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

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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,

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[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.

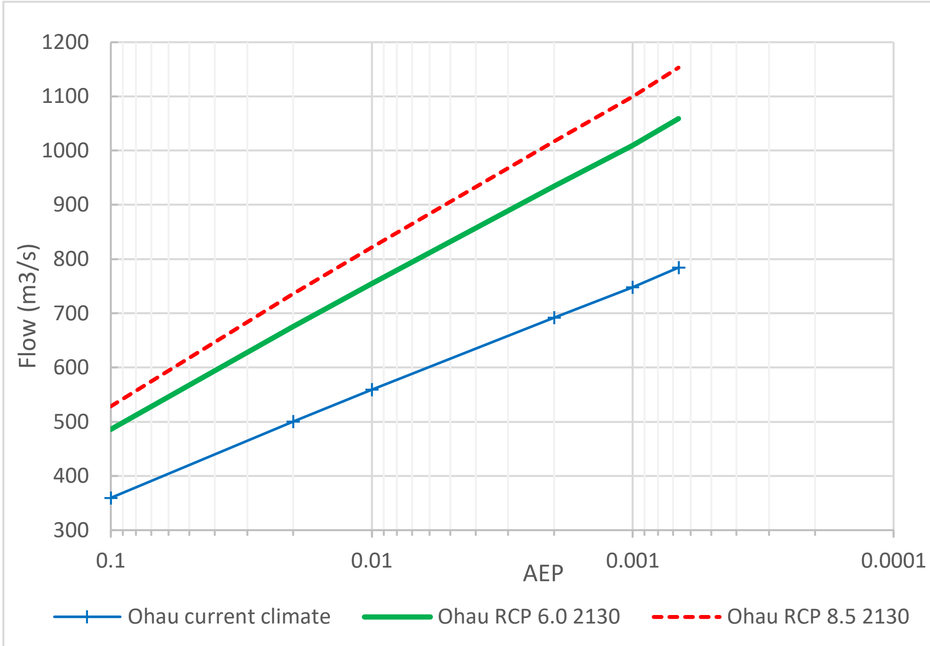

Figure F.1: Effect of climate change scenarios on flood peaks (Ohau at Rongamatane)

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.

