Integrated Sediment, Nutrient & Drainage Management Plan for the Arawhata Catchment

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REPORT

Tonkin+Taylor

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Table of contents

Executive summary

Intensive vegetable production in the Arawhata catchment in Horowhenua District has contributed to declining water quality in Lake Horowhenua. This has occurred through the discharge of sediment and nutrients to a network of drainage channels over a long period. The drainage network functions as a repurposed water race and is central to the issues in the catchment, acting both to generate sediment and nutrient loads through periodic over-topping inundation of cropland, and to transfer mobilised contaminants to the lake receiving environment. Consistently high sediment and nutrient loads are apparent in the monitoring record near the catchment outlet.

While many studies have sought to understand and address sediment and nutrient generation and transport processes in the catchment, no catchment-wide planning approach has been completed to address the issues in a more co-ordinated manner.

Tonkin & Taylor Ltd (T+T) was engaged by Horizons Regional Council (HRC) to develop an integrated sediment, nutrient, and drainage management plan for the catchment. This work forms part of a wider project of water quality improvements in the catchment under the Ministry for the Environment's *Jobs for Nature* programme. A complementary wetland concept design project being undertaken by Jacobs in the lower catchment is also funded under this programme. The Jacobs project has progressed along a different timescale and therefore is not yet integrated with this project report.

The plan outlines catchment issues and presents a suite of engineered and non-engineered management options that are aimed at improving drainage efficiency and reducing the generation and transport of sediment and nutrients within the catchment. Management options are a mix of on-paddock, in-network, and end-of-catchment measures. The options were scored against drainage and water quality objectives using multi-criteria analysis (MCA) and ranked for implementation.

The highest-scoring management options are those that are effective in meeting their primary objective for relatively low cost, such as grass buffer strips, or that achieve multiple drainage and water quality benefits despite generally high cost, including two-stage channels and a large offline wetland.

Recommendations for implementation depend on the primary function of each option and the particular issues facing different parts of the catchment. The upper catchment is focussed on flood detention measures to reduce peak flow rates entering the main cropping area during infrequent rainfall events. The mid catchment focusses on retaining sediment and phosphorus close to their source and improving network performance to reduce the frequency of channel overtopping and soil scour. The lower catchment focusses on advanced treatment through vegetated wetland systems to remove soluble nutrients and finer sediment.

Implementation should follow a specific sequence so that cumulative benefits accrue and interventions are not adversely affected by construction-related sediment discharges from upstream. Network capacity upgrades should be constructed from the bottom of the catchment in the upstream direction while flood detention should be constructed from the top of the catchment in the downstream direction. On-paddock systems interventions should be constructed before those within the network so that in-network systems are protected from high sediment loads. The end-of-catchment wetland and associated forebays should be constructed last once the sediment regime has stabilised following establishment of upstream measures.

Uncertainty about how sediment and nutrient patterns vary throughout the catchment limits the extent to which targeted placement of options can be recommended. Uncertainty around flow behaviour in the network and the size of contributing catchments further limits the confidence with which options can be located and sized. It is recommended that ongoing water quality monitoring is

undertaken and a hydraulic model of the drainage system be constructed to improve the understanding of system performance.

1 Introduction

1.1 Background

The 2,080 ha[1] Arawhata catchment is an important vegetable growing area for the lower North Island (**Figure 1** and **Appendix A1**). The catchment includes historic and more modern land drainage elements comprising a network of channels and culverts that collect farm and road runoff and convey stormwater and associated sediment and nutrients to the Arawhata Stream and ultimately to Lake Horowhenua.

It is understood that the drainage network was originally developed as a water race and that land drainage activities in the catchment were developed in an ad hoc manner over a long period before the network became the formal drainage scheme it is today.

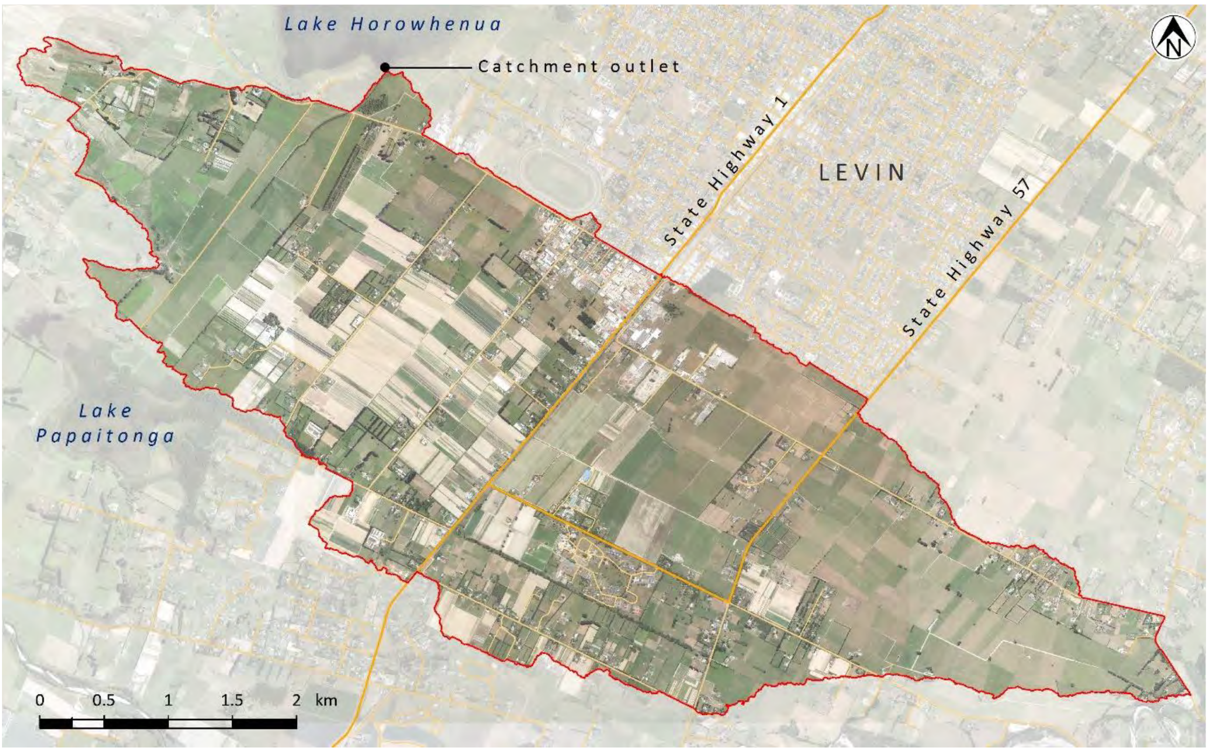

Figure 1. Arawhata catchment extent inferred from terrain analysis

The drainage network is central to the environmental issues currently facing the catchment, acting both to generate sediment loading through periodic inundation of cultivated land, and to transport mobilised sediment and nutrients downstream. Constraints in the network mean that the scheme is frequently under capacity. Under certain rainfall conditions, drainage channels may overtop, creating uncontrolled surface flows which can mobilise sediment and nutrients from cropping surfaces and deliver these to the network, ultimately contributing to the poor water quality in Lake Horowhenua. Sediment deposition within the network may further reduce conveyance capacity, adding to network inefficiencies.

Additional surface flows from higher in the catchment, as well as road runoff and urban stormwater inputs, add to the demands on the network. Nutrient-laden groundwater is also intercepted by the network and discharged to the lake via surface flow.

[1] No definitive catchment extent is known to exist. The extent shown in Figure 1 has been derived from a 1 m DEM.

A number of projects over the past two decades have sought to understand and address the issues of sediment and nutrient mobilisation on a case-by-case basis. However, no co-ordinated, catchment-scale planning process that examines the relationship between the drainage network, sediment and nutrient transport, and groundwater movement has yet been undertaken. This 'master-planning' approach is the focus of this project.

1.2 Project scope

The objective of this project is to develop an integrated sediment, nutrient, and drainage management plan for the Arawhata catchment. The plan is aimed at reducing the impacts of horticultural activity on local receiving environments by minimising sediment and nutrient loss from cropping surfaces and capturing sediment and nutrients where these do become mobilised. This is to be achieved through a combination of land management practices, modifications to the drainage network, and the implementation of engineered interventions on paddocks and within the network.

The scope recognises the inter-related nature of the issues facing the catchment and, consequently, the integrated nature of the responses that are required to address these issues.

The project scope includes the following items:

- Review existing reports and monitoring data to understand catchment issues and previous actions undertaken.
- Define drainage, sediment, and nutrient issues in the catchment, and identify opportunities for addressing defined issues.
- Engage with landowners to understand local concerns about network performance and ideas for mitigation.
- Develop management options to address identified issues and evaluate the options according to expected performance.
- Recommend specific actions for implementation throughout the catchment based on evaluation scores.
- Develop a strategy for implementing the recommended actions, including mapping of potential option locations and high-level cost estimates for these.

We note that a complementary wetland concept design project is being undertaken by Jacobs in the lower catchment. The Jacobs project has progressed along a different timescale and therefore is not yet integrated with this project report.

1.3 Report terminology

Specific terminology is used throughout this report to describe the characteristics of the drainage system, sediment, and nutrients in the catchment. These characteristics, including sediment particle sizes, nutrient constituents and transport pathways, and rainfall recurrence intervals, affect the nature of the issues in the catchment and the type of management responses required.

1.3.1 Sediment

The mobilisation, transport, and capture of sediment in the catchment are affected by the grain size distribution of entrained particles. Grain size analysis undertaken on a single sample from the water column in the Arawhata Stream in 2014 indicates a generally fine composition with approximately 90% of the sample occupying the medium silt to clay particle size range.

1.3.2 Nitrogen

Nitrogen comprises nitrate, nitrite, ammoniacal nitrogen, and organic nitrogen. The proportion of each of these constituents influences the dominant transport pathways to the receiving environment and the type of interventions required for their removal from runoff and groundwater. Nitrogen in Arawhata drainage water is predominantly nitrate (over 90%), with concentrations well in excess of One Plan targets (**Section 2.3.2**). Nitrate is water soluble and so tends to leach through the soil profile into groundwater, emerging to surface water in springs and seeps, or as runoff when soils are saturated. Nitrate load reduction in waterways requires preventative management at the soil surface or interception of nitrate-laden drainage water in well-designed denitrifying wetlands.

1.3.3 Phosphorus

Phosphorus comprises particulate phosphorus and dissolved reactive phosphorus. The majority of the phosphorus load (approximately 75%) in the Arawhata Stream is in the form of particulate phosphorus bound to sediment particles. Importantly, approximately 25% of the phosphorus load in the Arawhata Stream is in the form of dissolved reactive phosphorus (DRP). Because DRP is soluble and leaches through the soil profile like nitrate, it cannot be removed by sediment capture methods. It is instead best managed preventatively at the soil surface or in a wetland where it needs to be taken up by wetland vegetation.

1.3.4 Drainage

The main channels that comprise the drainage network run either parallel to (generally orientated SE to NW) or perpendicular to (generally orientated SW to NE) the prevailing contour (**Figure 5**). These drains are referred to in this report as cross-slope and down-slope channels, respectively. The drainage network responds differently to flows of varying magnitude that relate to rainfall frequency of recurrence. Management responses must similarly reflect these different magnitudes. The following design rainfall annual exceedance probabilities (AEP) are used in this report to distinguish different magnitude events:

- **Frequent rainfall** – 'Everyday' rainfall up to the 50% AEP event.
- **Infrequent rainfall** – Up to the 5% AEP event (taken to be the intended network level of service).
- **Extreme rainfall** – Greater than the 5% AEP event and generally up to the 1% AEP event.

1.3.5 Catchment scale

Catchment issues and proposed interventions are discussed according to the scale, or position, within the catchment at which they apply. The scale terms used are:

- **On-paddock** – Refers to the cropping surface itself, as well as the associated headlands and other non-productive parts of the paddock within the boundary.
- **In-network** – Refers to the open channels and culverts that make up the drainage network itself, as well as any devices that are offline to the network.
- **End-of-catchment** – Refers to the area downstream of the four main down-slope drains where all network flows converge prior to crossing Hokio Beach Road, bounded in the north-west by Arawhata Road, and referred to as 'Kane Farm'.

2 Literature and data review

A review of available reports and environmental monitoring data was undertaken to understand the wider project context and to identify the issues that continue to affect water quality in the catchment. This information covered drainage and flooding issues, sources of sediment and nutrients, mechanisms for sediment and nutrient mobilisation and transport, and groundwater behaviour in the catchment.

The full literature review is included as **Appendix D**. The review incorporates feedback from HRC in response to an initial draft. The main findings of the review that have influenced this project (in terms of developing management options) are summarised below.

2.1 Monitoring and spatial data

- Flow and water quality are monitored in the Arawhata Stream near the catchment outlet at Hokio Beach Road. Flow is measured continuously and various water quality parameters are measured monthly. This data provides information on the catchment as a whole.
- Mean daily flows from 2017-2020 are shown in **Figure 2**. Mean daily flow rates range from 46 L/s to 2,645 L/s over this period with an average of 219 L/s.

