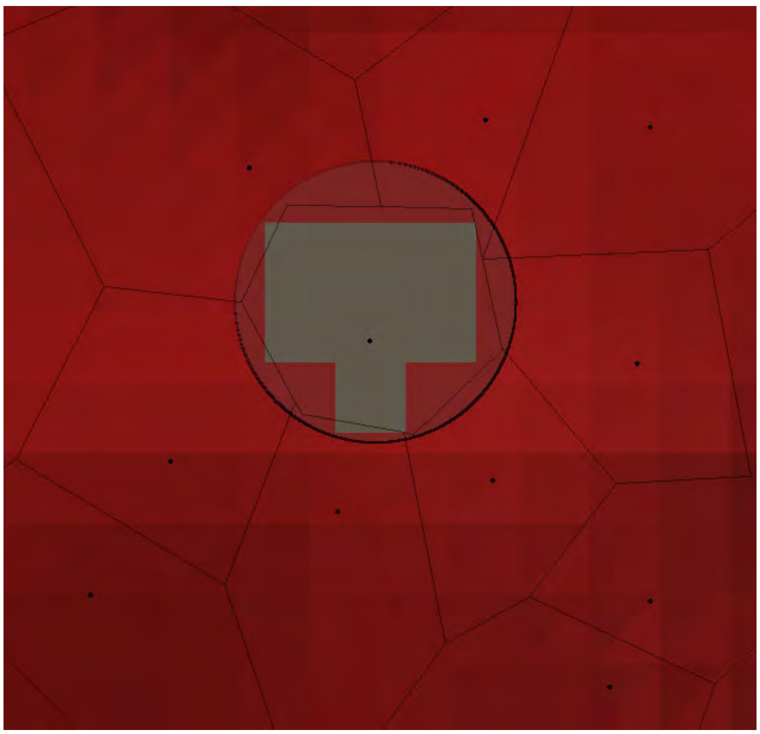


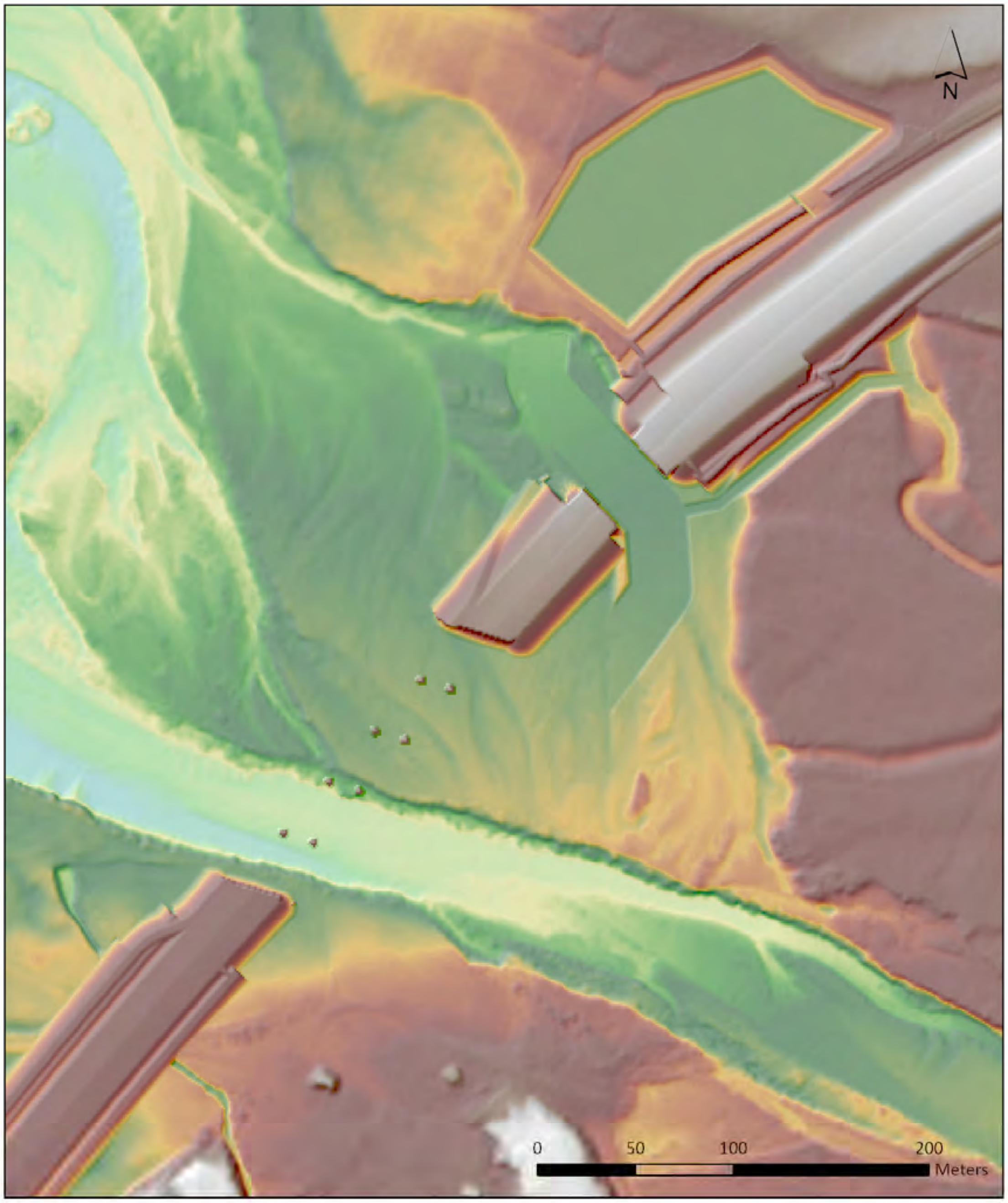
Figure 2-3: Example pier insertion and computational mesh

2.3.3 Ōhau flood relief bridge

The northern (right bank) of the Ōhau floodplain receives some Ōhau River flood flow from further upstream of the bridge, as in the baseline situation. This side of the floodplain slopes northwards away from the Ōhau River, see Figure 2-4. Therefore, a medium sized bridge with 35m top span (31m at floodplain level) is required to pass the flood flows that would otherwise cause a very large afflux (head loss or increase water levels) on the floodplain. A wide shallow scrape (terrain modification) is applied on the floodplain on the approach and throat of the flood relief bridge, which doesn't influence how much flow gets onto the floodplain but does improve the capacity of the bridge.

2.3.4 Ōhau River bridge

The total span (centres of bearings) of the main Ōhau bridge is 175m, although the effective width at floodplain level is reduced due to the spill-through abutments and the effect of piers.



Ohau Bridge Piers and Surface Modifications

Data Sources: Basemap Service Credits: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Stantec (2022)

Stantec

Figure 2-4: Ōhau River bridge opening with piers

2.3.5 Kuku Stream bridge

The Kuku stream bridge in the F3 consent design 3D model (on which the hydraulic model is based) has a clear width of approximately 17m.

The existing culvert and access track at the location of the proposed bridge are removed for the scheme and stamped down to prevailing river elevations for the with-scheme model.

Small bunds were also added to the ends of swales and small trapezoidal channels were added at various sites around the ponds, swales and cut slopes as described in section 2.4, to steer the water in the intended directions. The modified topography is shown in Figure 2-5 below.

Figure 2-5: Kuku bridge terrain modifications

2.3.6 Waikawa Stream bridge

The total span (centres of bearings) of the main Waikawa bridge is 140m, although the effective width reduces at floodplain level due to the spill-through abutments and the effect of piers.

Piers were added as terrain modifications following the same process as described in section 2.3.2. Small channel modifications were also added as described in Section 2.4. The model terrain is shown in Figure 2-6 below.