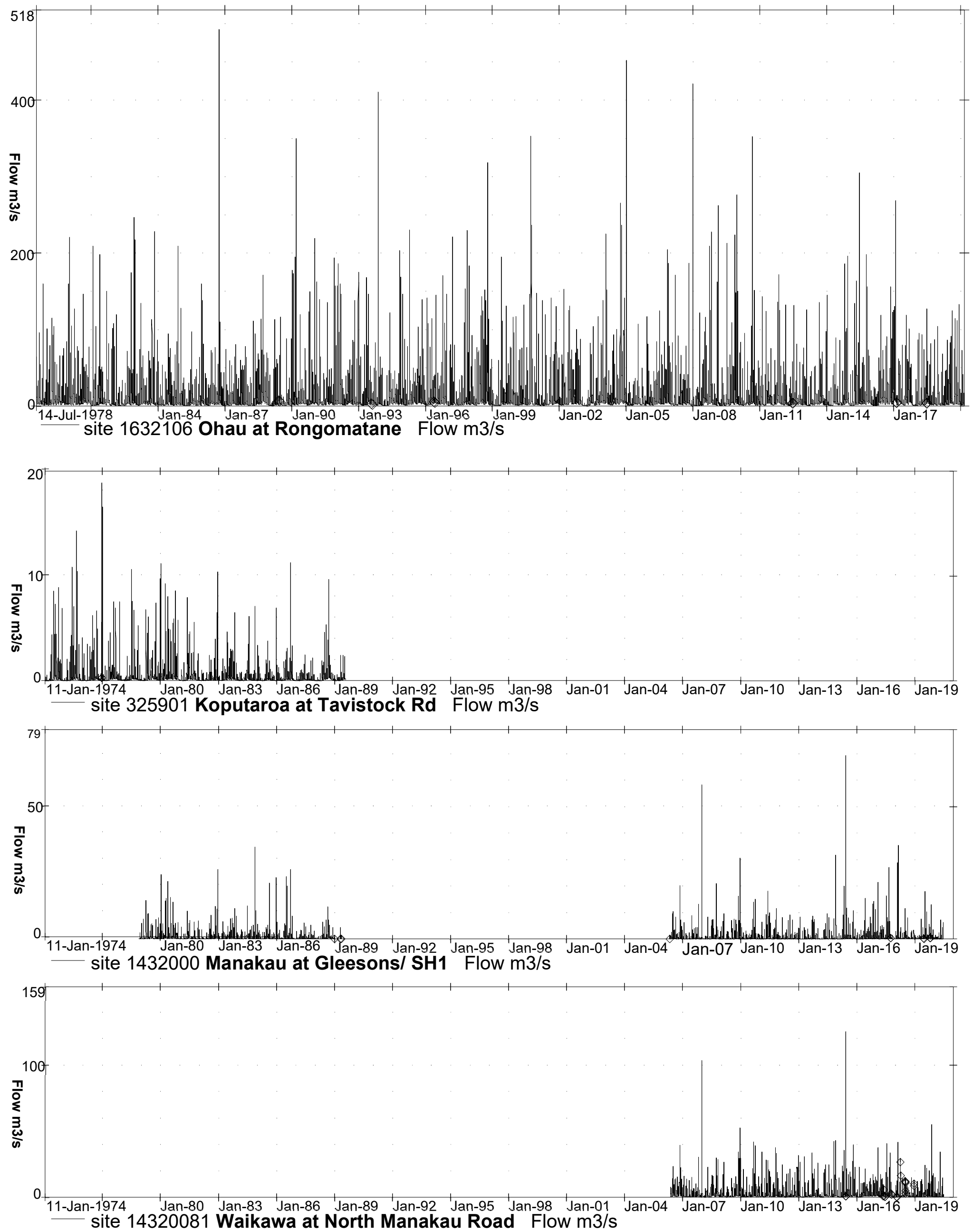

Figure F.2: Overview of flow data

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.

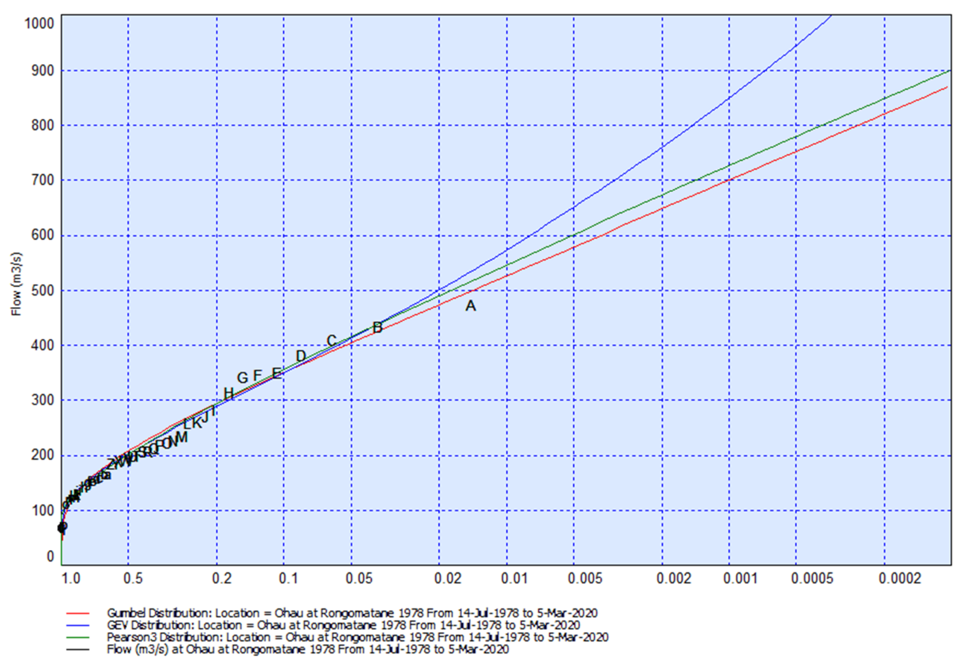

Figure F.3: Ohau at Rongomatane flood frequency analysis. The 1:100 AEP flood probability is indicated by the vertical dash line.