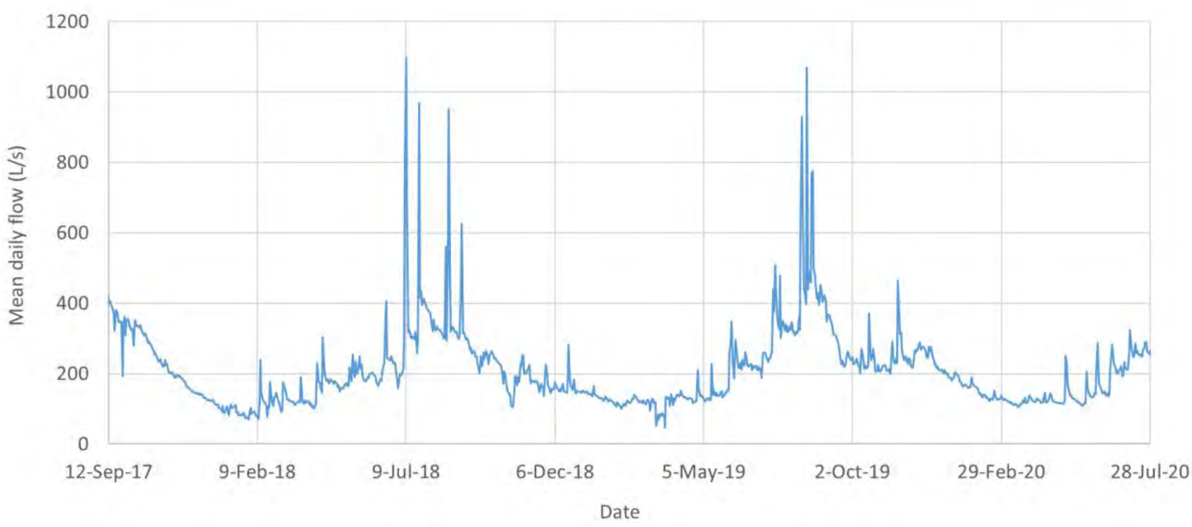

Figure 2. Mean daily flow in the Arawhata Stream at Hokio Beach Road (2017-2020)

- Finer-scale patterns of flow and sediment and nutrient distribution within the catchment are less well understood in quantitative terms. This affects the ability to target mitigation measures at specific 'hotspots' and puts the emphasis on large, end-of-catchment interventions.
- One-off flow gauging and nutrient sampling was undertaken at multiple sites throughout the catchment during a single rainfall event in August 2019. This information provides an indication of the spatial variability in channel flows and nutrient concentrations. **Figure 3** shows the TP concentration as an example of the data collected.

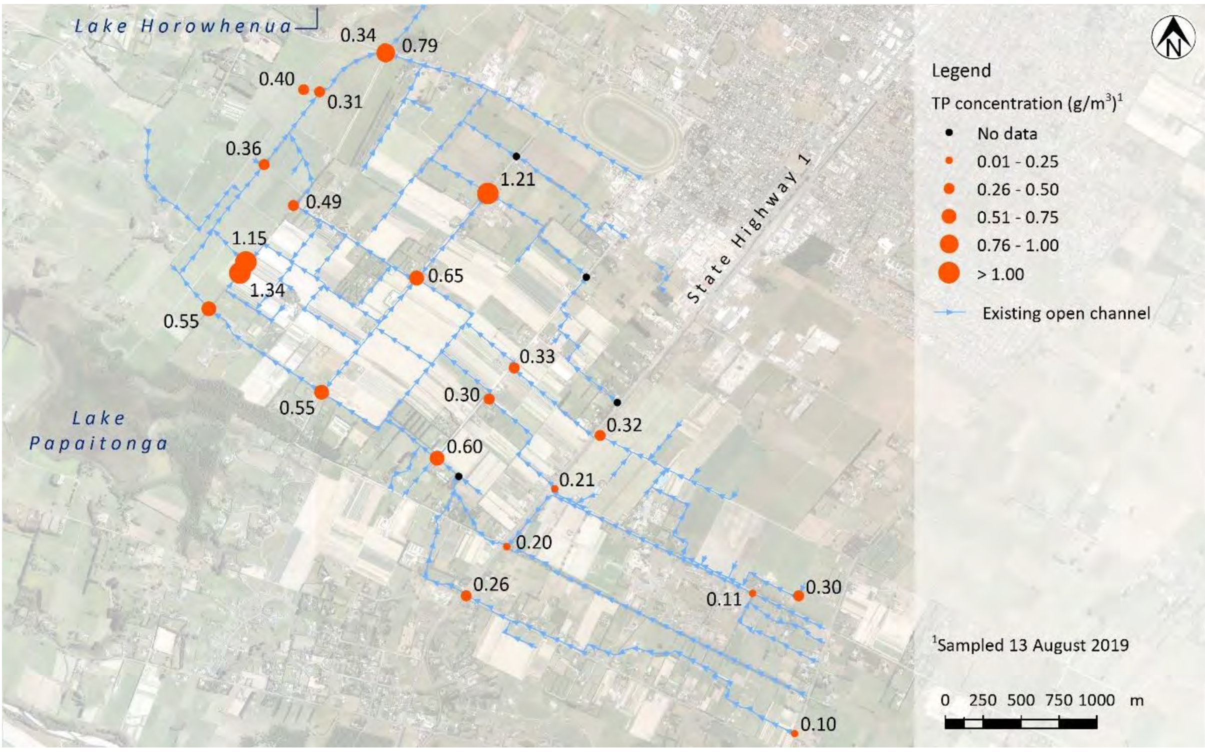

Figure 3. Observed TP concentrations during one-off sampling (13 August 2019)

- A high-resolution digital elevation model (DEM) created from LiDAR collected by Horowhenua District Council covers the catchment extent. The DEM can be used to understand patterns of surface flow and accumulation which may inform the placement and sizing of mitigation measures.
- A survey was conducted of the drainage network in 2014. This provides valuable information on network geometry and culvert specifications that can support assessments of network performance.

2.2 Drainage network

- The drainage network was originally developed as a water race and as such was not designed specifically to manage runoff from the catchment.
- Network constraints and alignment issues result in periodic overtopping of channels during high flow periods (anecdotally 2-3 times per year). Resultant surface flows can scour sediment and associated nutrients from cropping land for transport downstream.
- Channel alignment, cross-sections, and invert levels were recorded in a 2014 network survey. The survey defined 38,000 m of channel and 215 culverts. Additional unsurveyed channels recorded by HRC bring the total documented network length to 46,100 m.
- An ongoing programme of network refurbishment by HRC is addressing known network capacity issues. The network layout and refurbishment status are shown in **Figure 4** and **Appendix A2**.

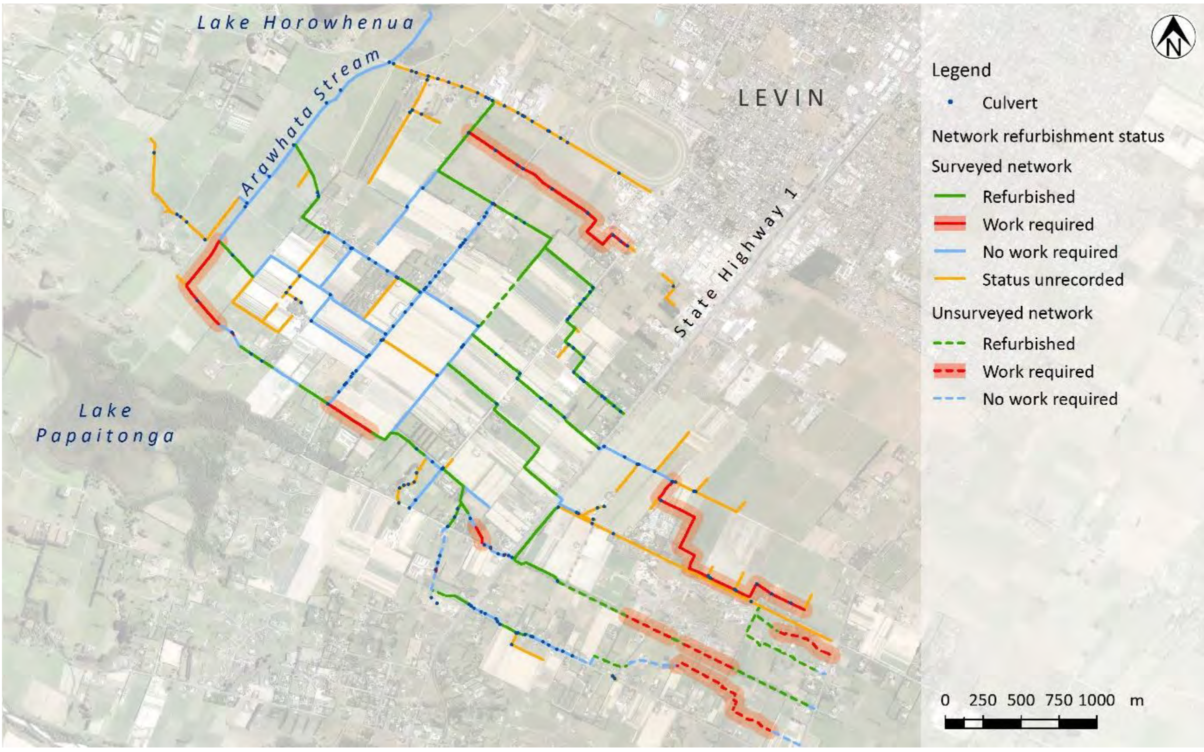

Figure 4. Arawhata drainage network and refurbishment status (as at February 2019)

- The catchment extent draining to different parts of the network is not fully understood due to uncertainty around the presence or absence of culverts beneath some roads, particularly state highways 1 and 57. This uncertainty affects the accuracy of sub-catchment definition and therefore estimates of peak flow rates for assessing channel capacity.
- Channel grades are generally low and vary according to drain orientation (**Figure 5**). The steeper down-slope channels (i.e. perpendicular to the contour) generally range from 0.5% to 1.5%. The flatter cross-slope channels are generally less than 0.5%.
- All channels except the main Arawhata Stream section are ephemeral (dry outside of infrequent rainfall events). This affects the type of interventions that can be implemented in different parts of the catchment.
- Flow direction in parts of the network is ambiguous due to flat grades and closed channel loops and may vary in response to different magnitude flow events.
- A high degree of surface water-groundwater connectivity exists in the lower catchment, with all outflow from the groundwater catchment thought to enter the lake via surface flow, including the Arawhata Stream.
- Routes of overland flow into the drainage network were extracted from a digital elevation model (DEM) provided by HRC based on 2013 LiDAR data. Overland flow paths can be used to delineate sub-catchments that drain to each of the main down-slope network drains, subject to the culvert uncertainty noted above (**Figure 5**).
- A hydraulic model of the system is required to fully understand the effect of network constraints on drainage performance and to evaluate engineered responses to these constraints.

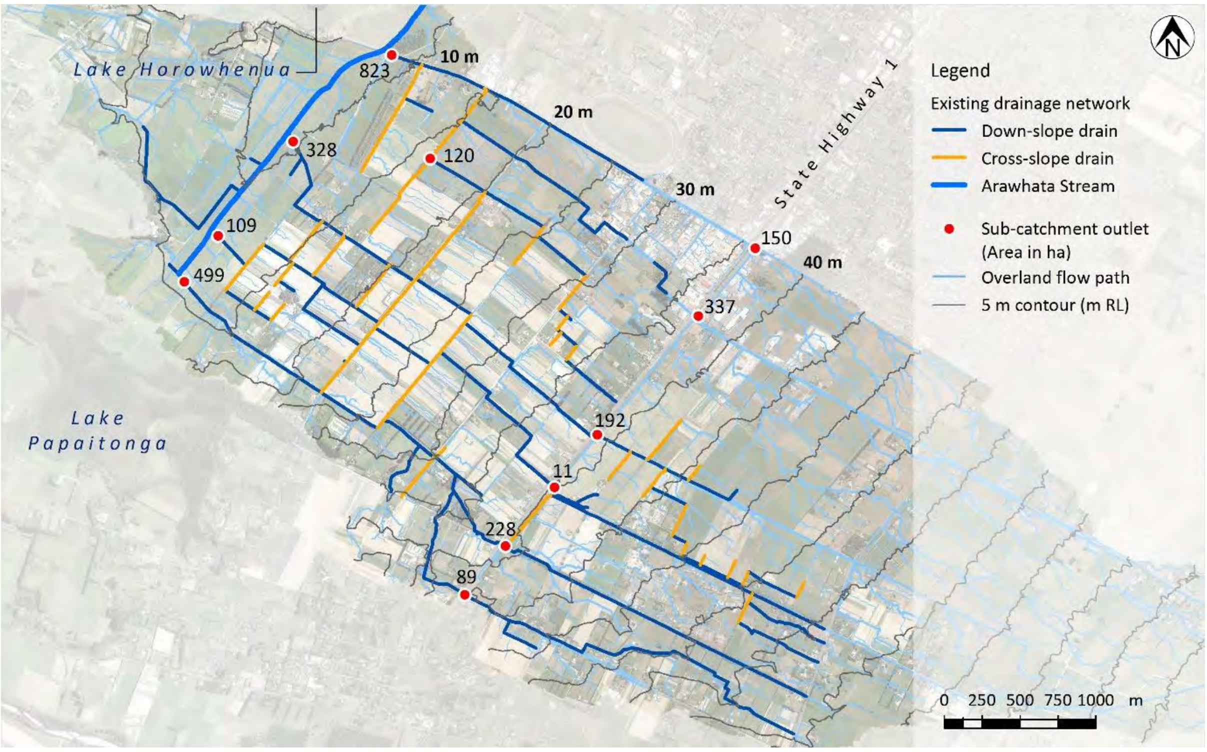

Figure 5. Drain orientation and inferred sub-catchment areas at key points on the drainage network

2.3 Surface water quality

2.3.1 Sediment

- The Arawhata Stream is acknowledged as the largest contributor of sediment to Lake Horowhenua, and vegetable cropping is the primary source of sediment in the catchment.
- Sediment enters the drainage network via three main pathways: in runoff from direct rainfall onto the cropping surface, in flood flows that scour paddocks when network capacity is exceeded, and through vegetable and vehicle washing operations at the processing facilities.
- Sampled sediment from the Arawhata Stream is at the fine end of the spectrum, mostly within the medium silt to clay particle size range. Particle size diameters from a single sample ranged from 0.1 µm to 100 µm, with a mean diameter of approximately 10 µm, i.e. very fine silt.
- Monthly State of the Environment (SoE) samples in the Arawhata Stream at Hokio Beach Road show total suspended solids (TSS) concentrations ranging from <3 g/m^3 to 318 g/m^3 with a mean of 23 g/m^3 (2016-2019). Event-based hourly samples within the monitoring period show concentrations as high as 3,920 g/m^3 (**Figure 6**).
- One-off sampling at multiple sites on the drainage network during a single rainfall event on 13 August 2019 show TSS concentrations to range from 6 g/m^3 to 161 g/m^3 with a mean of 51 g/m^3.