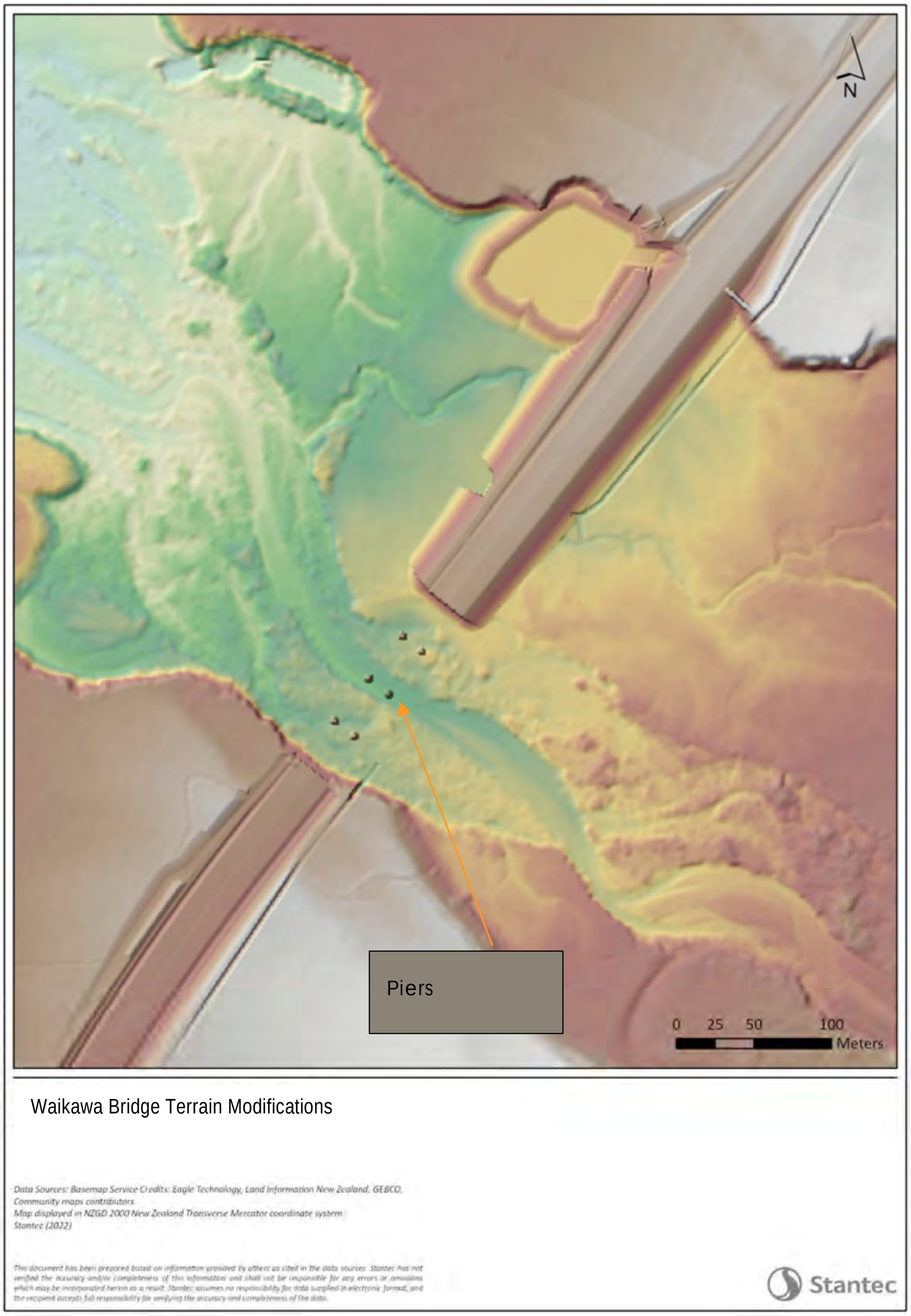


Figure 2-6: Waikawa Stream bridge opening with piers

2.3.7 Manakau Stream bridge

A stream realignment is applied in the model adjacent to South Manakau Road, as per the design drawings. Some flood flow occurs over the road in events above 1:10 AEP, and this behaviour is the same in both the scheme and baseline model. The total channel width of approximately 13m and road width of approximately 15m are combined in a single 28m bridge (bridge deck excluded from model).

Multiple terrain modifications using trapezoidal sections were added upstream and downstream for the new Manakau Bridge to help direct flows through the new structure and to smoothen irregularities in the existing DEM around the existing road. See Figure 2-7 in the next section.

As per the baseline model, the existing South Manakau road bridge over Manakau Stream was retained as a 1D structure. See the baseline flood report for more information.

2.3.8 Waiauti Stream bridge

The proposed Waiauti Stream bridge has been modelled with an opening between abutments of 20m. Stream realignments have been applied in the model as per the design, to maintain stream continuity where the Project footprint obstructs the existing stream. Two trapezoidal cross sections were used to stamp down the terrain to help the water flow through the bridge opening, see Figure 2-7 in the next section. The first trapezoidal shape had a base width of 4m, side slopes of 1 vertical to 5 horizontal units, and a top width of 10m. The second had a base width 20m, close to vertical side slopes of 1v to 0.1h and a max extent of 21m. The first trapezoid was created to model the low flow channel while the second was to model the floodplain under the bridge which sat slightly higher in invert.

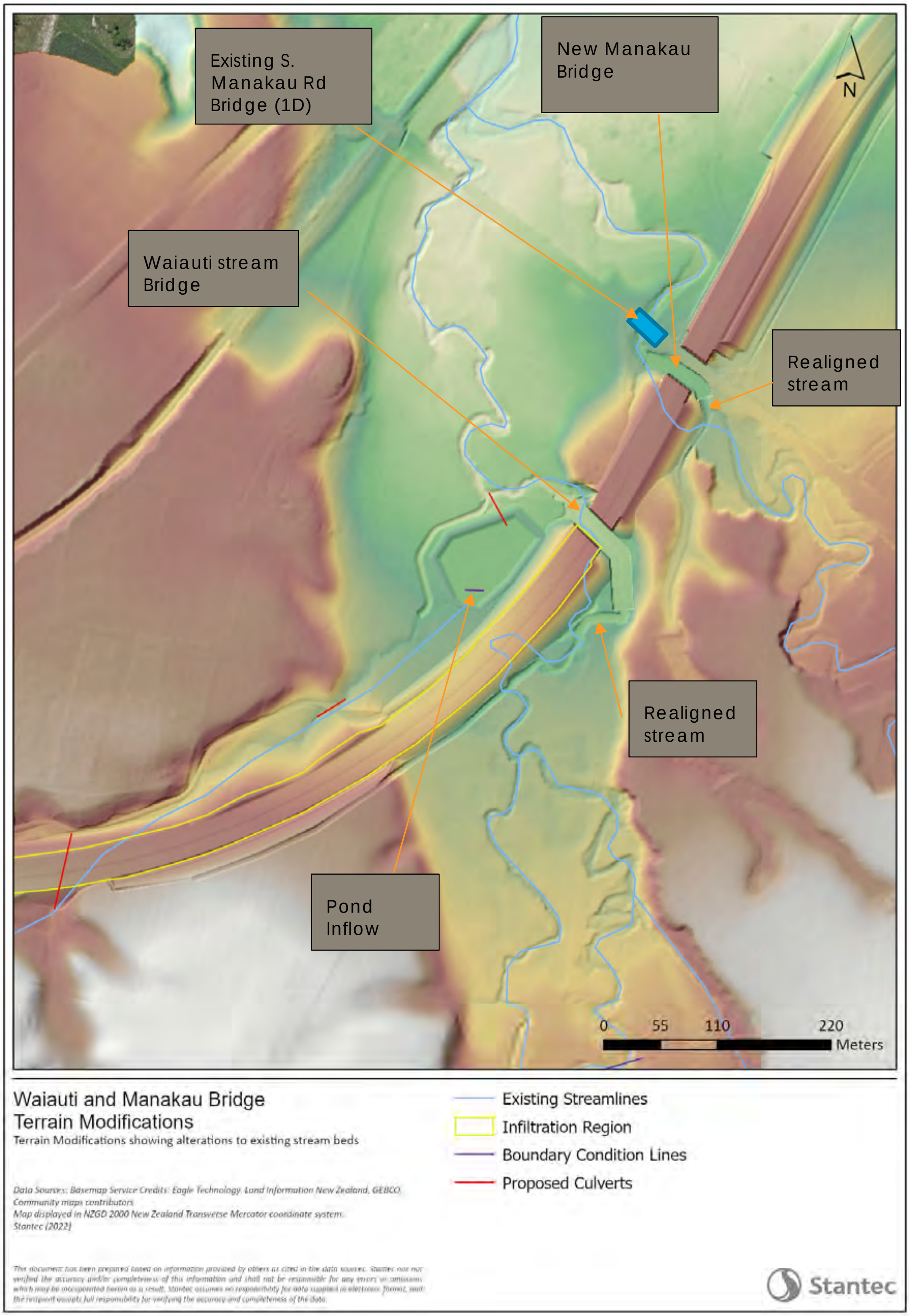


Figure 2-7: Example of terrain modifications and stream realignments around Waiauti Stream

2.4 Stream realignments and overland flow management

Stream realignments were added to the model as identified in the drainage design drawing set, to provide flow paths to culvert inlets and/or provide flow continuity where channels are disrupted by the proposed highway footprint. These stream realignments upstream and downstream of bridges have varied cross sections, based approximately on nearby channel topography. An example of some stream realignments is shown in Figure 2-7 above. See Section 2.3 above for more details.

Small open channel collector drains were added as per drainage design drawing set, to capture overland flows upstream of cut faces and to provide streamlined flow paths near toes of fill where necessary to prevent scour or ponding. These channels were modelled as modification lines with a trapezoidal cross section that typically had a top width of 2-3m, base width of 1-2m, side slopes of 1vertical to 2 horizontal units. A starting or minimum depth of ~0.3m was used as initial default, which was then deepened where necessary to retain forward slope in intended direction. Some of the channels were set back slightly further from the highway than shown in the design drawings, to allow hydraulic separation in the model mesh, but the model is still representative of the function of the consent design. The positioning, dimensions and gradients of the open channel collectors will be refined during detailed design.

Small low bunds were added in some locations to prevent water from flowing in unintended directions. For example, low bunds were added along the upstream side of some cut faces, that work in conjunction with the open channel collector to prevent water from spilling into the highway cutting, as shown in the typical cut-off section in drawing 310203848-01-300-C9100. Some bunds were also used to further raise the outside bank of some swales (relative to the 3D design model) to reduce spilling between natural overland flow and highway swales. All these bunds were constructed as raised trapezoidal shapes (like inverted stream modifications). The water being managed by these bunds is shallow, short duration flooding and only in rare events. The height of these bunds will be optimised in detailed design together with the open channel collector drains and highway swales.

Mesh breaklines were added to force cell edges along the top of banks, bunds, high points, and low channels so that water would not prematurely side-step these important features. HEC-RAS does all its calculations for flow at cell edges, thus hydraulic features that are not represented by cell edges could otherwise be missed in mesh cell calculations.

2.5 Proposed Culverts

Culverts were added to the model as indicated in the drainage plan set and culvert table (refer 310203848-300 drawing series). Culvert embedment was applied as shown in the table. The design philosophy for the culverts is reflected in the Design and Construction Report, and the effects are discussed in the consent application Technical Assessment #F.

At some locations, stream realignments or other small changes to mesh inverts were needed to allow model-compliant connectivity of inverts. However, these adjustments are small relative to the water depth upstream of the culvert, and do not impact on bore area of the culvert, and therefore the model is still considered representative of the consent design.

The culverts were assigned default entrance and exit loss factors of 0.5 and 1.0 respectively, assuming standard square edge headwalls for circular culverts and wingwalls (between 30 to 75 degrees) for rectangular culverts. All culverts were assumed to be made of concrete and backfilled with mixed substrate where shown for fish passage with a Manning's 'n' roughness of 0.05 along the bottom and 0.018 on the soffit of the culvert. If no embedment was required, the invert and soffit Manning's 'n' values were both set to 0.018. These are relatively high roughness values for a straight concrete culvert, to allow for some variation in sediment transport and energy dissipation along the length of the culvert. Roughness values may be reviewed during detailed design.

As specified in the culvert table, some culverts on ephemeral flow paths have a scruffy dome inlet to manhole drop structure at the inlet, to allow a straight culvert to pass underneath the highway and associated drainage. A low forward slope is still applied within the culvert, assuming that coarse sediment will be captured in upstream stilling basins and in the upstream manhole, so that forward velocity can maintain the pipes clear of sediment build-up. These culverts typically have a similar bubble-up structure at the downstream end, to return water to the surface along original overland flow paths.