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.

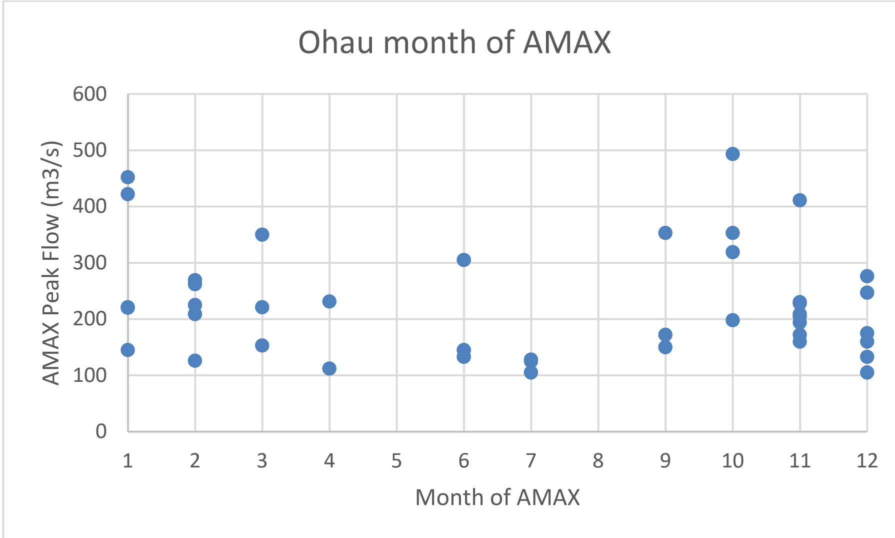

Figure F.4: Ohau at Rongomatane month of annual maxima ("AMAX")

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.

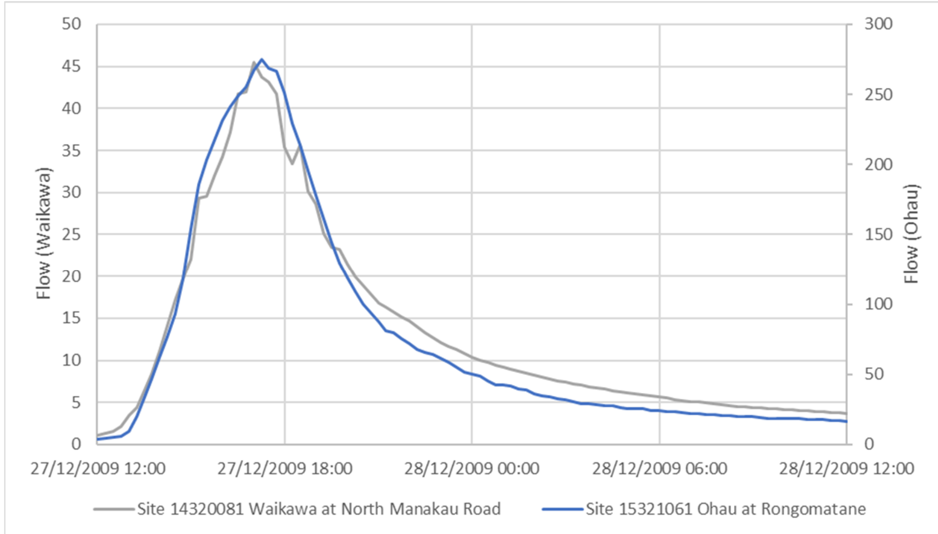

Figure F.5: Hydrograph timing comparison, December 2009

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.