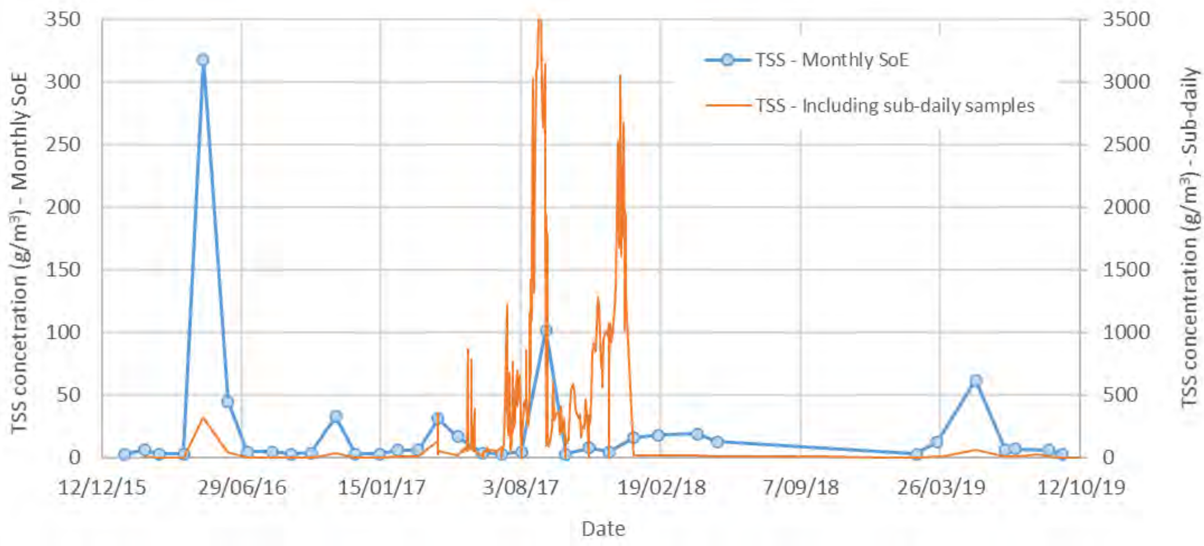

Figure 6. Monthly SoE and sub-daily TSS concentrations at Hokio Beach Road (note different y-axes)

2.3.2 Nitrogen

- The Arawhata Stream is the largest contributor of nitrogen to Lake Horowhenua of the surface tributaries. Vegetable cropping and intensive dairy farming are the primary sources of nitrogen in the catchment.
- Nitrogen enters the system through surface runoff and leaching to groundwater. The relative contributions of these two pathways, and of cropping versus dairy farming, are not currently known.
- Monthly SoE monitoring at Hokio Beach Road shows total nitrogen (TN) concentrations ranging from 3.6 g/m^3 to 13.8 g/m^3 with a mean of 10.3 g/m^3 (**Figure 7**). The mean proportion of TN present as nitrate over the monitoring period is 96% (some values shown as greater than 100% due to reported nitrate concentrations exceeding TN concentrations).

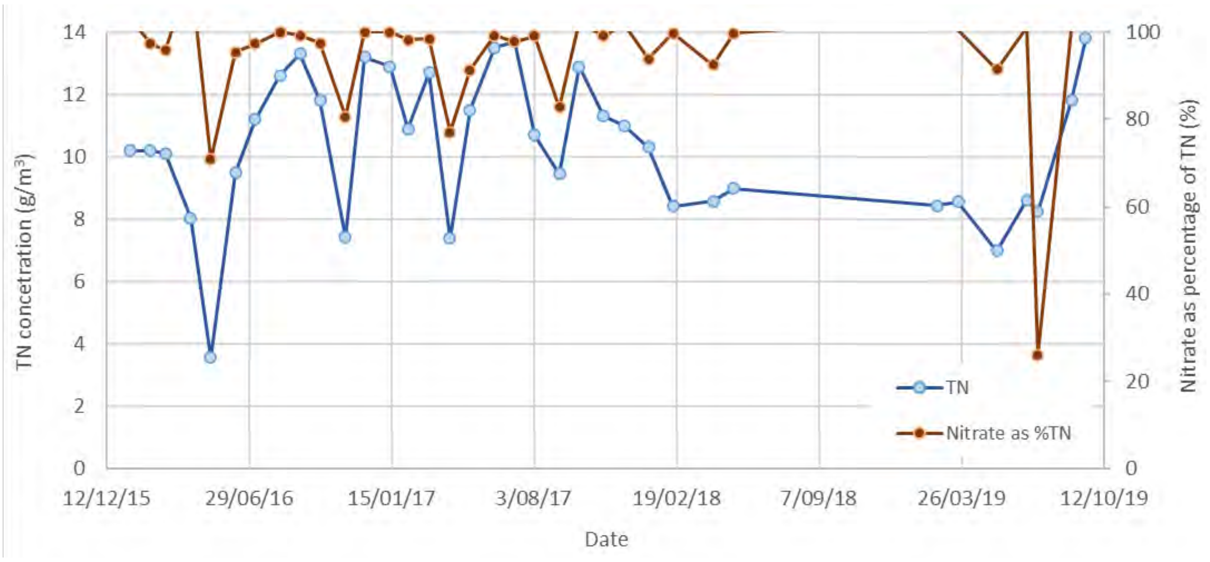

Figure 7. TN concentration and the proportion of TN present as nitrate at Hokio Beach Road

- The mean monthly nitrate concentration of 9.9 g/m^3 greatly exceeds the One Plan target of 0.167 g/m^3.
- Groundwater has a high nitrate concentration and is the dominant source of nitrogen to Lake Horowhenua as a whole.
- Groundwater monitoring from 1995-2016 shows nitrate concentrations across the catchment to range from 0.005 g/m^3 to 23.0 g/m^3 with a mean of 5.4 g/m^3.
- The multi-site sampling shows a range of nitrogen concentrations from 1.2 g/m^3 to 12.3 g/m^3 with a mean of 3.7 g/m^3. The proportion of nitrogen as nitrate across all sites is 64%.

2.3.3 Phosphorus

- It is understood that the largest contributor of phosphorus to Lake Horowhenua is associated with recirculation of phosphorous from existing lake bed sediment.
- Of the surface flows into Lake Horowhenua, the Arawhata Stream is the largest contributor of phosphorus to the lake.
- Monthly SoE monitoring in the Arawhata Stream at Hokio Beach Road shows total phosphorus (TP) concentrations ranging from 0.02 g/m^3 to 0.62 g/m^3 with a mean of 0.12 g/m^3. A high of 2.78 g/m^3 is reported when event-based sub-daily records are included.
- The one-off multi-site sampling shows a range of TP concentrations from 0.10 g/m^3 to 1.34 g/m^3 with a mean of 0.49 g/m^3.
- TP is closely related to TSS in the catchment (**Figure 8**). This implies that sediment-based treatment systems will likely be effective against phosphorus removal. This assumption forms the basis for the scoring of management options in **Section 5.3**.

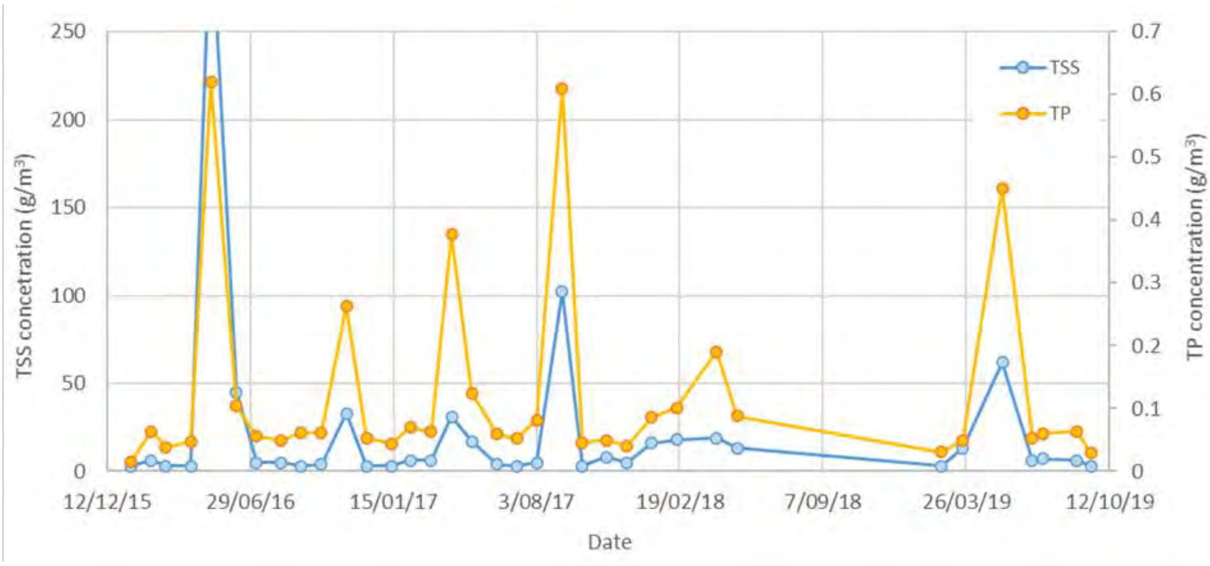

Figure 8. Monthly SoE concentrations for TSS and TP at Hokio Beach Road

- Monthly dissolved reactive phosphorus (DRP) concentrations range from 0.01 g/m^3 to 0.11 g/m^3 at Hokio Beach Road and are as high as 0.23 g/m^3 in the sub-daily record. The DRP fraction shows an inverse relationship with the TP (and therefore TSS) concentration, i.e. the percentage of DRP is higher during periods of lower TP and TSS (Figure 9).
- Importantly, the proportion of TP present as DRP is relatively high, averaging approximately 25% for both Hokio Beach Road and the multi-site samples. This indicates a need for targeted management in the form of vegetated treatment systems to address this.

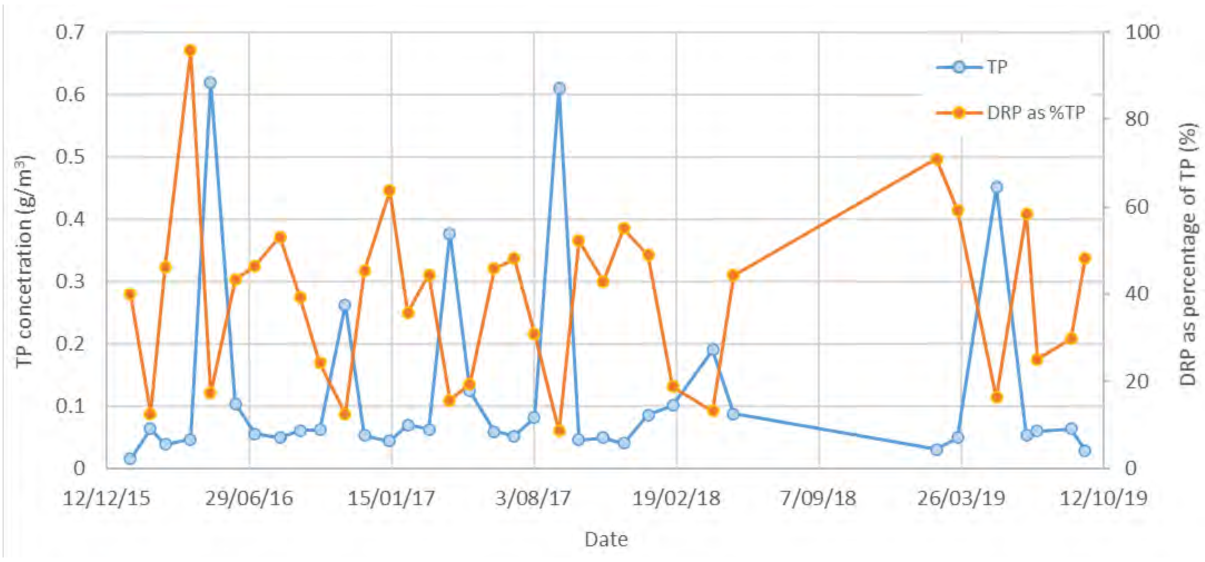

Figure 9. Monthly SoE concentrations for TP and DRP as a proportion of TP at Hokio Beach Road

2.4 Management actions

Based on the literature review, a number of actions have been carried out or investigated in addition to the network refurbishment work being carried out by HRC to address issues in the catchment.

- Two of 15 actions proposed under the 2014 Lake Horowhenua Accord Action Plan that are directly relevant to the Arawhata Stream have been completed: the development of drainage and erosion management plans (DEMPs) for several of the cropping farms, and the construction of a sediment trap at the lower end of the catchment. The remaining 13 actions pertain specifically to Lake Horowhenua rather than the Arawhata catchment specifically.
- The DEMPs used modelling to assess erosion risk on individual farms and described actions required to manage drainage and reduce sediment loss to waterways. Several of the recommended actions have been carried out by farmers, with anecdotally positive outcomes.
- An offline sediment trap designed by HRC has been constructed at the downstream end of the catchment (**Appendix A7**). The trap specifically targets 'larger' particles mobilised during extreme events. 'Finer' sediment associated with normal channel flows is bypassed directly to Lake Horowhenua. This distinction is important because particulate phosphorus is closely associated with finer sediment.
- A concept design for a denitrifying wetland is currently being prepared for the 'Kane Farm' property in the lower catchment to treat whole-of-catchment flows.
- Bioreactors have been proposed as a nitrate management measure. The specific location for bioreactors in the catchment depends on detailed knowledge of nitrate 'hotspots'.

2.5 Considerations for future actions

A number of considerations emerged from the literature review in relation to the implementation of future drainage and water quality actions in the catchment. These include:

- Future interventions need to be tailored to the particular characteristics and distribution of target contaminants. As noted in **Section 2.1**, much of the detailed information does not exist which increases the uncertainty of outcomes of proposed interventions.
- Knowledge of spatial variability is particularly important for nitrate due to its solubility in water which means it cannot be captured by interventions that rely on physical settling alone.

- Sediment and nutrient capture is most effectively achieved using distributed devices located close to the contaminant source where lower runoff velocities and volumes permit sufficient residence times for settling.
- Distributed wetlands may not be viable due to intermittent flow in the network being unable to sustain plant communities. Fewer larger wetlands in the lower catchment may be required.
- HRC are investigating opportunities for reconfiguring the HRC sediment trap so that it becomes engaged more frequently. The diversion of lower flows into the trap than those currently designed for can be expected to capture a higher proportion of fine sediment and associated phosphorus than is currently the case.
- The efficacy of bioreactors depends on targeting nitrogen hotspots but these are not well understood. High sediment loading may also cause bioreactors to frequently become clogged.
- SRPs have been proven to be highly effective at capturing sediment in horticultural land but have been noted as less suitable in the Arawhata catchment due to relatively flat grades. This concern is not considered to be valid catchment-wide but we acknowledge that SRPs may not be suitable everywhere.
- Fine sediment requires large devices to provide sufficient residence time for particle settlement. This has a correspondingly high land area cost.