2.6 Longitudinal stormwater management features

The longitudinal stormwater management features are intended to convey high intensity rainfall runoff from paved areas, for subsequent treatment and attenuation at the ponds. A key requirement for the hydraulic model is to keep reasonable separation between the longitudinal water and the natural transverse streams or overland flow paths, so that potential significant constraints or effects can be identified. The design and modelled representation of the stormwater system will need to be refined in detailed design stage. Since the stormwater ponds provide significant attenuation in a 1h or 4h storm, it is not required to model the depths or volumes within the longitudinal stormwater system with great precision at this stage for assessment of effects outside the designation.

2.6.1 Rain falling on the highway

Rain falling on paved areas of the highway, and unpaved areas of cut faces, road margins, swales, and fill faces, is modelled in HEC-RAS 2D using the same direct rainfall approach as the baseline model. For most of the Project, this water is captured in swales to lead to treatment and attenuation facilities, as discussed in subsequent subsections.

As discussed in section 2.1 there are a few small sections of the highway that were modelled using infiltration zones and direct inflows to approximate grey infrastructure. An approximation was required as HEC-RAS does not currently support underground pipe networks, and not all of the required detail is available at this stage in the design. However, the intention is reflected, namely that rainfall on the grey infrastructure will be routed efficiently to the appropriate pond for treatment and attenuation. The detailed design stage will provide more optimised and detailed stormwater component design, which can be tested in the hydraulic model where appropriate.

2.6.2 Swales

The swales in the design 3D consent model are based on parametric highway design and have minor deficiencies in conveyance continuity. These have addressed for the hydraulic model as follows:

- Closing the upstream ends of swales with a small bund to force water to flow along the swale in the directions intended in the design (since upstream ends of 3D swales were open ended sections in the design surface, which would otherwise allow a small quantity of backflow).
- Closing the downstream ends of swales with a small bund to force water to flow into the correct pond (since downstream ends of 3D swales were open ended sections in the design surface, which would otherwise allow flow over the end of the swale).
- Enforcing computational mesh lines along the outside edges of swale bunds, to prevent premature overtopping. In a few locations, these lines were also raised to prevent mixing with overland flows, which will be reviewed and refined in detailed design.
- At ‘kinks’ in the swales associated with maintenance bays, the invert of the swale was widened with a small terrain modification to provide continuity of flow.
- Minor widening of the swales under the new Muhunoa East overpass, where the narrowed 3D design conveyance swales were difficult to represent using the 1m model surface grid. This will not have a material impact on the model representation of the function of the swale conveying water to the appropriate treatment pond.

2.6.3 Swale cross connector culverts

Cross connections between swales were modelled as culverts following the input information provided in the drawing pack (310203848-300 series). These culverts were not embedded and were assigned a Manning’s ‘n’ of 0.018. Where the cross culverts were directly opposite the target pond, the cross culvert outlet was placed directly into the pond forebay to simplify model computation.

2.6.4 Swale to pond drop structures

Drop structures to take water from the swales to the SW ponds were not fully specified in the consent design and were therefore modelled as wide ‘spillways’ stamped down as a trapezoidal ramp / channel from the invert of the swale to connect to the invert of the pond.

Where ponds are on the outside of a highway curve (super-elevation) with no outside swale, for example at chainage 32400, the inside swale is directly connected to the pond via a cross culvert.

2.6.5 Treatment wetlands and attenuation ponds

The consent 3D design represents the pond volume as a combined treatment/attenuation storage area with a flat base and a surrounding bund. The separate volumes have been calculated for sediment forebay, wetland treatment pond and attenuation area, but the hydraulic model currently combines these as per the 3D design model.

Each pond was modelled in the 2D domain relying on the 3D terrain pond terrain and bunds. Break lines were applied along the tops of the pond bunds.

Outlet culverts were added to the model, to release flood flows at an attenuated rate.

Checks were completed against the stormwater calculation to confirm that the modelled ponds were attenuating the outflows approximately as intended for the 4h modelled storm.

2.6.6 Roundabouts, Local Roads, Accessways, and SUP

Roundabouts are generally designed with kerb and pit drainage to capture water for treatment, as shown on the drainage design plan set. However, apart from the southern interchange roundabout, all other roundabouts have been left in the hydraulic model direct rainfall zone with flow generating as per the design terrain slopes. Since the footprint of the roundabouts is relatively small, this minor simplification will not have a material impact on the accuracy of the hydraulic model for assessment of effects in the current stage of design. The representation can be improved during detailed design.

Similarly, local roads will generally have small stormwater management features (e.g. narrower infiltration swales) to approximately match existing local road drainage. These small features have not been explicitly included in the model. New or modified local roads that cross watercourses will have culverts as indicated in the drainage design plan drawing set.

Accessways in the form of pedestrian or vehicle underpasses beneath the new highway have not been explicitly modelled in the hydraulic model, as they do not convey significant flow. These features, including any associated bunds or drainage will be specified during detailed design.

The SUP crosses swales at many locations, and the size of the culverts or footbridges for these minor crossings have not yet been specified. For modelling purposes, these locations were represented either as estimated culverts or as 2D terrain modification (i.e., the deck of the SUP removed) to allow the swales to convey water unimpeded. This will be resolved during detailed design.

The southern section of the SUP that follows the existing SH1 was not modelled explicitly due to its distance from the new highway, and the small variations from the existing terrain are assumed to be insignificant. Any drainage requirements will be resolved in detail design.

2.7 Terrain stationarity and gravel mobility

For the purposes of the hydraulic modelling, it is assumed that topography and sediment remain at current levels and predominantly in 'equilibrium'. The small streams and ephemeral flow paths generally have finer sediment that is assumed to pass through the project culverts. The larger streams have some gravel and cobble bed load, which can pass through the bridges that typically span these streams. The combination of wide bridge spans and scour protection is assumed to provide adequate room for some migration, but bed elevations and flood elevations are assumed to remain similar to the current situation.

Terrain changes, including scour or injections of gravel and sediments due to earthquakes or major storm events are not considered in the hydraulic modelling.

2.8 Surface Friction

A roughness surface was developed for the baseline model following existing land use information, as discussed in the baseline flood report. Small modifications were added to the roughness layer in the with scheme model, for example where new open channels were constructed through dense vegetated areas. In these locations the roughness was set to be the same as the open space Manning's n value, namely 0.048.

The remainder of the roughness layer was left the same as the baseline models for the with scheme models, despite the increase in paved area on the expressway. Because the new paved areas drain to SW management features, the more rapid runoff is attenuated in the stormwater ponds. Only the outflows are relevant for assessment of potential downstream effects, in the 4h storm. The lack of infiltration in the HEC-RAS model, and the representation of the stormwater attenuation ponds, means that outflows can be reasonably reflected without specifically adjusting for infiltration or roughness within the paved areas when assessing downstream effects. The stormwater features are subject to design calculations outside of the HEC-RAS model to ensure appropriate performance across a range of event durations. The stormwater design performance will be further validated in the detailed design stage.

Scour protection details have not been modelled explicitly as roughness patches at this stage. The impact of scour protection on modelled water levels is expected to be minimal.

2.9 Run Parameters and Model Stability

The model used an adaptive time step based on courant formula with a maximum value of 2 and a minimum value of 0.5. The equation set used in all models was 'SWE_ELM Original'.

The three models have been simulated successfully across all AEP events, no major mass/volume balance errors.

3. Model results and differences from baseline

3.1 With-scheme model results

The scenarios modelled are the same as the baseline model, as discussed in Section 1.3.

The various AEP design event scenarios were applied to the models and run for 6 hours of simulation time to allow the peak value to pass the downstream boundary.

Appendix B presents modelled results for the with-scheme model. These can be compared with the modelled results in the baseline flood report appendices.

3.2 Scheme differences from baseline

Maps showing with-scheme differences (with-scheme model minus baseline model) are presented in Appendix B. Further discussion and evaluation of the difference maps is provided in Technical Assessment F.

3.3 Blockage risk assessment

A high-level assessment was carried out to evaluate the risks associated with culvert blockage, following the steps outlined below.

A desktop assessment of expected debris loads from contributing catchments and flow paths was performed, in line with AR&R (2015) Blockage Guidelines For Culverts And Small Bridges. This informed the preliminary recommendation for upstream debris arrestors (soldier piles or large screens) reflected in the culvert schedule. The debris loads and debris arrestors were not applied to the hydraulic model.

The concept design earthworks surface around each culvert was viewed in GIS and 3D views to ensure that in the event of blockage, water could either pass along the highway embankment to another nearby culverts or pass over the highway at shallow depth, without posing risk to upstream dwellings or preventing emergency services from passing through floodwaters.

Depressed low gradient culverts with dropped inlets and/or bubble-up outlets can sometimes be subject to reduced performance by blockage of debris arrestors and/or sediment deposition over time. The detailed design will provide upstream debris screens and stilling basins, plus safe maintenance options. For example, vehicle-mounted jec-vac systems that can evacuate sediment from stilling basins or from manholes via a small opening at the top of the scruffy dome without removing the screen. Periodic inspection or additional cleaning of the culverts can be carried out by removal of the screen and insertion of remote-controlled CCTV crawlers and/or cleaners. Further detail of the design and of monitoring and maintenance regimes will be established during detailed design.

3.4 Limitations and Residual Uncertainties

The modelling is a reasonable representation of the consent F3 design and can detect changes relative to baseline in flow rates and water levels on account of the proposed Ō2NL Project.

As indicated in the baseline model report, we have relied upon third party data sources when building the model. The source data and the hydrological and hydraulic modelling processes have followed industry best practice but still naturally contain some assumptions or uncertainties as normally anticipated. Depending on the changes after the consent design and criticality of decisions during detailed design, consideration could be given to reducing some of the residual uncertainties. Potential limitations and uncertainties to consider include:

- If using the model to optimise or validate the performance of the longitudinal stormwater management features, then shorter and longer duration storms would be required, in addition to other model refinements.