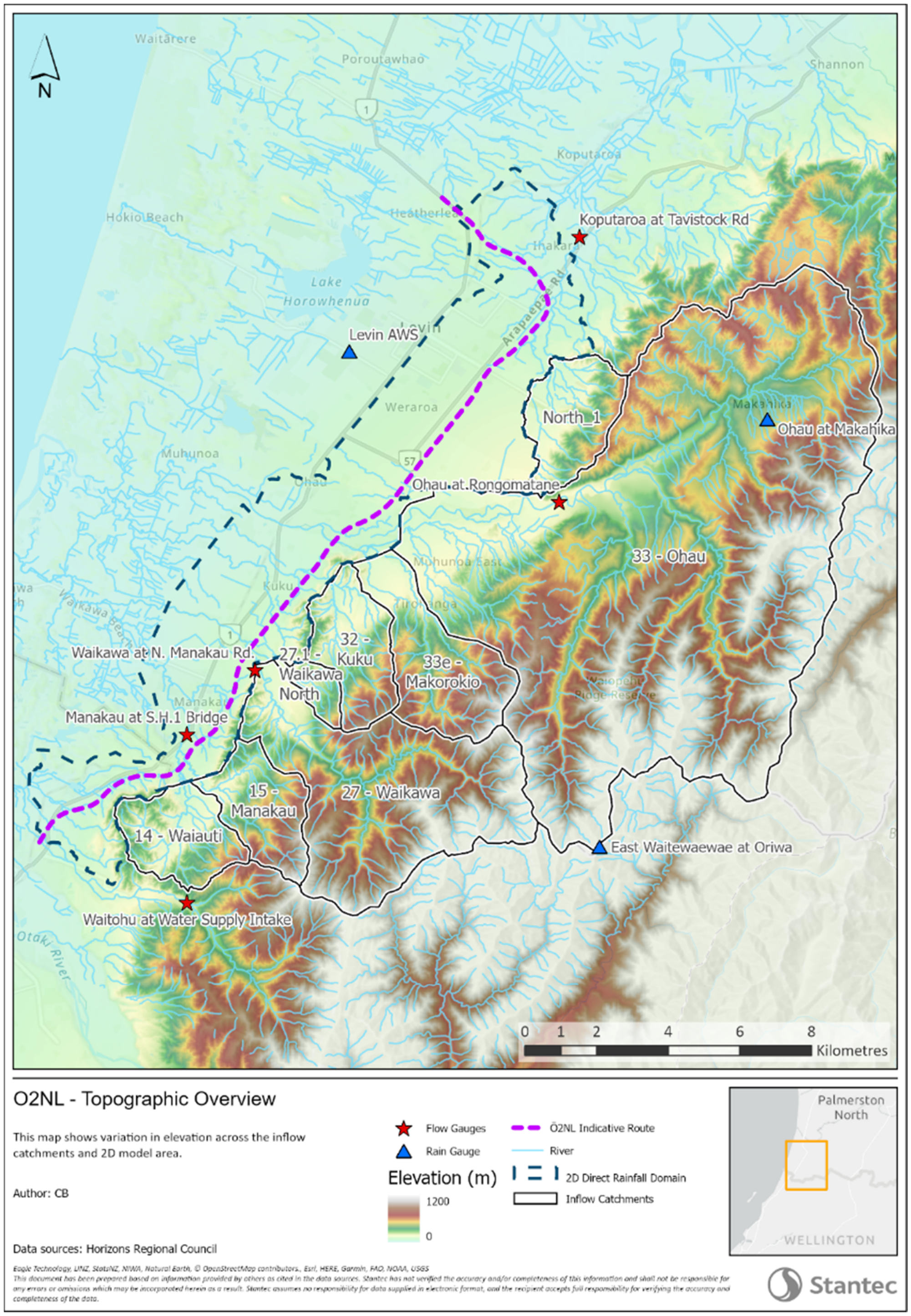

Figure F.6: Ō2NL Project topographic overview

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.