3 Interpretation of issues in the catchment

The nature and location of drainage, sediment, and nutrient issues in the catchment were identified from the literature review, consultation with landowners, and discussions with HRC engineering staff. Further issues were inferred from an analysis of the drainage network survey and the DEM. A landowner engagement session was held at Woodhaven Gardens on 5 August 2020 to gather information on known issues directly from farmers[2].

This section provides our interpretation of the information available at the time of writing.

3.1 Drainage issues

3.1.1 Channel capacity

Inadequate capacity in the drainage network is understood to be a primary driver of flooding and sediment generation in the catchment. A 5% AEP level of service for the network was identified in the literature review. Future network upgrades should aspire to meet this standard.

Overtopping of channels has been observed during periods of high flow because of undersized, misaligned, or 'absent' channels and culverts. The movement of concentrated flows across the cropping surface from adjacent properties and roads was described as an important issue by Woodhaven Gardens during the landowner engagement session.

Figure 10 shows the approximate path of uncontrolled surface flows within Woodhaven Gardens observed during heavy rainfall in the winter of 2019.

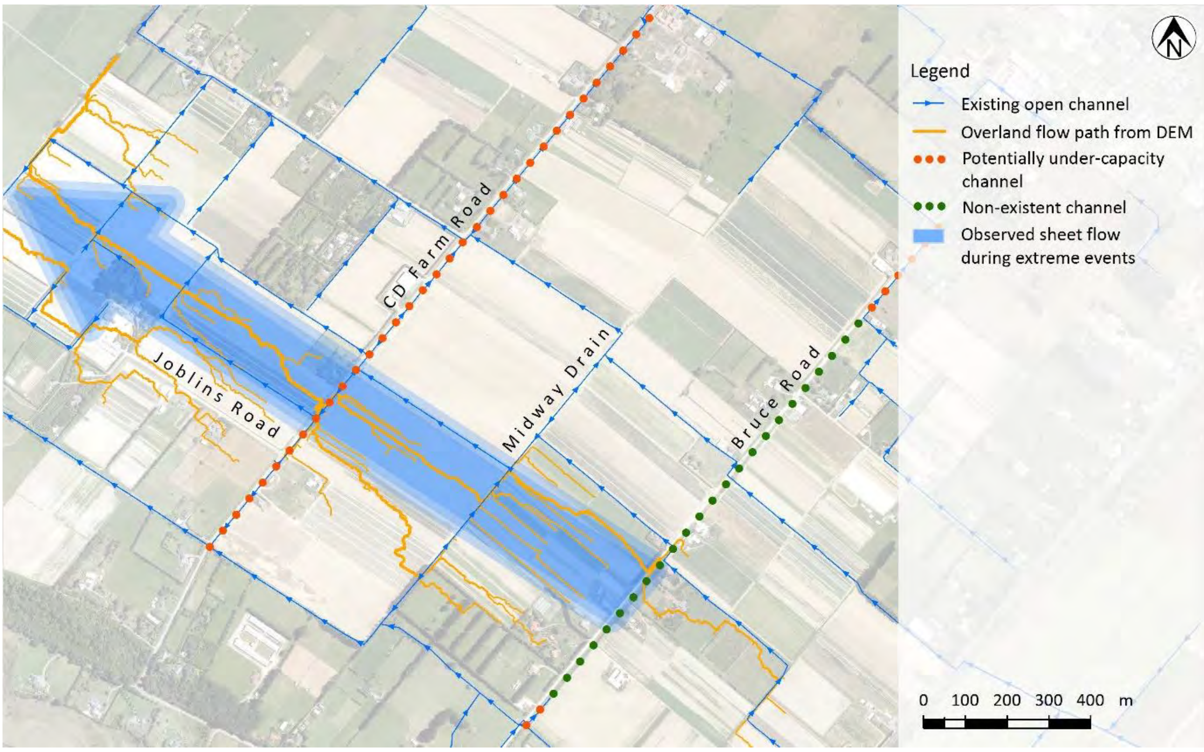

Figure 10. Indicative path of overland flow within Woodhaven Gardens

[2] Session attended by Jay Clarke and John Clarke (Woodhaven Gardens), Travis Sue (BS Young & Co), Staci Boyte, Ella Whale, and John Foxall (HRC), and Reuben Ferguson (T+T). Chris Pescini (Pescini Brothers) conveyed issues by telephone.

Landowners (Jay Clarke, pers. comm.) attributed this overland flow event to:

- The limited channel capacity on the CD Farm Road cross-slope drain
- The absence of a cross-slope drain on Bruce Road
- Overall lack of ability to intercept surface flows from higher in the catchment
- The inability of the connecting down-slope drains to convey accumulated flows downstream without over-topping

The Midway drain (between CD Farm Road and Bruce Road) is also understood to be under capacity (Paul Arcus, pers. comm.).

Out-of-channel flows are understood from the landowners at Woodhaven to occur 2-3 times per year, with the events of the scale described above and illustrated in **Figure 10** occurring annually. The observed surface flows described by the landowners are supported by overland flow analysis from the DEM, which shows concentrated runoff between the existing down-slope channels when channel function is not accounted for (**Figure 10**). This pattern suggests that the existing channel positions may not be ideally positioned for efficient collection of surface runoff.

Uncontrolled runoff from State Highway 1 is also believed by the landowners to contribute to the observed surface flows at Woodhaven Gardens. The flow path analysis indicates that similar patterns of surface flow may also occur on the cropland to the north-east of the Woodhaven flow.

Channel capacity may be constrained by cross-sectional area, vegetation growth, or network discontinuities (**Figure 11**). Where culvert upgrades have been implemented to level of service standard, the net benefit to the network may not change if the channels and culverts immediately downstream remain undersized or abrupt changes in grade or alignment exist (**Figure 12**).

Figure 11. Examples of drainage network constraints due to vegetation growth in channels

Figure 12. Undersized culverts and narrowing channel downstream of upgraded culvert (left). Upgraded culvert invert approximately 1.2 m below and perpendicular to downstream channel invert (right)

Existing channel capacity was evaluated at several example cross-sections in the mid-catchment with respect to the assumed level of service (i.e. 5% AEP design peak flow rate). The location and capacity status of assessed cross-sections is shown in **Figure 13**. The cross-sections are shown at a catchment scale in **Appendix A3**.

Peak flow rates were estimated using the Rational Method. Estimated times of concentration ranged from 35 minutes to 64 minutes. A uniform runoff co-efficient of 0.2 was assumed. Catchment areas were derived from the DEM[3]. The capacity assessments ignore any tailwater conditions that may exist due to downstream constraints, as well as any upstream attenuation effects.

[3]The peak flow estimates for the two cross-slope sections (XS109 and XS66) take account only of direct inflow from the immediate upstream paddock catchment and do not reflect flows that may enter from the connecting down-slope drains.

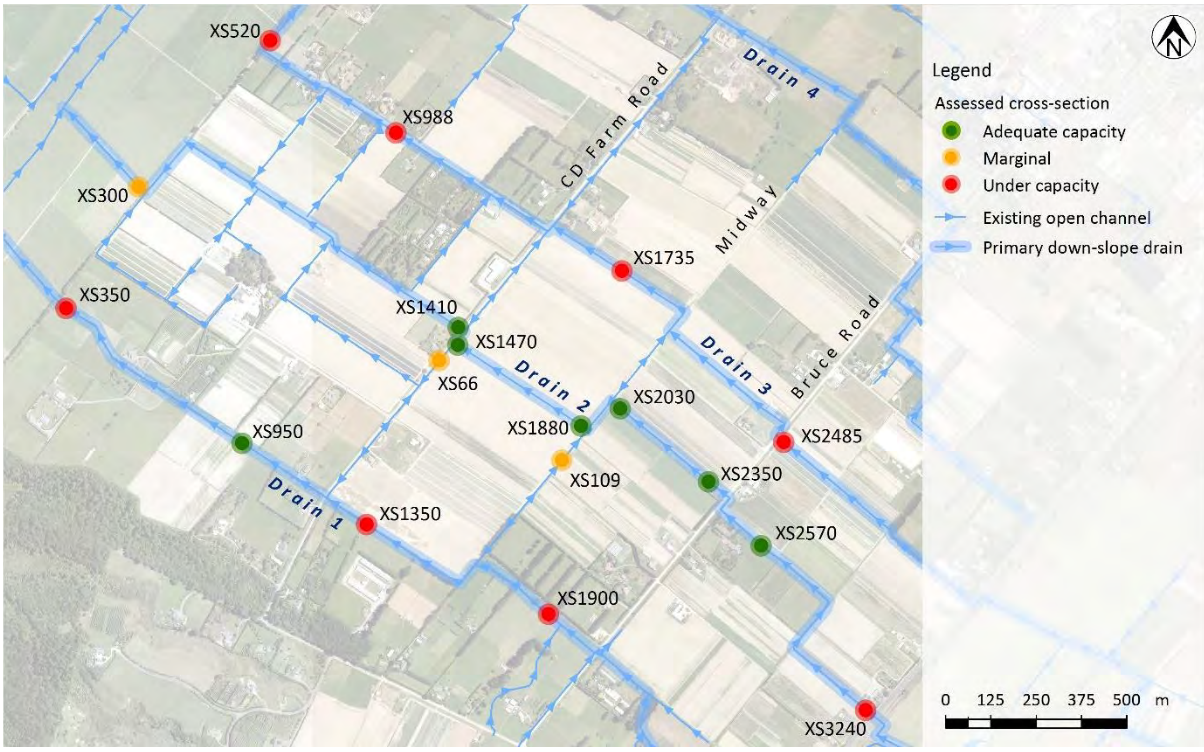

Figure 13. Location and capacity status of surveyed cross-sections assessed for level of service capacity

The theoretical maximum channel capacity is compared to the corresponding peak flow estimate for each cross-section considered in **Table 1**. The assessment indicates that the sections of Drain 2 are generally able to pass the 5% AEP peak flow (**Figure 13**), although some of these are marginal and within the range of runoff coefficient sensitivity.

In contrast, the two parallel sections of down-slope channel on Drain 1 and Drain 3 are shown to be significantly under capacity relative to the design flows tested. It is noted that the allocation of flows between cross-slope and down-slope channels may not be accurately accounted for in assumptions of catchment area. This is due to complexities in the network, such as closed loops and ambiguous grade, in which flow direction must be assumed. This observation further supports the value of detailed network modelling discussed in **Section 6.8**.

Table 1. Comparison of estimated 5% AEP peak flow rate to channel capacity at selected cross-sections

Cross-section ID	HRC Drain ID	Catchment area (ha)	Peak flow rate (m^3/s)	Channel capacity (m^3/s)	Capacity as % of flow	Capacity adequate?
XS1900	1	412.7	**7.45**	**1.69**	**23**	No
XS1350	1	436.6	**7.77**	**1.97**	**25**	No
XS950	1	453.5	**8.03**	**10.78**	**134**	Yes
XS350	1	480.8	**8.43**	**5.48**	**65**	No
XS3240	2	11.2	**0.29**	**0.24**	**84**	No
XS2570	2	18.2	**0.44**	**0.95**	**218**	Yes
XS2350	2	24.4	**0.57**	**2.18**	**380**	Yes
XS2030	2	24.5	**0.57**	**1.12**	**197**	Yes

XS1880	2	44.4	**1.02**	**1.29**	**127**	Yes
XS1470	2	45.9	**1.02**	**1.28**	**125**	Yes
XS1410	2	50.1	**1.12**	**5.41**	**484**	Yes
XS300	2	107.6	**2.22**	**2.31**	**104**	Marginal
XS2485	3	202.7	**4.04**	**0.55**	**14**	No
XS1735	3	246.3	**4.73**	**1.03**	**22**	No
XS988	3	283.0	**5.26**	**3.75**	**71**	No
XS520	3	299.4	**5.44**	**3.00**	**55**	No
XS109	30	8.1	**0.28**	**0.33**	**118**	Marginal
XS66	27	5.1	**0.17**	**0.17**	**101**	Marginal

The generally adequate capacity indicated in Drain 2 is clearly contradicted by landowner observation. The substantial lack of capacity indicated in Drains 1 and 3 may result in excess flows from these channels being redistributed towards Drain 2 via the cross-slope channels which, combined with additional surface flows, generate the overland flow path evident in **Figure 10**. Channel overtopping is therefore likely to be a function of tailwater conditions imposed by undersized culverts and other downstream constraints, as well as the inability of cross-slope drains to intercept surface flows and distribute these efficiently to the down-slope drains.

Channel alignment issues may further constrain network performance. The network is characterised by a large number of right-angled bends that limit the hydraulic efficiency of down-slope drains. Head losses associated with these junctions may contribute to observed overtopping during infrequent rainfall events and to scour at the junctions which generates sediment.

The proportional allocation of flows across the main down-slope channels can be inferred from gauging records taken during a rainfall event on 13 August 2019 (34 mm depth)[4]. The gauge records are mapped in **Figure 14**. It should be noted that the gauge records are around two orders of magnitude lower than the 5% AEP peak flows estimated in **Table 1**.

If we ignore the confounding influence of flow being recorded at different times, and therefore describing parts of the hydrograph, we can infer:

- **Figure 14** shows Drain 1 to carry the majority of the catchment flows to Arawhata Stream.
- Diminishing flow rates in the downstream direction in Drains 2 and 3 may indicate flow attenuation effects of culverts beneath the railway, State Highway 1, and Bruce Road.
- A loss of flow due to channel overtopping, or redistribution to the Midway and CD Farm Road cross-slope drains, may also account for this observation.

The uncertainty around contributing catchment areas and flow behaviour in the network limits the confidence with which specific interventions can be recommended. This uncertainty and low confidence can only be improved upon by constructing a hydraulic model of the drainage system so that system performance under various flow conditions and configurations can be evaluated.

[4] Flow observations were made over a 3-hour period across the sites and so reported flow rates may describe different parts of the hydrograph.