- Baseline hydrology limitations (refer to baseline flood report). The impact of this uncertainty is mitigated by applying the same hydrology to both pre and post project models, however the hydrological uncertainty could still influence some design decisions.
- There are ground model differences between the DEM (LiDAR data) on which the modelling was primarily based and the 2020 drone-based DEM on which the highway earthworks design is based. The differences could potentially be reduced by applying additional ground control survey to both datasets to reduce discontinuities and allow only one merged ground model to be used for modelling and detailed design. The onus will rest on the Detailed Design project stage to confirm suitability of the ground model and any associated hydraulic modelling for the final design and construction purposes.
- The representation of climate change is based on the IPCC 5th assessment global climate model predictions downscaled to New Zealand by NIWA (2018). Science from the new 6th assessment may become available to the project during detailed design.

Appendices

Appendix A Map Figures Data Source

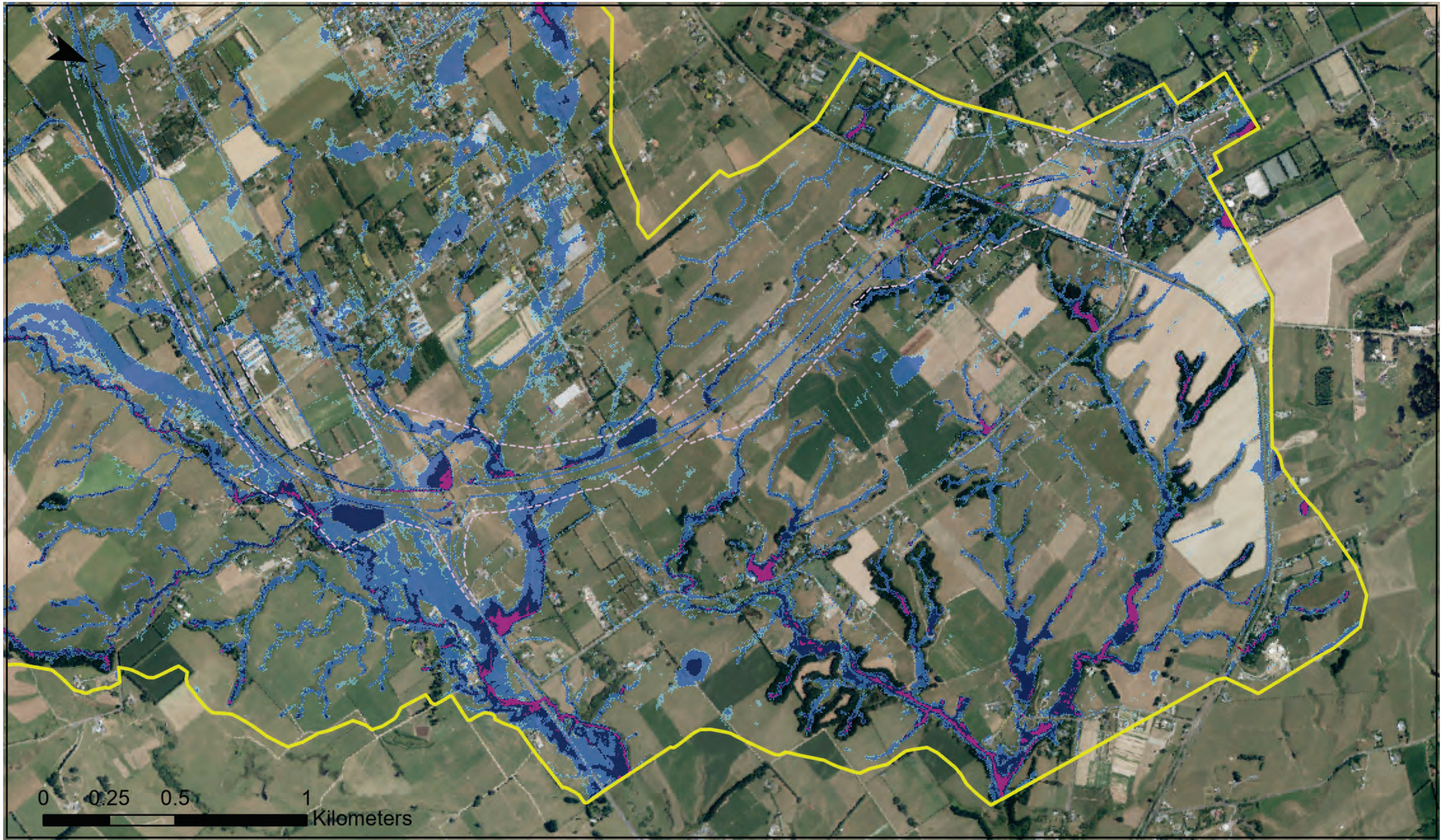
Data Sources: GWRC, HDC, HRC, KCDC, KiwiRail, LINZ, and Stantec NZ.

Basemap Service Credits: Eagle Technology, Esri, FAO, Garmin, HERE, LINZ, Natural Earth, NIWA, NOAA, © OpenStreetMap contributors, StatsNZ, USGS.

All maps displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system unless otherwise specified.

All elevations relative to Wellington 1953 datum unless otherwise specified.