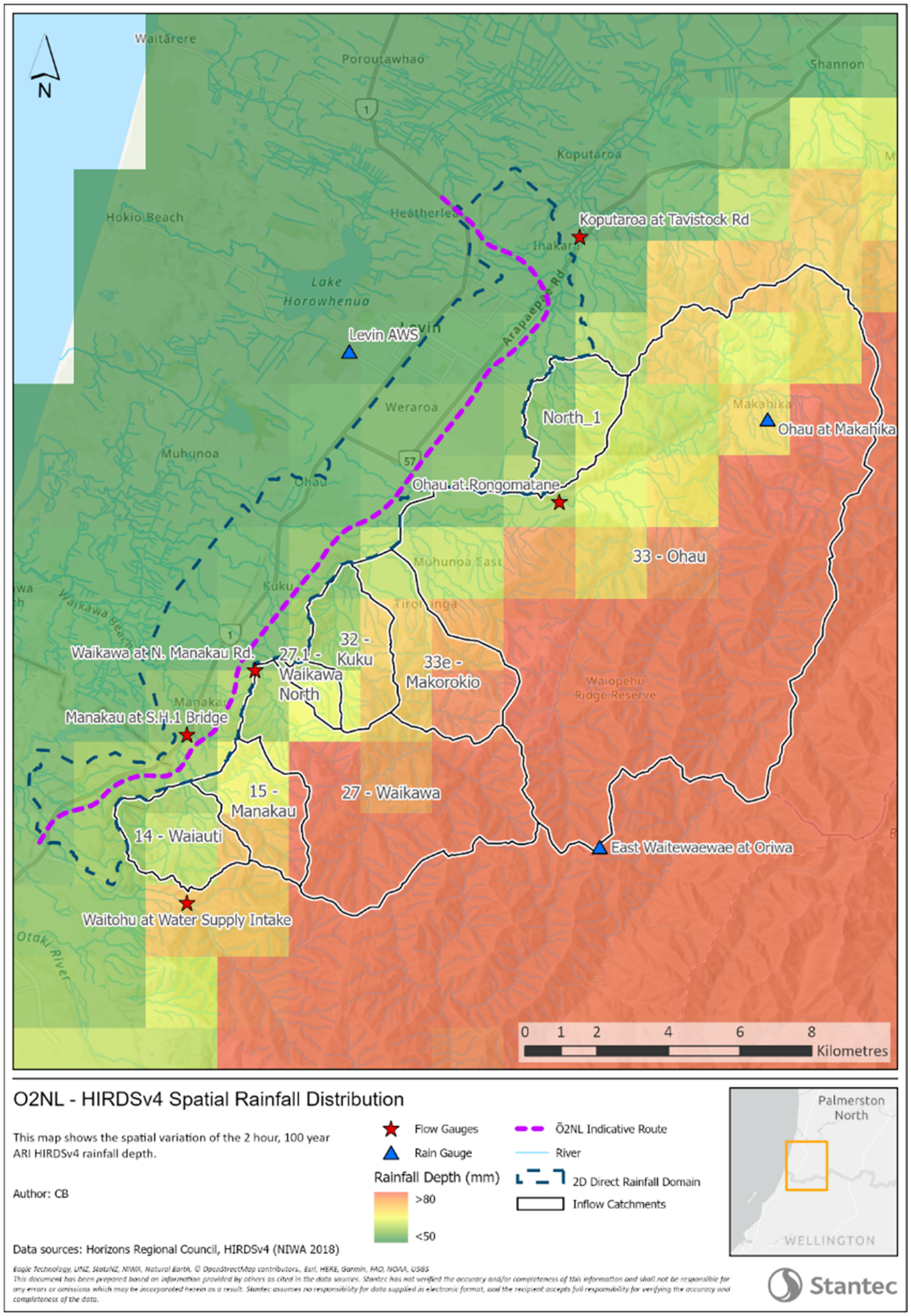

Figure F.7: Catchment rainfall spatial variation

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.