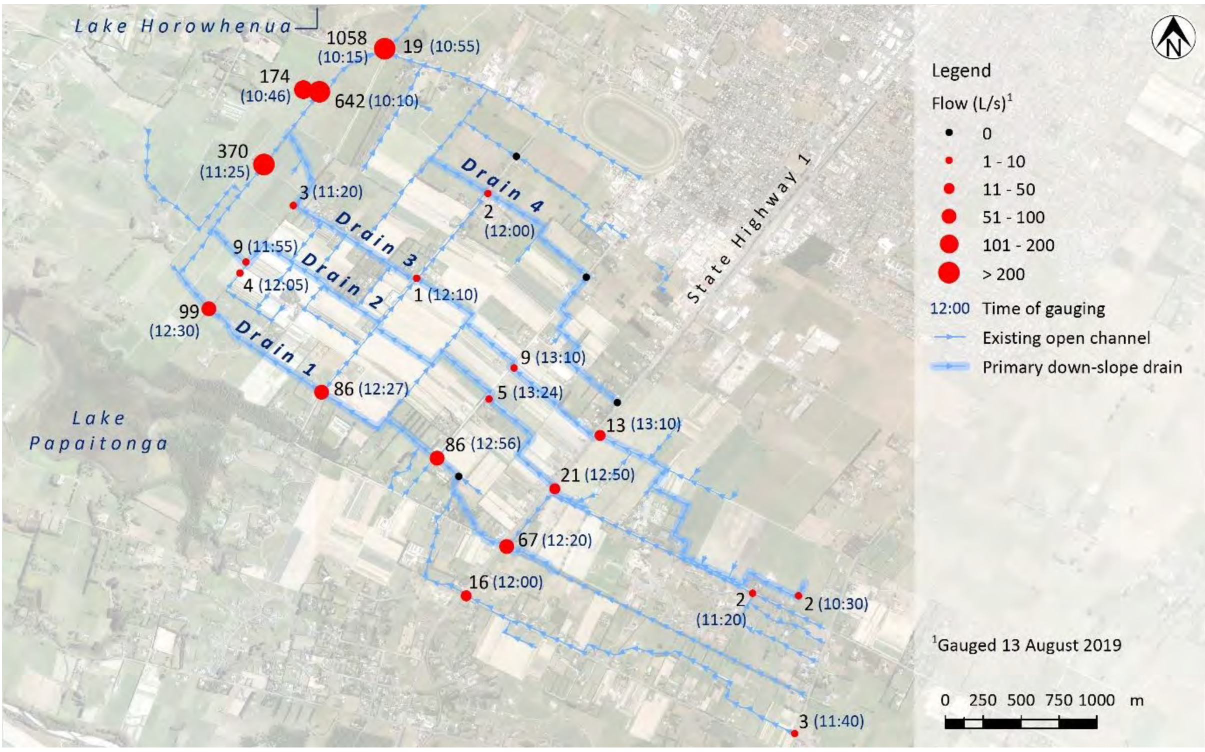

Figure 14. Observed channel flows during a 34 mm rainfall event on 13 August 2019

3.1.2 Culvert capacity

Undersized culverts have previously been identified for upgrade as part of HRC's ongoing network refurbishment programme (**Appendix A2**). Additional culverts that are potentially undersized can be inferred from the network survey based on the diameter sequence down the network. Where a sequence of culverts of progressively larger diameter in the downstream direction are interspersed with smaller culverts, the smaller culverts may represent a flow constriction. An example of this pattern is shown in **Figure 15**. Potentially undersized culverts at a catchment scale are shown in **Appendix A4**.

Of the 214 culverts recorded in the network survey, 40 were shown to be potentially undersized (some of which are already noted for upgrade by HRC). This excludes those culverts in the upper reaches of the network where a reduction in diameter is unlikely to significantly affect conveyance in the priority (mid-catchment) area.

This is a basic analysis only and does not take account of culvert slope, available headwater that drives capacity, or contributing catchment areas that drive peak flow rates. Detailed analysis of all culverts, preferably within a hydraulic model of the network, would be required to definitively identify culvert capacity issues.

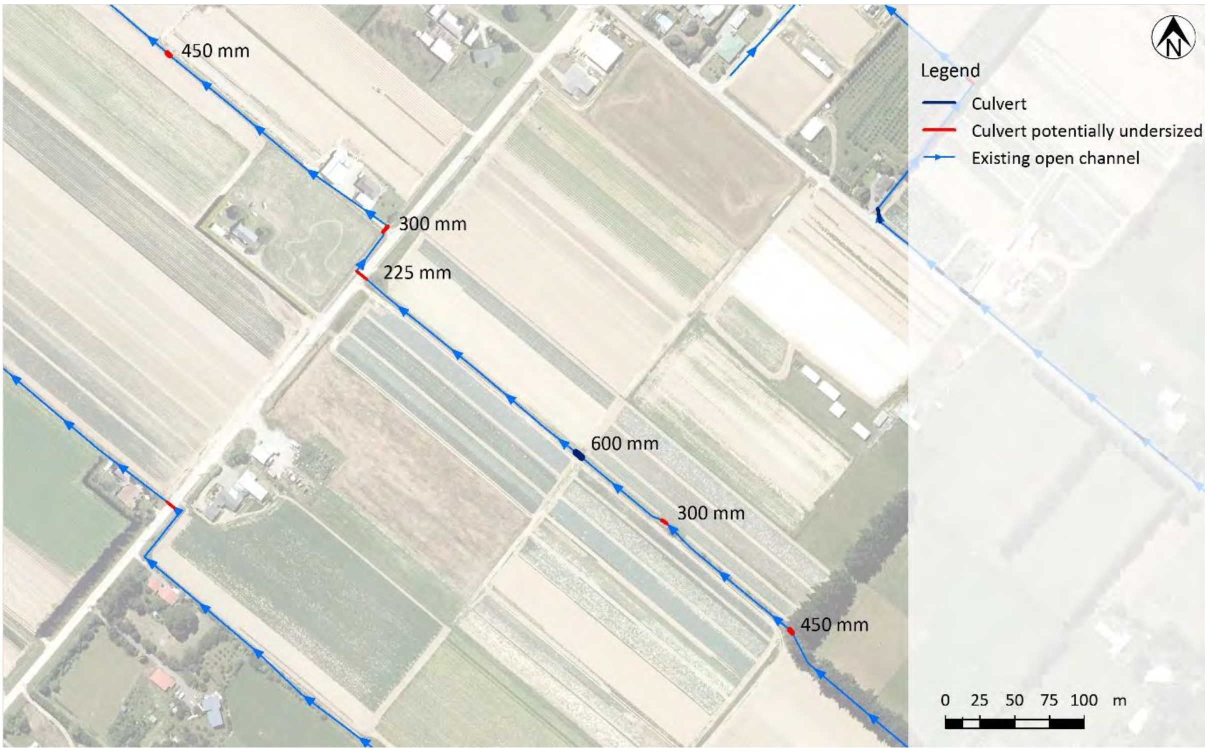

Figure 15. Example of decreasing culvert diameters representing potential hydraulic constraints in the network

3.1.3 Surface ponding

Surface flows from the upper catchment were reported during the consultation session to accumulate within the Pescini property against the railway embankment after heavy rainfall. An indicative ponding extent in this area, based on DEM analysis and excluding culvert function, is shown in **Figure 16**. Ponding has also been observed higher in the catchment against the Arapaepae Road embankment due to undersized culverts throttling flows, or non-existent culverts (Paul Arcus, pers. comm.). Surface ponding at a catchment scale is shown in **Appendix A5**.

Figure 16. Example of inferred maximum surface ponding against the railway embankment

3.2 Sediment issues

The cropping areas of the Arawhata catchment are reported to be the primary source of sediment to the Arawhata Stream which is itself the greatest contributor of sediment to Lake Horowhenua. As with nutrients, there is a lack of information on the spatial distribution of sediment, other than the one-off multi-site sampling.

The movement of sediment from crop paddocks to the drainage network occurs via three main pathways:

1. Direct rainfall onto the cropping surface during frequent rainfall events that generates localised runoff which mobilises sediment to the drainage network.
2. Concentrated surface flows that enter cropland from adjacent properties or the road reserve during infrequent and extreme rainfall events and mobilises sediment to the network.
3. Discharge to network from vegetable and vehicle washing facilities on a daily basis irrespective of rainfall conditions.

It is not known which of these mechanisms generates the largest sediment load to the network on a mean annual basis. The mean TSS concentration of 23 g/m^3 (refer **Section 2.3.1**) will include all three sources.

Vegetable-washing activity discharges water and sediment to the network on a fairly constant basis. Woodhaven, for example, has a six-day-a-week vegetable-washing operation that discharges up to 280 m^3/day from the Joblins Road site throughout the year (Jay Clarke pers. comm.). A tiered sequence of weirs are used to capture much of the discharged sediment close to source (**Figure 17**) which is periodically excavated and stockpiled for redistribution on the paddocks.

Additional wash water is understood from the landowner consultation session to enter the network south of Buller Road from the BS Young & Co. operation. Diffuse roadside discharge from a washing operation on Bruce Road was also observed during this session, where no drain currently exists to capture and convey these flows.

Figure 17. Captured sediment at discharge point from Woodhaven vegetable-washing facility

3.3 Nutrient issues

3.3.1 Nitrogen

Monitoring shows that nitrate concentrations in the Arawhata Stream vary greatly, and consistently exceed guideline values (**Section 2.3**). While this pattern describes the effects of land use activity in the catchment as a whole, the manner in which nitrogen is distributed throughout the catchment, in time and space, is not well understood.

Nitrogen is present in the catchment predominantly as soluble nitrate. It is therefore more likely to move through the soil profile for diffuse transfer to the drainage network rather than as surface runoff, and be unresponsive to settlement-based capture methods. The current lack of sub-catchment-scale monitoring data makes it difficult to target nitrogen 'hotspots' directly with appropriate treatment measures and instead places the emphasis on catch-all downstream measures.

3.3.2 Phosphorus

Phosphorus concentrations also exceed guideline values in the catchment. As with nitrogen, the spatial variability in phosphorus concentration throughout the catchment is not well understood. However, this is less significant than for nitrate due to the close association between particulate phosphorus and sediment and the likelihood of this being captured by sediment trapping devices whose functionality is less reliant on knowledge of specific hotspots.

A relatively high proportion of total phosphorus is apparent in the monitoring data as DRP. The solubility of this constituent means that it will not be removed by sediment control measures and will therefore require specific interventions.

3.4 Inter-relationship of the issues

The integrated nature of the management plan recognises that the issues noted above do not exist in isolation. Issues may interact with each other to compound the overall impact on water quality, as well as provide opportunities for multi-benefit outcomes. The development of options for managing catchment issues should therefore balance any competing objectives (negative relationships) as well as look to provide multi-functional outcomes (positive relationships) wherever possible.

3.4.1 Negative relationships

The two primary project objectives, i.e. improved drainage network performance and improved drainage water quality, require engineering solutions with potentially opposing velocity objectives. Improvements to hydraulic efficiency, that are intended to reduce channel overtopping, will often create increased flow velocity, whereas in-channel water quality measures to encourage settlement of suspended material rely on reduced (low) velocities. As such, measures to improve network performance and those to improve water quality should be spatially separated within the network.

Interventions targeted at one constituent may be impeded by the effects of other constituents where their mechanisms for capture differ. For example, structural interventions that target dissolved nutrients, such as bioreactors and wetlands for nitrate removal, may rapidly become blocked where their placement is subjected to elevated sediment loads in the network. Appropriate pre-treatment measures therefore need to be put in place. As such, all interventions need to be considered holistically, and long-term operational and maintenance issues need to be included in the design development stage.

3.4.2 Positive relationships

Positive relationships between issues also exist where the targeting of one project objective may be effective against another, or result in peripheral non-target benefits that sit outside immediate project objectives.

The association of particulate phosphorus with fine sediment particles, for example, means that interventions that target sediment are likely to also be effective against phosphorus. Interventions that create a low-velocity environment to encourage settlement of particles may also enable some soakage of soluble nitrate into the substrate. Similarly, flood detention measures that are intended to attenuate peak flow rates within the network may also provide an opportunity to capture sediment and allow soakage of detained flows. The realignment of channels to improve conveyance efficiency and reduce overtopping may also reduce channel scour and sediment generation within the channel itself where junction angles are eased.

Vegetated treatment systems that are effective in removing nutrients and fine sediment may also provide an inherent biodiversity component that emulates lost wetland and riparian environments in the catchment. It should be noted, however, that biodiversity considerations are secondary, and that habitat creation is not the focus of this piece of work. Shallow wetlands (and shallow sediment traps) can also reduce the loading of non-target constituents, including faecal bacteria such as *E. coli*, which monitoring data shows to be present (likely from dairy cattle in the lower catchment).

4 Opportunities for addressing issues

Opportunities for addressing the issues outlined in **Section 3** can be investigated where features of the existing network and catchment surface provide a suitable basis for engineered interventions. This approach provides a generalised guide to identifying the potential location and type of interventions given current limitations of specific data that would be required for more targeted interventions. Where preconditions for a particular management purpose exist, these features may be optimised to perform specific drainage and water quality improvement functions. The location and nature of these features can be inferred from the drainage network survey data and terrain information using hydraulic assessments and GIS methods.

4.1 Drainage management opportunities

The following network and surface features provide opportunities for improving drainage in the catchment through enhanced storage, distribution, and conveyance of flood flows. It is noted that several of these features may also support water quality improvements.

- **Surface depressions**: Natural ponding areas in the upper catchment can be formalised to provide flood detention or sediment capture during extreme events (e.g. **Figure 16**). Detention devices are dry outside of extreme rainfall so can continue to be used for productive purposes. Conversely, sediment traps maintain a standing water body so would not be suitable for ongoing productive use.
- **Channel grade**: Channel sections can be adapted to perform specific functions on the basis of existing or modified grade, cross-section, and velocity conditions. The network shows a general pattern of steeper down-slope drains and flatter cross-slope drains (**Figure 18**). Down-slope drains can be widened and benched as two-stage channels to improve hydraulic efficiency and sediment capture. The lower slope and lower velocity cross-slope drains can be widened to provide detention storage and may also be benched for sediment capture.