Appendix B Model Results



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec

Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

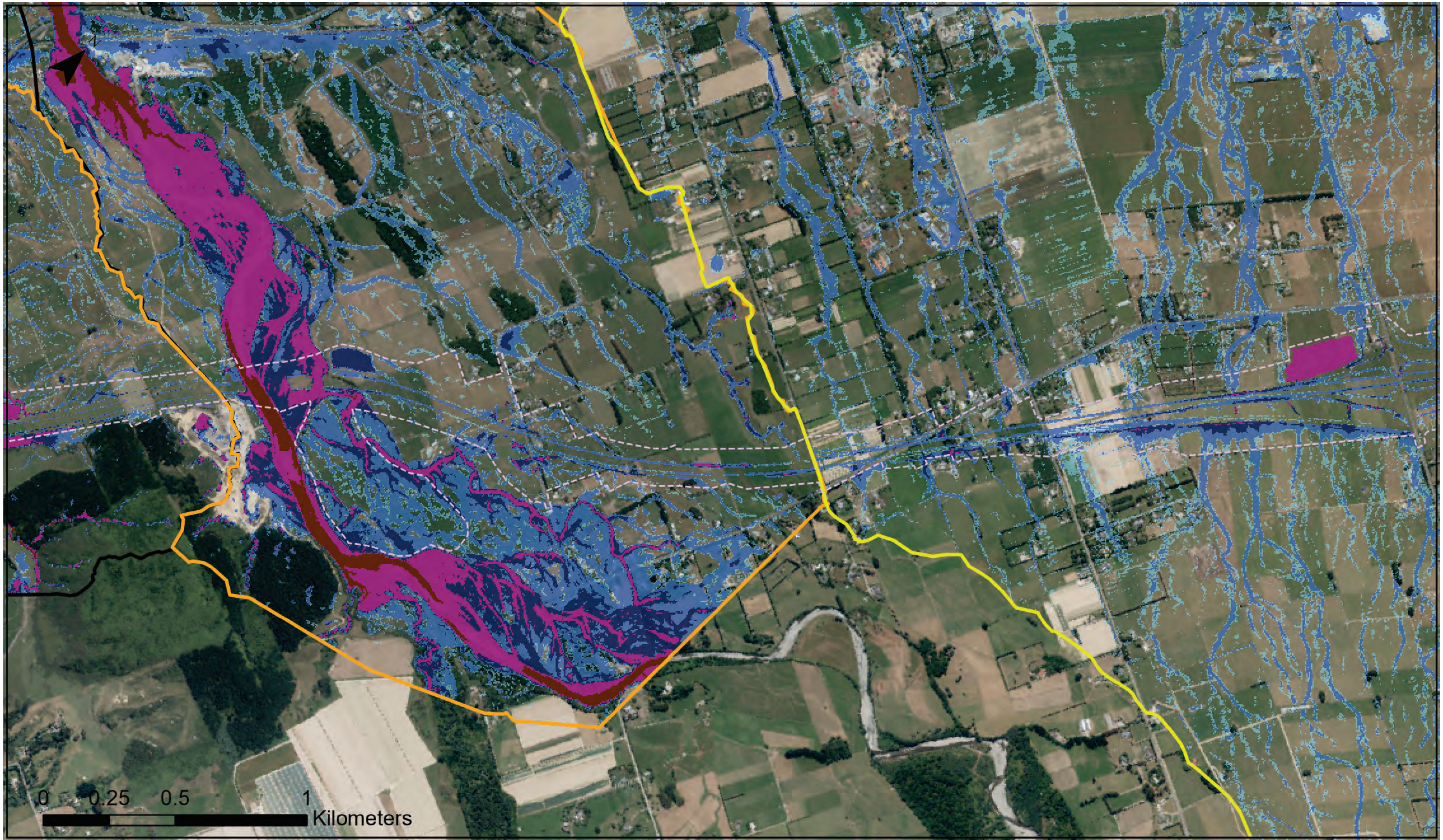
Stantec

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

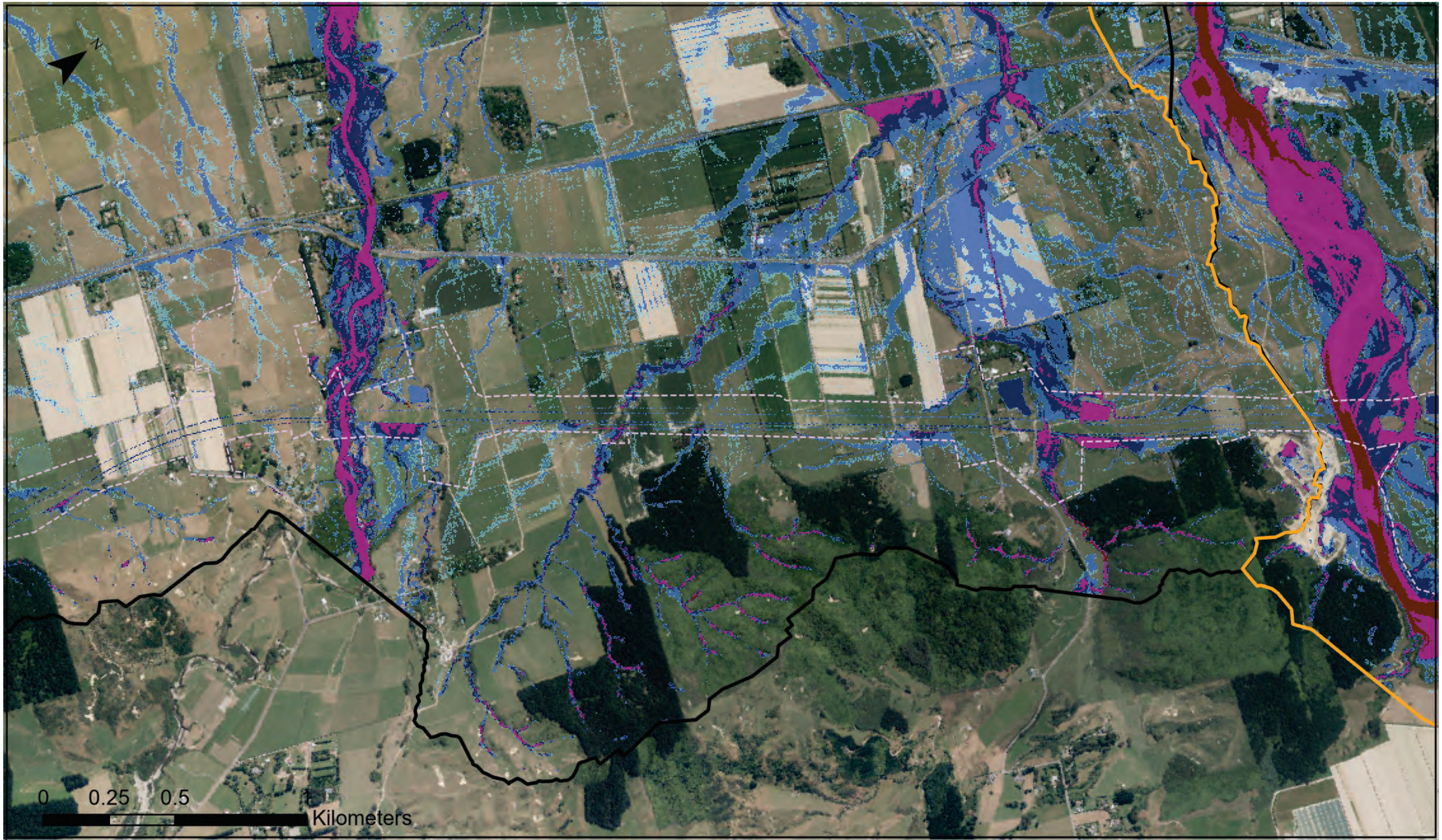
South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

South Model Extent
Ohau Model Extent
North Model Extent
Proposed Designation July 2022

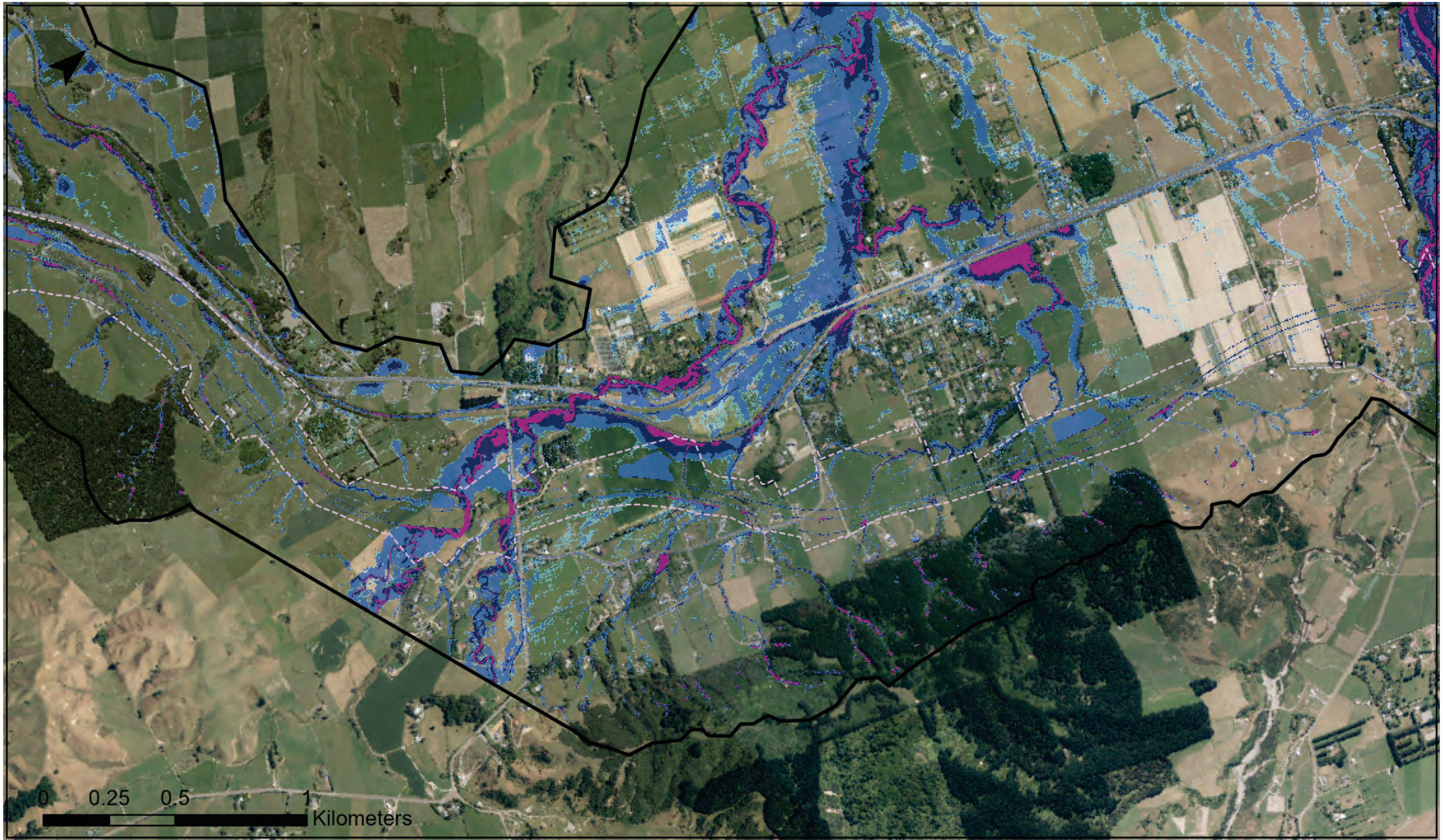
Max. Water Depth (m)

0.05 to 0.1
0.1 to 0.5
0.5 to 1
1.0 to 3.0
Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Stantec



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

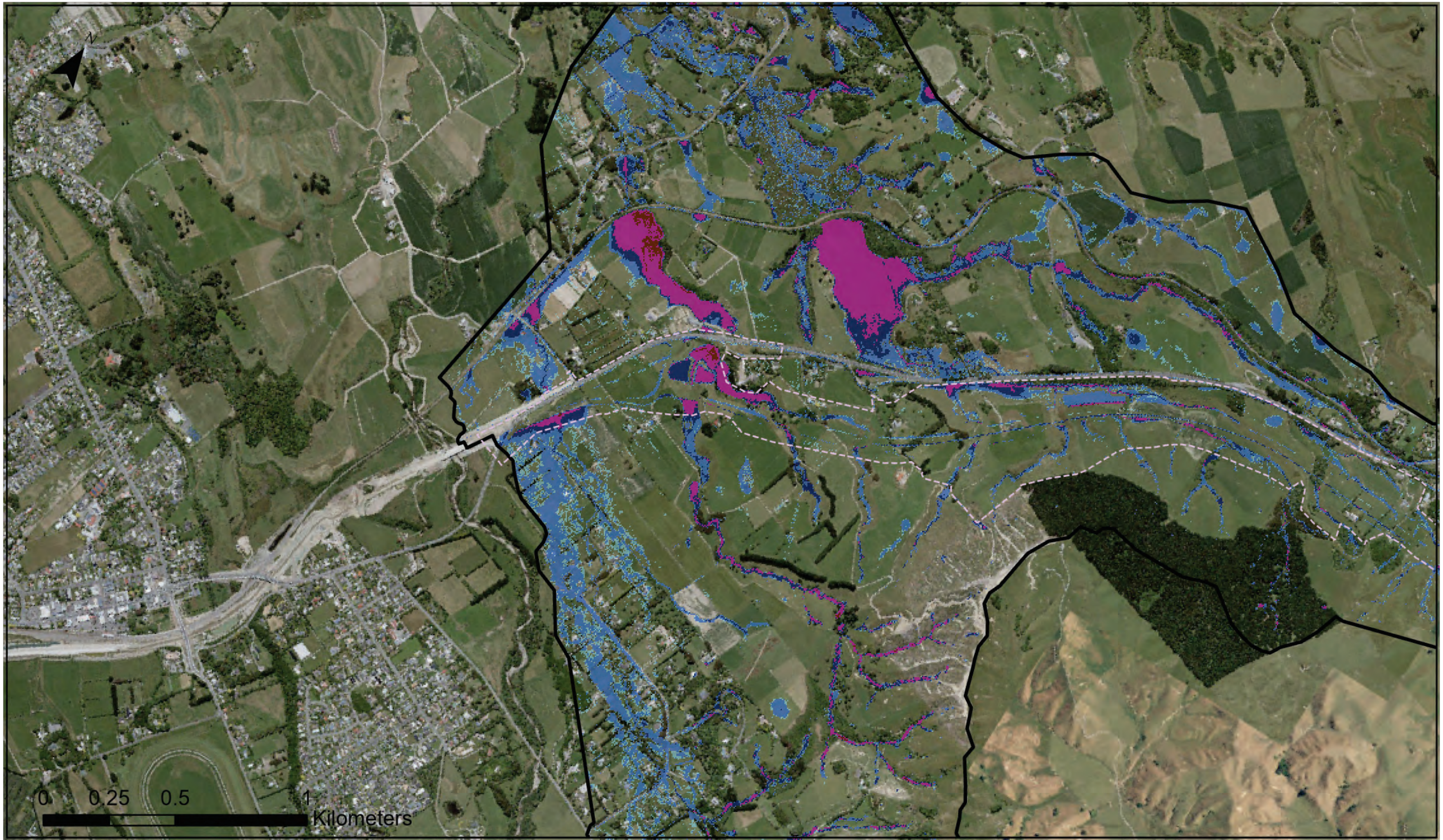
Stantec

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022

Max. Water Depth (m)

- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1
- 1.0 to 3.0
- Greater than 3

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, Maximum Water Depths 1:100 AEP With Climate Change RCP 6.0 2130

Storm duration: 4hr for the Ohau and North models and max of 4hr and 1hr for the South model

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022

Max. Water Depth (m)

- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1
- 1.0 to 3.0
- Greater than 3

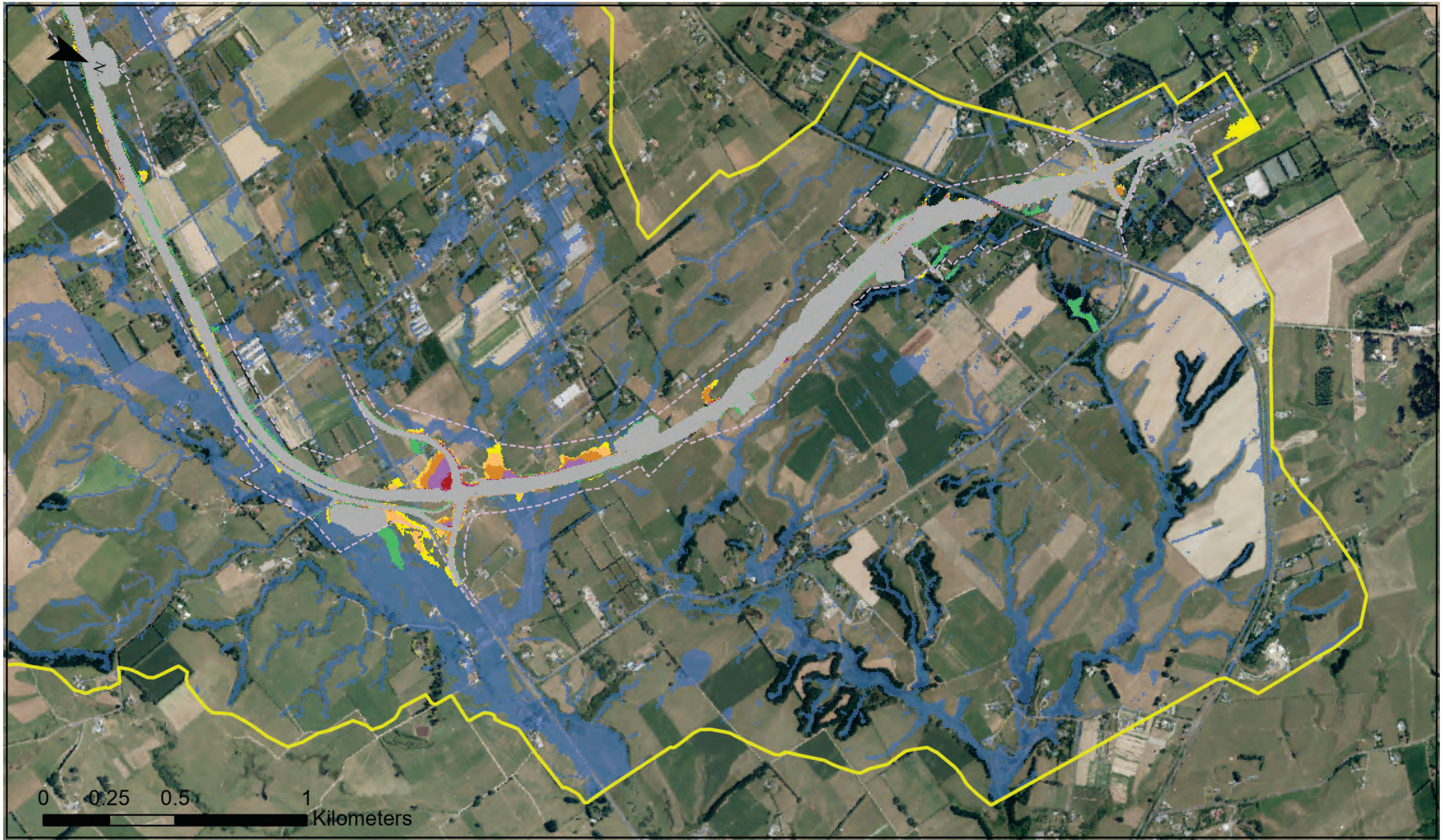
Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.

Author: Stantec (2022)

This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Stantec



Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

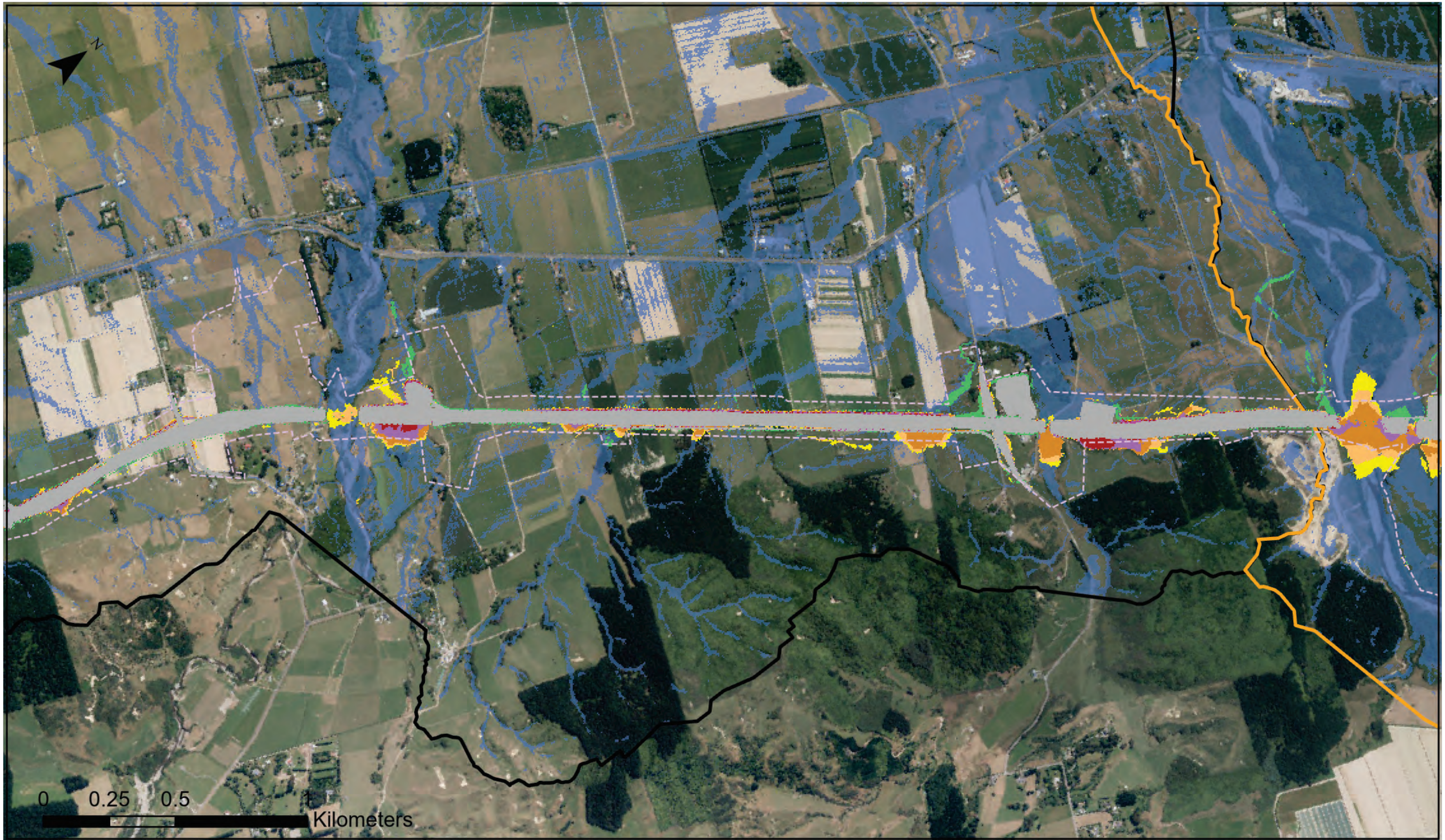
Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