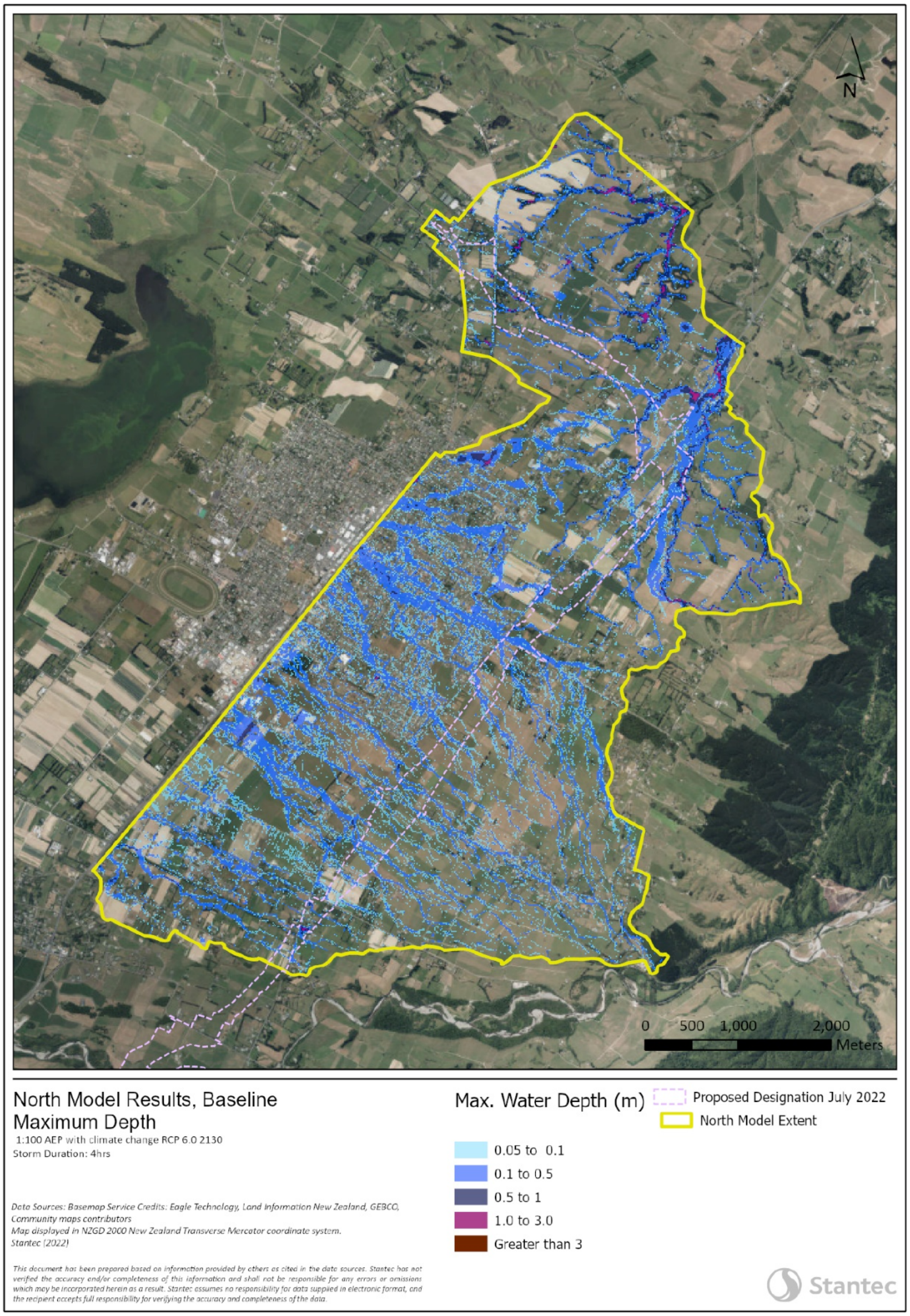

Figure F.9: Baseline (without Project) maximum modelled depths 1:100 AEP RCP6.0 2130 (North)