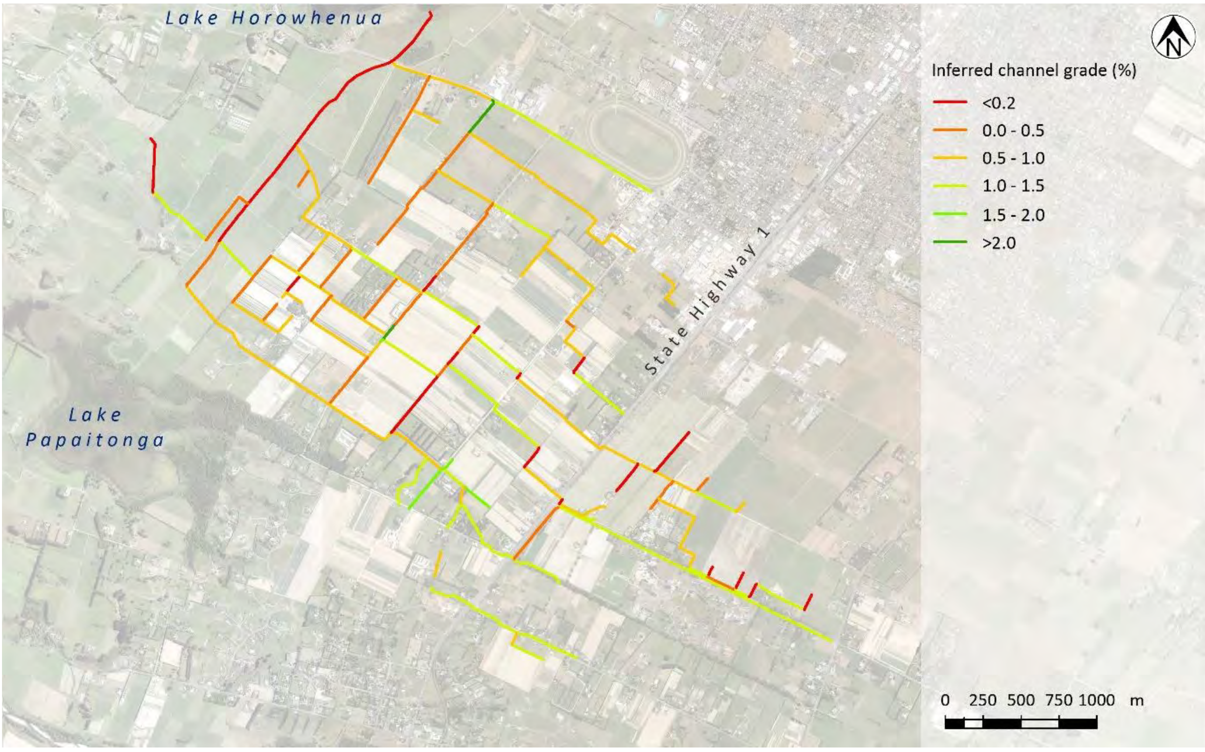

Figure 18. Channel grade derived from 2014 network survey invert levels

- **Channel alignment**: Down-slope channels can be realigned to reduce head losses and scour at junctions with cross-slope drains. Potential realignment options are shown in **Figure 19** and include:

1 Create new channels parallel to existing sections that connect directly with upstream and downstream channels. No net loss of productive land would result from this option but some loss or gain to individual land-owners can be expected.

2 Realign short sections of channel as required to reduce junction angles. While this option would reduce productive land, the 'dead space' created could be used to accommodate on-paddock or in-network runoff or sediment management devices.

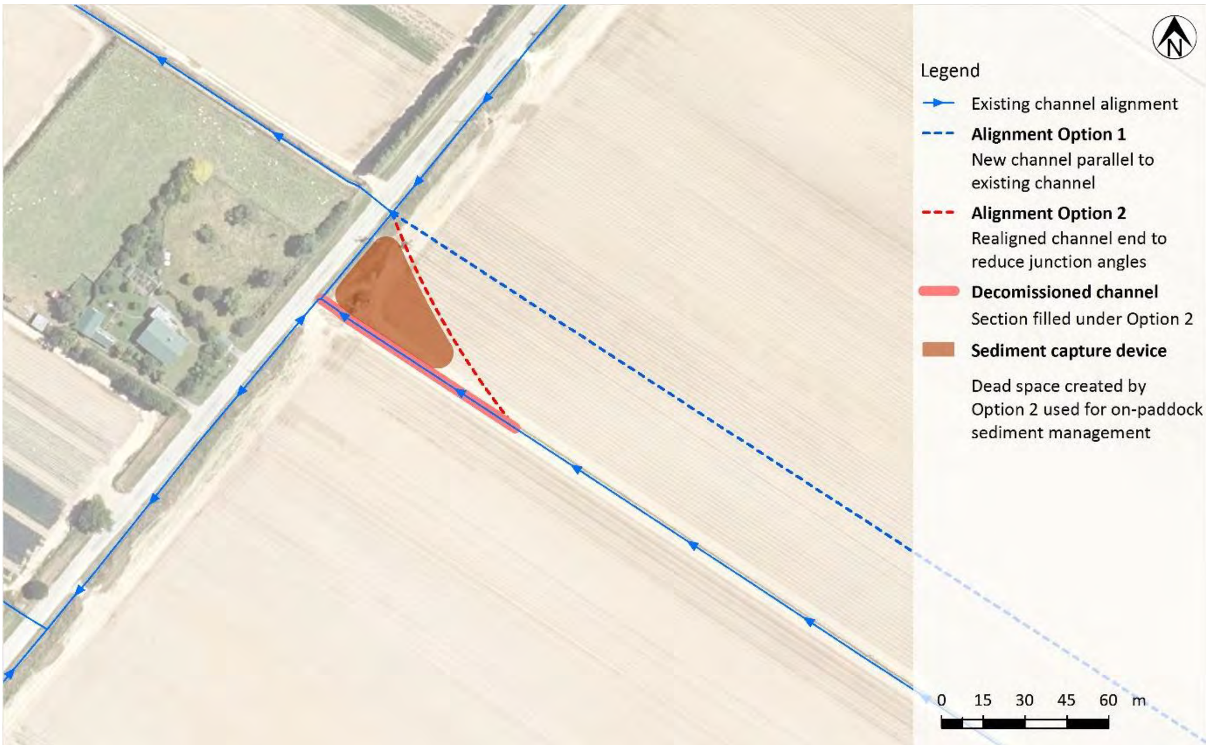

Figure 19. Potential options for channel realignment

- **Constriction points**: Natural stilling areas, such as sections of channel immediately upstream of undersized culverts in which flows are throttled, can be optimised to encourage sediment deposition for removal. Conversely, upgrading culverts to larger diameters allows greater flows to be passed and reduces erosion at the culvert outlet. Outlet erosion should be addressed through hand placement of rock to form an apron.

4.2 Sediment management opportunities

Most sediment management techniques rely on physical settlement of particles in a reduced velocity environment. For the Arawhata catchment, the primary opportunities for this lie in the construction of on-paddock sediment retention devices and modifications to the drainage channels. The optimum location for on-paddock devices can be identified through the GIS methods described in **Section 4.5.1** and illustrated in **Figure 21**.

As noted in **Section 4.1**, the benching of down-slope channels to create additional capacity at higher flow rates also reduces the velocity above the bench, allowing for the deposition of entrained sediment as flood flows recede. Additional opportunities for sediment capture include online sediment traps excavated directly into the bed of low-grade channels, and sediment forebays that are typically associated with constructed wetlands as a pre-treatment measure.

All sediment management devices will need regular maintenance (clean-out) in order to provide long-term benefits.

We note the potential use of flocculant as a complementary sediment (and phosphorus) management tool. While flocculant is not evaluated as a specific management option within the multi-criteria analysis framework (**Section 5**), it may have use as a supplementary measure in sediment retention devices. The specific type and dosage of flocculant would need to be considered within the context of each application. Consideration must also be given to the potential for overdosing and the risk posed to the Lake Horowhenua receiving environment of uncontrolled discharge.

4.3 Nitrogen management opportunities

The presence of soluble nitrate as the dominant form of nitrogen in the catchment means that settlement-based systems will be ineffective in its removal. Opportunities for managing nitrogen will therefore lie largely with vegetated treatment systems in the form of constructed wetlands.

Wetland performance is largely governed by water residence time which must be long enough to allow adequate exposure to denitrifying bacteria in anoxic soils and on plant biofilms. Two conditions for optimum residence time are the availability of a sufficiently large area to site a wetland, and a permanent source of water to sustain the wetland plant communities.

The ephemeral nature of flow in most of the drainage network precludes the placement of wetlands upstream of the main Arawhata Stream channel (**Figure 5**). This limits potential sites to the existing dairy farm at the lower end of the catchment ('Kane Farm') where all network flows converge and flow is perennial. The ability to intercept nitrate-laden groundwater in this location further supports this opportunity.

Further nitrate reduction may occur in sediment control devices where a portion of detained runoff is able to soak through the base of the device. While this removes nitrate from the runoff water, it may reappear in groundwater lower in the catchment.

4.4 Phosphorus management opportunities

Phosphorus exists predominantly in particulate form in the Arawhata catchment. This means that all opportunities for sediment capture, such as the two-stage channels and on-paddock retention systems noted in **Section 4.2**, can be expected to also be effective against phosphorus. Trials on vegetable growing land elsewhere in New Zealand have demonstrated this.

The DRP fraction of phosphorus in the catchment will not be captured in this way and exists in too high a proportion to be ignored. Soluble DRP is taken up by plants and algae so is most effectively managed in a wetland environment. While wetlands are not as effective against DRP as for nitrate removal, residence time is still the core criterion for DRP reduction, and the other conditions noted in **Section 4.3** apply equally to DRP.

Abundant plant cover is required to facilitate DRP reduction processes, but this must be harvested and removed periodically to prevent recirculation of phosphorus and subsequent export from the wetland. In keeping with all constructed interventions, maintenance is a critical component to ongoing performance.

4.5 Opportunity identification

4.5.1 Spatial analysis

The placement and physical specifications of potential management options can be informed by patterns of surface flow and accumulation which in turn can be defined from the DEM using spatial analytical techniques.

Overland flow paths (OLFPs) describe one-dimensional surface flow routes. They are created by 'burning' known channels, culverts, and urban stormwater pipes into the DEM to force surface flows to converge at the network. An example is shown in **Figure 20**. OLFPs at a catchment scale are shown in **Appendix A6**. OLFPs can be used to identify optimal channel alignments relative to existing channel positions on the basis of preferential flow patterns. Flow accumulation algorithms allow the catchment area to be defined at any point on the network.

Localised surface depressions can also be defined from the DEM and their geometry can be quantified to assess suitability for flood detention functions. The ponding shown in **Figure 16** can be further detailed as shown in **Figure 20**. At the finer scale of an individual paddock, flow paths can help guide the optimum placement of on-paddock sediment trapping interventions (**Figure 21**).

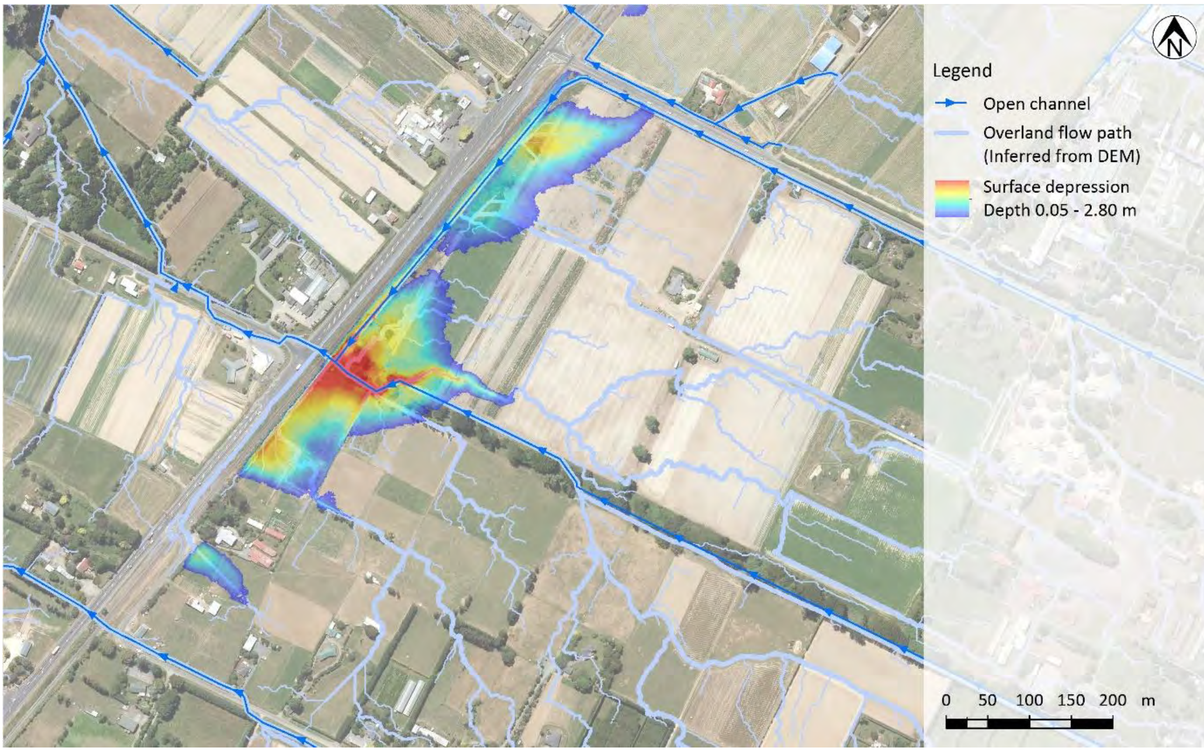

Figure 20. Use of overland flow paths and depressions to support placement and sizing of detention devices