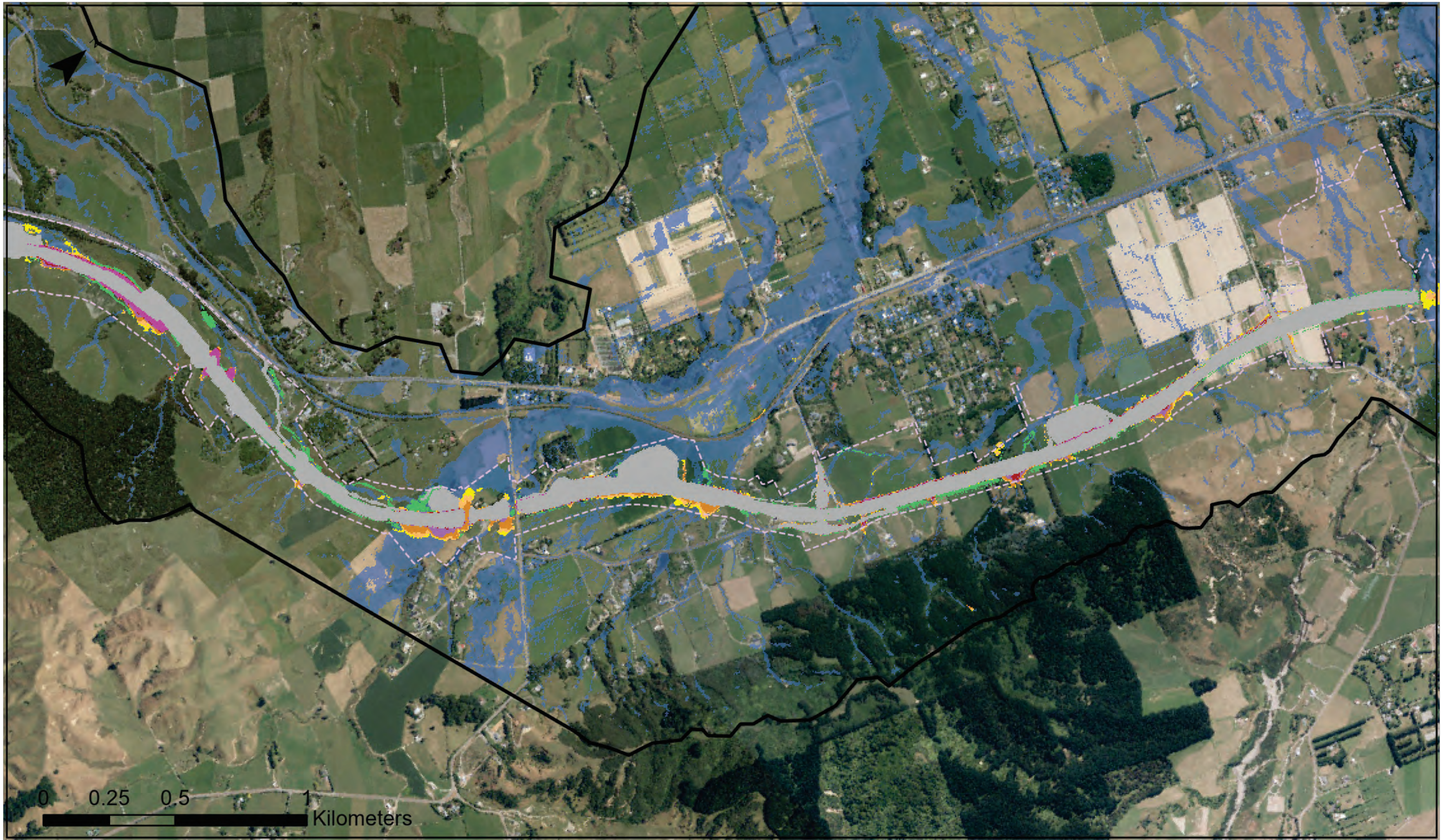
Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

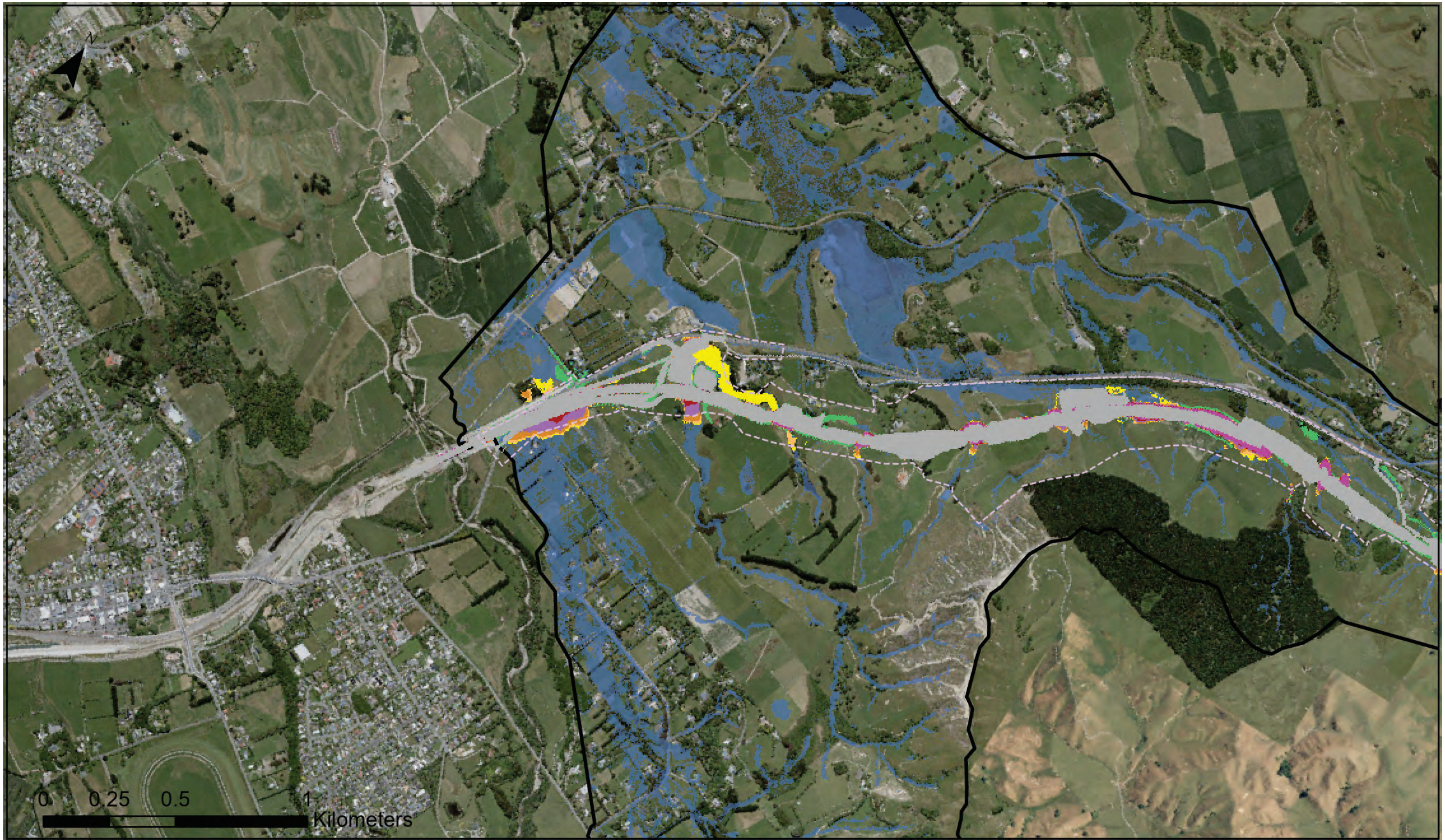
Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, 1:100 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:100 AEP event with RCP 6.0 2130 climate change considerations. The North and Ohau models show differences for a 4hr event, while the South model includes both 1hr and 4hr max elevation differences.

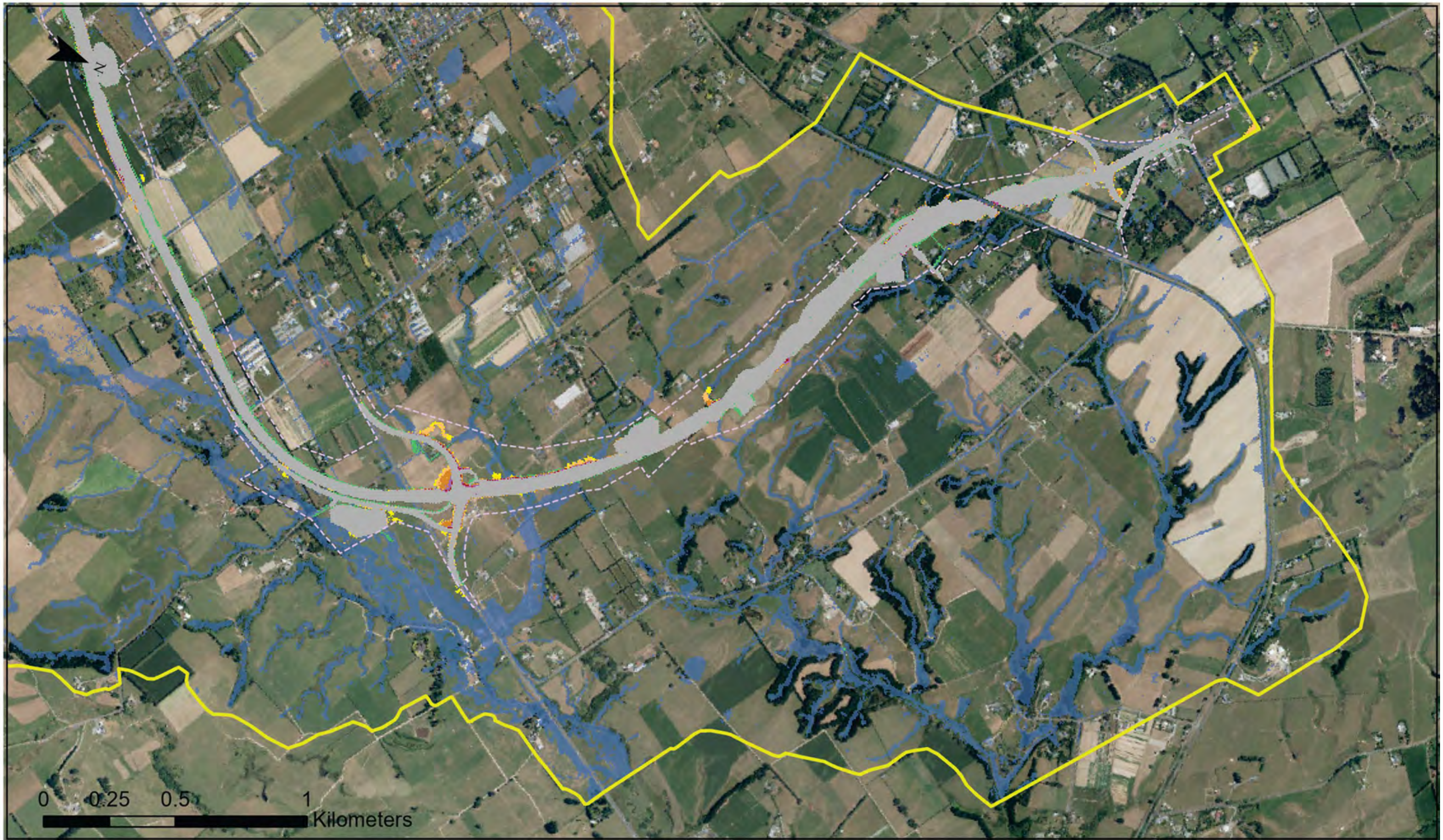
Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