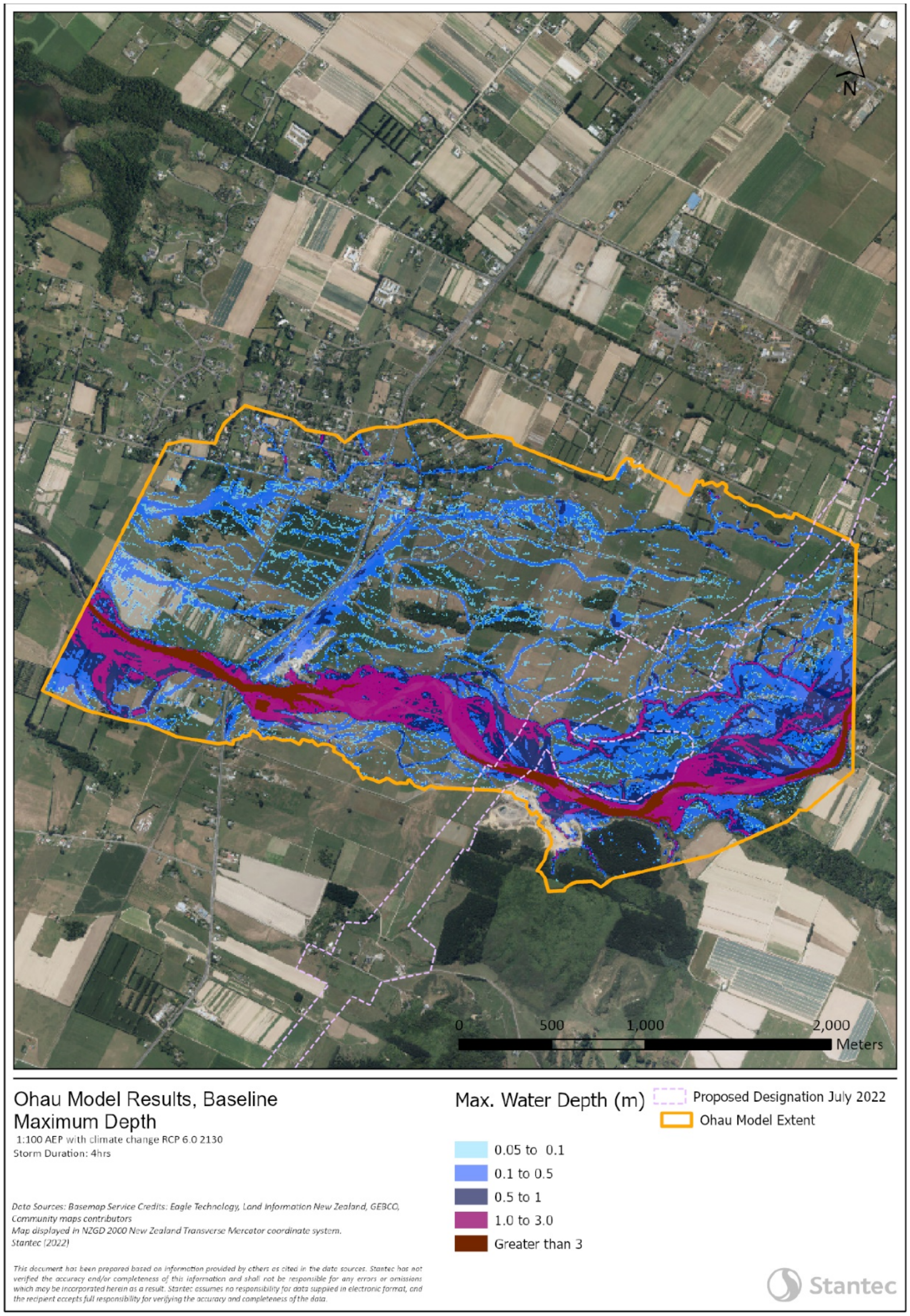

Figure F.10: Baseline (without Project) maximum modelled depths 1:100 AEP RCP6.0 2130 (Ohau)