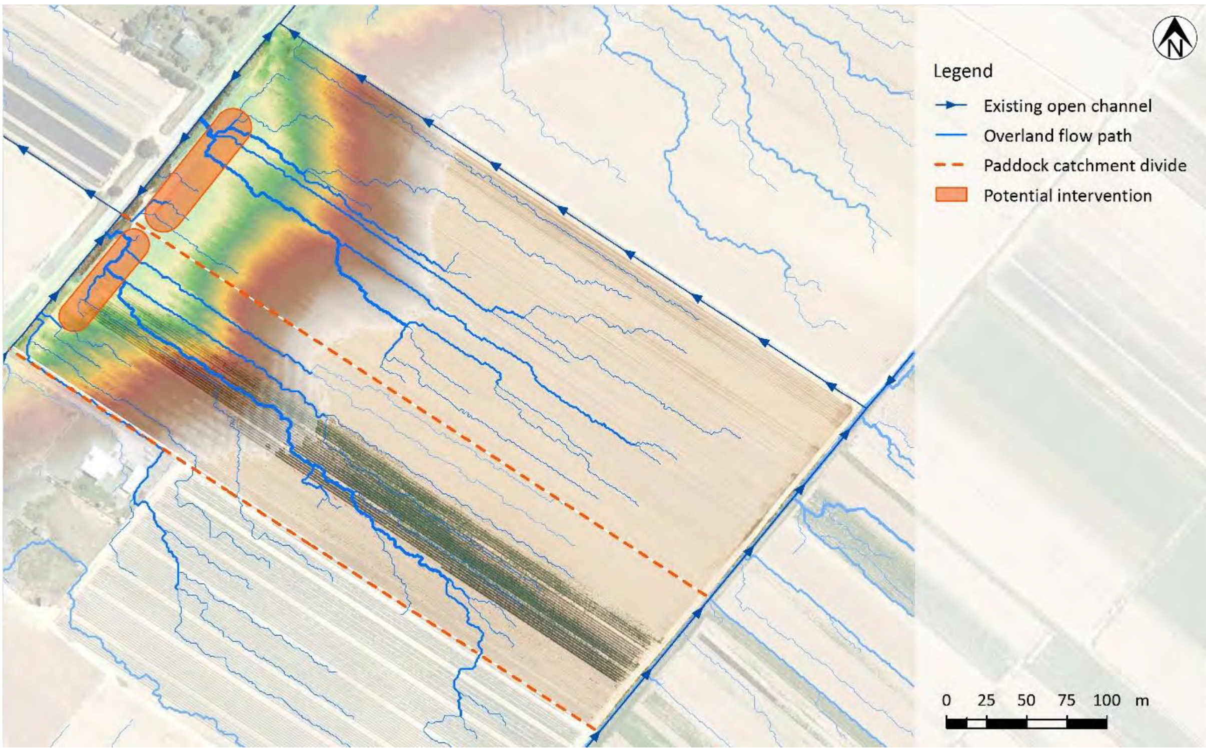

Figure 21. Use of overland flow paths to locate and size paddock-scale sediment retention devices.

4.5.2 Hydraulic assessment

Where sections of channel are shown to be under capacity, the cross-section required to pass the desired peak flow rate can be defined using a hydraulic assessment. In the Arawhata network, channel invert level and ground level are essentially fixed so potential cross-section changes are limited to varying the bed width, bench width, and side slope. Measures to increase drain capacity will therefore almost always translate to a loss of productive farmland.

Using XS1735 in Drain 3 as an example (shown in **Table 1** to be undersized), the current estimated top width of 2.2 m applied over the full 430 m length of the channel section equates to an area of 950 m^2. In order to pass the estimated 5% AEP design flow (4.73 m^3/s), it would be necessary to increase the bed width from 0.75 m to 4.5 m and flatten the side slopes to 1V:2H[5]. This gives a top width of 6.5 m and a corresponding channel area of 2,800 m^2, i.e. a loss of productive land of 1,850 m^2 compared to the existing channel footprint. This effect is shown spatially in **Figure 22**.

Lower frequency events were also considered to understand potential upgrade requirements for providing a higher level of service. For this purpose, the 1% AEP peak flow rate at XS1735 was estimated using the same assumptions used to derive the 5% AEP peak flow. A bed width of 6.2 m was identified as being required to pass the 1% AEP peak flow of 6.37 m^3/s (adopting the same channel depth and side slopes as above). This corresponds to a top width of 8.2 m, yielding a channel area of 3,530 m^2, i.e. a loss of productive land of 2,580 m^2 compared to the existing channel footprint and 730 m^2 compared to the concept 5% AEP channel footprint (**Figure 22**).

[5] Batter slope as a ratio of vertical (V) to horizontal (H) length.

Figure 22. Change in land area requirement for channels of variable bed width and side slope (Drain 3 XS1735)

Indicative cross-sections for the existing channel form and the 5% AEP and 1% AEP upgrade options presented in Figure 22 are shown relative to each other in **Figure 23**.

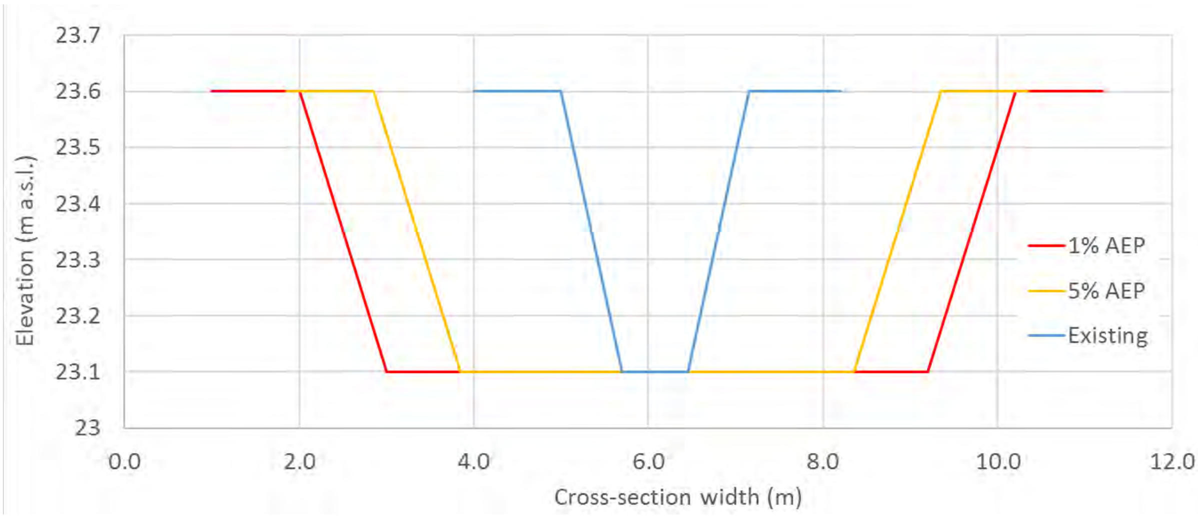

Figure 23. Indicative cross-sections for existing and upgraded cases (XS1735)

The difference in flow capacity for XS1735 across a range of bed widths and side slopes is illustrated in **Figure 24**. The existing channel depth of 0.5 m and channel slope of 0.009 m/m are applied as any future channel upgrades would likely be constrained by these conditions.

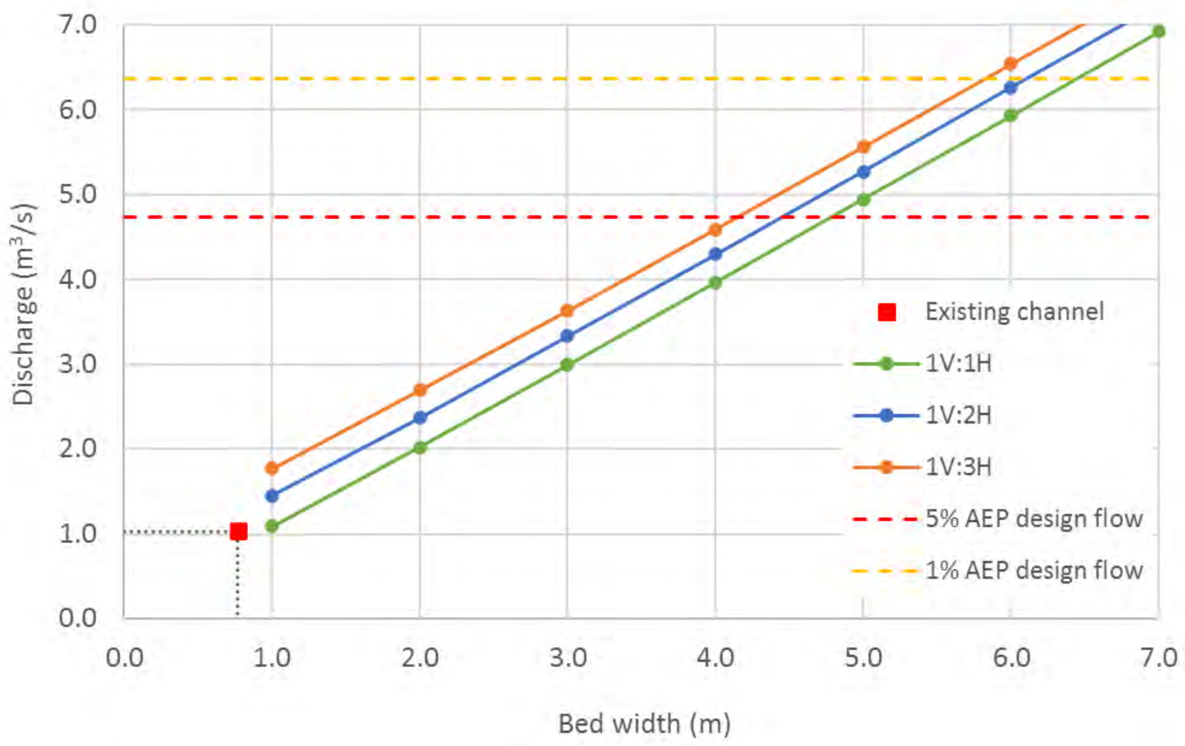

Figure 24. Channel flow capacity for varying bed widths and side slopes at cross-section XS1735 (Drain 3)

4.6 Opportunity constraints

The viability of sediment, nutrient, and drainage opportunities may be constrained where the implementation or performance of potential management options is compromised by inherent features of the catchment or by farming practices. Example constraints are noted below.

4.6.1 Paddock characteristics

Sediment control devices such as decanting earth bunds (DEBs) and sediment retention ponds (SRPs), which are primarily aimed at the construction industry, can be applied in a horticultural context to reduce sediment and phosphorus discharges. Their expected performance (often cited as 75% TSS reduction) is predicated on a maximum catchment area which is generally achievable on a construction site. Many of the Arawhata crop paddocks, however, are close to, or exceed, the maximum catchment area threshold recommended for these devices which are generally accepted as 0.3 ha and 5.0 ha for DEBs and SRPs, respectively. In order to use construction-type sediment control devices in the Arawhata catchment, it may therefore be necessary to divide paddocks into sub-catchments using interception drains, bunds, or longitudinal divides to improve the efficiency of sediment capture. While compartmentalising paddocks in this way is ideal for drainage and sediment management purposes, we acknowledge that this may result in a loss of productive land or inefficiencies in crop management practices.

Additionally, the sizing of on-paddock devices assumes that the paddock boundary represents the entire catchment draining to the device. Device sizing is invalidated when surface flows enter a paddock from outside its boundaries, as is known to occur in the catchment. As such, perimeter bunds or drains would also likely be required to enable effective management at a paddock scale.

SRPs may be less suited to the flat paddock grade that characterises much of the Arawhata catchment (generally 1.0-1.5%) compared to cropland elsewhere in New Zealand (Andrew Barber, pers. comm.). This is because the relatively small elevation differential that may exist between the base of the pond and the invert of the channel to which the pond drains could preclude free discharge of decanted water. While the effect may be mitigated with bunding to raise the water level in the pond, this would need to be evaluated on a case-by-case basis.

4.6.2 Network characteristics

The intermittent nature of channel flows upstream of the main Arawhata Stream means that wetland plant communities are not able to be sustained outside of the lower catchment. This limits the placement of a critical treatment option to the downstream end of the catchment, where perennial flows exist.

The low channel grades may also constrain network upgrades in that channels cannot be deepened or steepened to increase capacity. Capacity increases therefore translate to loss of productive land as channels are widened.

4.6.3 Land ownership

Some interventions may span multiple legal boundaries in order to provide the desired level of hydraulic or treatment performance. Success of the intervention therefore depends on the agreement of the affected parties. The loss of productive land due to implementation may also not be shared equally among the parties who benefit from the intervention.

4.6.4 Maintenance

A significant constraint common to all structural interventions is the need for maintenance. Where a device retains sediment and associated nutrients, the captured sediment and nutrients, and sometimes plantings, must be removed periodically. If regular maintenance does not occur, a net negative effect may result when excessive sediment or nutrient stores are mobilised en masse during a storm. A larger device may lower the maintenance burden by reducing the clean-out frequency. This decision is a trade-off between time and cost to maintain and loss of productive land due to device size.

Similarly, effective grass buffer strips trap sediment. Excessive sediment build-up may begin to impound runoff if the accumulated sediment is not periodically removed. If the impoundment structure is then breached (deliberately or otherwise) to release stored water to prevent crop inundation, erosion may occur and sediment laden water may be released to the environment, as shown in **Figure 25**.

Figure 25. Example of deliberately breached grass buffer strip (left) and regraded headland prior to grassing to prevent ponding (right) [21]

5 Option development and evaluation

A suite of management options were developed to reduce the generation and transport of sediment and nutrients within the catchment and to improve the function of the drainage network. The options were compiled on the basis of literature review findings, our own experience with established erosion and sediment control methods (typically used for managing the effects of construction-related earthworks), and conversations with landowners and other practitioners who have worked in the catchment.

Option development follows a 'treatment train' structure in which issues are managed as close as possible to the source as a priority before moving to distributed sediment and nutrient capture methods and network improvements, and lastly to large treatment measures located at the bottom of the catchment to manage residual water quality effects. These complementary practices are intended to provide cumulative load reductions through the catchment.

Options were evaluated against high-level performance and cost criteria to generate an overall score. The evaluation provides the basis for the recommendations made in **Section 6**.

5.1 Option development

Management options comprise a mix of structural and non-structural interventions that are collectively intended to:

1. Reduce the supply of sediment and nutrients to the drainage network
2. Capture or transform constituents that do become entrained in network flows
3. Improve network conveyance function to reduce the incidence of uncontrolled surface flows

While each option has a primary intended function, it is recognised that co-benefits may accrue which contribute to wider improvements in water quality and habitat value. This effect is captured in the option evaluation process and weighted to reflect its secondary consideration.

The specific options considered for implementation are listed in **Table 3**. Further information on each option is provided in **Appendix B**, including intended function, catchment position, implementation rules, and expected performance. Where possible, the measures of effectiveness used to guide the evaluation process are based on published performance data.