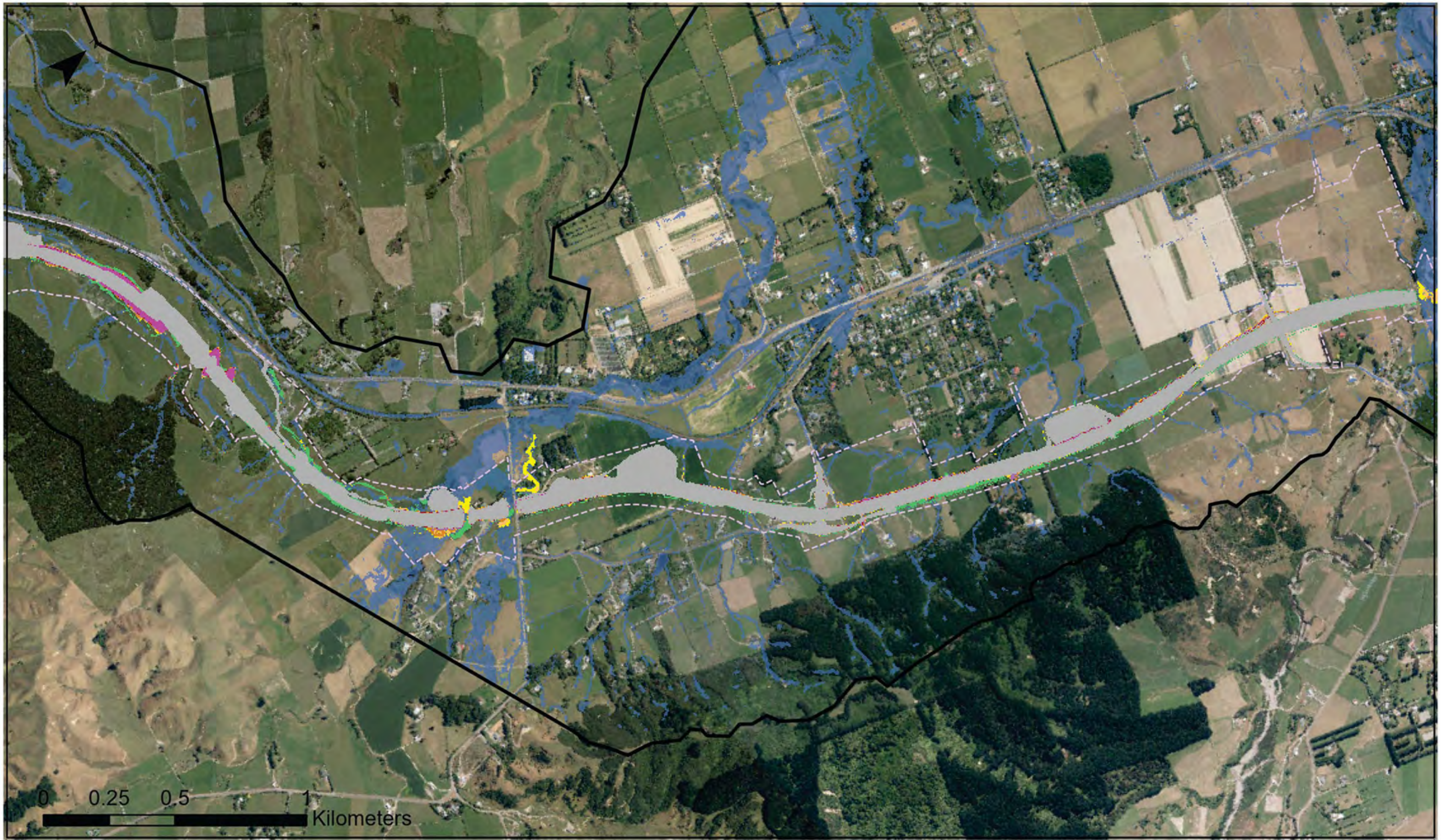
Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)



Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Model Results, 1:10 AEP Water Surface Elevation Difference, Scheme Minus Baseline

This map shows the difference in maximum water surface elevations for the 1:10 AEP event in existing climate. The North and Ohau models show differences for a 4hr event. The South model shows differences for a 1hr event

Stantec

Max WSE Difference (m)

- Less than -0.1
- -0.1 to 0.05 (baseline no change)
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- Greater than 1.0

- South Model Extent
- Ohau Model Extent
- North Model Extent
- Proposed Designation July 2022
- Concept Design Footprint

Data Sources:Basemap Service Credits: LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: Stantec (2022)

Wellington

Level 15, 10 Brandon Street
Wellington 6011
PO Box 13-052, Armagh
Christchurch 8141
Tel +64 4 381 6700
Fax +64 4 473 1982

APPENDIX F.3: PEER REVIEW MEMORANDUM PROVIDED BY DR MCCONCHIE

Memorandum

To:	Caitlin Kelly	**At:**	Ō2NL Project Team, Waka Kotahi
From:	Dr John (Jack) McConchie	**At:**	SLR Consulting NZ Limited
Date:	20 October 2022	**Ref:**	720.30017.00000 O2NL Hydrology Peer reviewer FINAL.docx
Subject:	Role as hydrology peer reviewer		

Introduction

I was asked by the Ō2NL Project team to provide independent peer reviews of the hydrology, results of the computational hydraulic modelling, and the assessment of environmental effects that underpin *Technical Assessment F – Hydrology and Flooding*. That assessment is part of a body of investigations and technical information that will support an application for the various resource consents and approvals necessary to construct the Ō2NL Project.

On other occasions, I have also been asked to provide advice on separate hydrology-related issues associated with the Ō2NL Project. These include:

- Options for the supply of the water necessary for construction of the Project;
- The hydrology of wetlands that might be considered for rehabilitation and for offsetting any potential adverse effects of the Ō2NL Project e.g., Kereru Wetland; and
- Options for potential material supply sites.

Background

My principal involvement in the Ō2NL Project has been related to groundwater. My background, skills and experience are summarised in *Technical Assessment G – Hydrogeology and Groundwater*. However, I also have skills and extensive experience in the areas of hydrology and flooding, and how these processes interact with infrastructure.

I have considerable experience working on major infrastructure projects including: the Hamilton North Bypass; Western Link Road; Kopu Bridge; Tauranga Eastern Link Road; Basin Bridge; Transmission Gully; Peka Peka to Ōtaki Expressway; Petone-Grenada Link Road; the realignment of SH3 at both Mt Messenger and Awakino Gorge; and Te Ahu a Turanga: Manawatū Tararua Highway. This experience gives me an in-depth understanding of climate, hydrology, and flooding and how they interact with infrastructure.

I have considerable local experience having worked on various hydrology-related projects in and around Horowhenua and Manawatū over the past 20 years; including the PP2Ō Expressway and Te Ahu a Turanga: Manawatū Tararua Highway. I provided technical evidence relating to the flood hazard and stormwater management at Tara-Ika during hearings into the proposed change to the Horowhenua District Plan. I have provided technical advice to Horizons on several applications for resource consents involving works related to streams and rivers. This experience has given me an in-depth understanding of climate, hydrology, and flood hazard in the area to be traversed by the Ō2NL Project.

Peer review

Any review of the potential effect of the Ō2NL Project must be undertaken within the context of the existing flood hazard of the area. In my opinion, the Project will not only increase the resilience and security of the State Highway but have a small, positive effect on reducing the existing flood hazard.

Regarding my independent peer reviews of *Technical Assessment F – Hydrology and Flooding*, I have:

- Reviewed the various hydrological inputs to the computational hydraulic modelling, including the design rainfalls and flows. This included undertaking an independent frequency analysis of the annual flood maxima from the various flow records. I believe that the inputs adopted are realistic but likely conservative i.e., the design flows, in my opinion, are likely to be slightly high;

- Considered the criteria adopted when defining the design events and believe that these are appropriate for the Ō2NL Project;

- Considered the inclusion of the potential effects of predicted climate change over the design life of the Ō2NL Project and believe that the approach adopted is appropriate;

- Not reviewed the detail of the computational hydraulic modelling, however, this has followed current industry practice and used an industry-standard suite of software;

- Considered the issue of calibration and validation of the computational hydraulic models. Given the extremely limited availability of empirical flow data, particularly for the very large design events modelled (apart from the 10% AEP event under current climate), a greater level of calibration and validation is not possible. However, this uncertainty is accommodated by adopting conservative flows (i.e., high) which exacerbates the impact of the Project and therefore any potential adverse effects;

- Considered the conceptual design for the Project incorporated within the computational hydraulic modelling and believe that it is realistic. In my opinion, once the Project has been refined and the design finalised, the effects of the Project on hydrology and flooding are likely to be less than assessed in Technical Assessment F;

- Considered the assessment of effects of the Project on the existing flood hazard. Again, I believe that a conservative approach has been adopted and that the effects that might eventuate from the Project will likely be less than stated; and

- Considered the feedback from Horizon's peer reviewer and the responses provided to the various matters raised.

Conclusion

Based on the information and materials that I have reviewed, and numerous discussions with Andrew Craig (Stantec), I believe that *Technical Assessment F – Hydrology and Flooding*:

- Has adopted industry standard methods and measures, and that these have been applied in an appropriate manner;
- Has included appropriate, although likely conservative (i.e., high), hydrological inputs to the computational hydraulic modelling;
- Has provided appropriate consideration of the future potential effects of climate change; and
- By considering a conceptual design, provides a realistic, although likely conservative (i.e., high) assessment of potential effects of the Project on hydrology and flooding. This assessment provides a realistic envelope of effects within which the final design and construction of the Project can be developed.

In summary, in my professional opinion, the methodologies, results and conclusions provided in *Technical Assessment F – Hydrology and Flooding* are realistic, but likely conservative i.e., high. That is, in my professional opinion and experience the effects of the Ō2NL Project on hydrology and flooding are likely to be less than assessed.