Structural options apply at a range of scales throughout the catchment. In order of priority, these are:

- **On-paddock options**: Control measures aimed at preventing sediment mobilisation from the cropping surface and retaining sediment and nutrients within the paddock before being discharged to the drainage network.
- **In-network options**: Control measures aimed at improving network performance and capturing runoff-borne sediment and nutrients that have been discharged from paddocks.
- **End-of-catchment options**: Treatment measures aimed at removing dissolved and particulate nutrients and fine sediment in large devices that receive flows from the whole catchment.

Non-structural options include:

- **On-paddock practices**: Altered cropping practices to reduce sediment and nutrient loss from paddocks such as altered row orientation or paddock compartmentalisation.
- **Shift production**: Move vegetable growing and processing operations to the upper catchment (i.e. up-slope of State Highway 1).

- **Land retirement**: Complete cessation of cropping activity with passive or active transition to native landcover (at paddock and catchment scales).
- **Land use change:** Conversion of cropping land to other land use types (e.g. dairy farming, residential).

5.2 Evaluation criteria

A Multi-Criteria Analysis (MCA) was used to evaluate each management option against a set of performance criteria. The MCA provides a semi-quantitative measure of expected performance against the core project objectives, i.e. drainage improvement and water quality improvement. The MCA scores are used to rank the options to support recommendations for implementation.

Each option was scored on a 7-point scale in which a positive 3-point spread is used for benefits, a negative 3-point spread for costs, and a value of zero where effects are neutral. These fairly broad intervals reflect the inherent uncertainty in device performance, the wide range of reported removal efficiencies, and the circumstances under which they are tested. Performance can therefore not be more accurately defined by using finer scoring intervals (e.g. 11-point spread). It is noted that the calculated rank can be very sensitive to the individual criterion scores so the underlying benefit and cost scores must be assigned with care (recognising that they can be changed at any time).

For the evaluation criteria that describe sediment and nutrient reduction performance, scores were assigned on the basis of removal efficiencies reported in the literature for each intervention type. The scores and corresponding performance bands are: **0**: 0% removal, **1**: 1-33% removal, **2**: 34-67% removal, and **3**: 68-100% removal. The drainage network performance scores were assigned on the basis of engineering judgement and experience.

Four primary benefit criteria have been identified and weighted equally at 22.5%. Two co-benefit criteria make up the difference with 5.0% each. Two cost criteria were identified and weighted equally at 50%. The collective benefit and cost scores are provisionally weighted at 70% and 30%, respectively, to reflect the emphasis on solutions. It is important to note that weighting is applied according to perceptions of relative importance and therefore represents the views of those making the choice. The weights are therefore not fixed and may evolve over time.

The option evaluation criteria, intervention performance measures, and scoring scales are listed in **Table 2**.

Table 2. Evaluation criteria used to score interventions

Benefits			
Evaluation criterion	**Performance measure**	**Scoring scale**	**Weighting (%)**
Sediment reduction	Potential to reduce sediment generation at source or to capture sediment that becomes mobilised.	0-3	22.5
Nitrogen reduction	Potential to reduce nitrogen loading to the drainage network and to capture nitrogen that becomes mobilised.	0-3	22.5
Phosphorus reduction	Potential to reduce phosphorus loading to the drainage network and to capture phosphorus that becomes mobilised.	0-3	22.5

Network performance	Potential to improve hydraulic efficiency, attenuate flood flows, or reduce frequency of channel overtopping.	0-3	22.5
Co-benefits – Water quality	Potential to improve water quality through reduction of non-target contaminant, specifically faecal pathogens.	0-3	5.0
Co-benefits – Environmental	Potential to enhance biodiversity value through provision of aquatic or riparian habitat.	0-3	5.0
Costs			
Evaluation criterion	**Performance measure**	**Scoring scale**	**Weighting (%)**
Cost to HRC	Combined capital and operating cost of the intervention (without consideration of opportunity cost or lost productivity).	-3-0	50
Land requirement	Loss of productive land to accommodate intervention.	-3-0	50

5.3 Option evaluation

MCA scores are calculated as the weighted sum of the individual criterion scores. The scores and associated rank for each option are provided in **Table 3**. The calculated rank applies at the catchment scale to which the intervention applies rather than to the catchment as a whole, i.e. a rank of 1 is assigned to an option in each of the on-paddock, in-network, and end-of-catchment scales. The underlying scores for each constituent benefit and cost criterion are provided in **Appendix C2**.

The provisional scores recorded in this report are based only on scientific and engineering considerations for improving drainage performance and water quality in the catchment. The scores take no account of land ownership or other legal or political considerations, and do not allow for potential economic consequences from any disruptions to existing farming practices that may result from implementing the interventions.

Table 3. Evaluation scores and rank for each management option

Intervention type	Weighted evaluation score			Rank
	Benefits	Costs	Total	
On-paddock options				
Land retirement (revegetate)	2.8	-2.0	**1.3**	1
Sediment trap (vegetable wash)	1.9	-1.0	**1.0**	2
Grass buffer	1.6	-1.0	**0.8**	3
Land use change (residential)	2.2	-2.5	**0.8**	4
Silt trap with decanter	1.9	-2.0	**0.7**	5
Cover cropping (when fallow)	0.9	-0.5	**0.5**	6
Contour cultivation	0.9	-0.5	**0.5**	6
Soakage	1.0	-1.0	**0.4**	8
Land use change (dairy farming)	1.1	-1.5	**0.3**	9
Erosion control bund	0.9	-1.0	**0.3**	10
Bioreactor (pit - surface water)	0.9	-1.0	**0.3**	10
Riparian buffer	0.8	-1.0	**0.3**	12
Stabilised discharge point	0.5	-0.5	**0.2**	13
Bioreactor (trench - groundwater)	0.5	-1.0	**0.0**	14
In-network options				
Channel upgrade (conveyance)	1.9	-1.5	**0.9**	1
Sediment trap (offline)	1.6	-2.0	**0.5**	2
Channel upgrade (distribution & storage)	1.4	-1.5	**0.5**	3
Culvert upgrade	1.1	-1.0	**0.5**	4
Channel realignment	1.1	-1.0	**0.5**	4
Flood detention storage	1.4	-2.0	**0.3**	6
Sediment trap (online)	1.1	-1.5	**0.3**	7
Check dams	0.5	-0.5	**0.2**	8
Whole-of-catchment options				
Land retirement (revegetate)	3.0	-3.0	**1.2**	1
Land use change (residential)	2.5	-3.0	**0.8**	2
Wetland (offline)	2.3	-3.0	**0.7**	3
Sediment trap (offline)	1.7	-2.5	**0.4**	4
Land use change (dairy farming)	1.4	-2.0	**0.4**	5

6 Recommended actions

6.1 Introduction

The MCA scores were used to rank the management options so that they can be prioritised for potential implementation. The recommendations are based on the MCA scoring alone and reflect what is required to meet the drainage and water quality objectives using the information available at the time of evaluation. It is possible that option scores will vary over time as higher resolution (temporal and spatial) flow and water quality monitoring data becomes available, project objectives change, or different perspectives are used to assign weights to the evaluation criteria.

Ranks are assigned separately for each of the three main catchment scales rather than for the catchment as a whole. The top-ranking interventions for each scale are listed in **Table 4**.

We note that of the nine highest-ranked interventions, two are land retirement and one is land use change. This indicates that a clear and definitive way of improving water quality in Lake Horowhenua and, to a lesser extent drainage issues, would be to end horticulture activity entirely. We recognise the wider implications of this and therefore the actions recommended below focus on interventions that enable the continuation of vegetable cropping in the catchment. Of these, we also note that farm management practices (e.g. cover cropping and contour cultivation), while important, are outside the control of HRC.

Table 4. Top-ranked interventions for each scale within the Arawhata catchment

Catchment scale	Rank	Intervention
On-paddock	1	Land retirement
	2	Sediment trap (vegetable wash)
	3	Grass buffer
In-network	1	Channel capacity upgrade (conveyance)
	2	Sediment trap (offline)
	3	Channel capacity upgrade (distribution & storage)
End-of-catchment	1	Land retirement
	2	Land use change (residential)
	3	Wetland with forebay (offline)

Typical details for recommended actions are tabulated separately below according to their drainage, sediment and phosphorus, and nitrogen management functions. The actions are recorded in order of priority based on the MCA scoring. Some interventions have more than one function, e.g. drainage and sediment management, so are recorded in more than one table.

The spatial implementation of specific actions throughout the catchment is presented in **Section 6.2**. Catchment zones referred to are shown in **Figure 26**.

6.2 Spatial implementation

The spatial implementation of recommended actions follows a broad pattern based on catchment position. This recognises the specific issues that dominate each part of the catchment and the opportunities that exist for addressing these. The catchment zones and associated management strategies are shown in **Figure 26** and can be summarised as follows:

- **Upper catchment**: Focus on volume and peak flow management to attenuate flows entering the mid-catchment network during infrequent and extreme rainfall events.
- **Mid catchment**: Focus on network function to improve conveyance and attenuation, and sediment retention and capture to reduce loading on the network and provide pre-treatment for downstream treatment devices.
- **Lower catchment**: Focus on treatment to manage soluble nutrients in surface water and groundwater, and residual contaminants in channel flows.

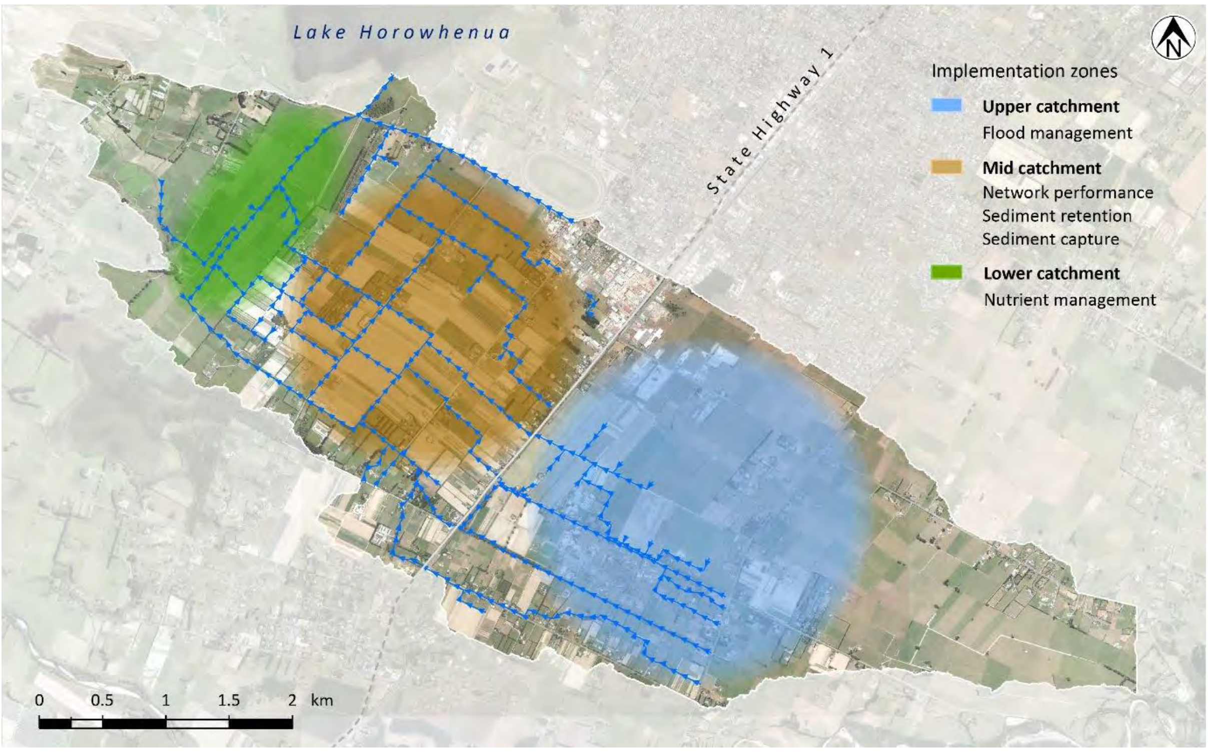

Figure 26. General spatial arrangement for implementation of management options

An important assumption of the implementation strategy is that the principal source of sediment and nutrients is the horticultural activity concentrated in the mid catchment. It is further assumed that the upper catchment (defined as upstream of State Highway 1) is not a significant source of sediment but does generate runoff that affects the lower parts of the network. It is therefore recommended that sediment monitoring be implemented to confirm this assumption (**Section 6.8.3**). The question of how much sediment enters the mid catchment from upstream of the cropping land was also raised during a HRC-led workshop on future monitoring in the catchment (12 August 2020) and remains unresolved.

The spatial implementation of recommended actions at a catchment scale is shown in **Appendix A7**. Paddock-scale actions are shown in **Appendix A8**.

6.3 Sequencing

In an ideal world, implementation would follow a specific sequence so that each intervention adds to the water quality and drainage improvements conferred by the previous intervention, no redundancy results from premature installation, and downstream interventions are not adversely affected by construction-related sediment discharges from upstream interventions.

Implementation sequencing depends on the primary function of each option and should ideally follow the order:

- Network capacity upgrades – Construct in the upstream direction from the bottom of the network up.
- Flood detention systems – Construct in the downstream direction from the top of the catchment down.
- On-paddock sediment systems – Construct first to control sediment and associated nutrients close to source.
- In-network sediment systems – Construct second to protect downstream treatment systems from high sediment loads.
- Lower catchment nutrient wetland – Construct last once the sediment regime has stabilised following establishment of upstream measures.

We acknowledge that the combined issues of land ownership, funding, and practicalities of physical implementation provide a complex overlay to the above idealised sequencing. For this catchment, the key 'must-do' with regard to sequencing is to provide sediment reduction interventions prior to commissioning any wetland devices.

6.4 Drainage actions

Drainage network improvements are central to reducing flooding and minimising sediment generation. By removing flow constraints and increasing capacity, the frequency of inundation of farmland can be expected to reduce with a corresponding reduction in the quantity of soil and associated nutrients that are delivered to the network during extreme events. Specific actions to improve network performance are listed in **Table 5**.

Table 5. Recommended actions to improve network drainage function

Intervention	Function	Catchment zone	Activity and objective
Channel capacity upgrade (Conveyance)	• Improve conveyance	Mid catchment Down-slope channels	• Widen and regrade channels to improve hydraulic efficiency. • Construct new channels where OLFPs indicate preferential route. • Also refer **Table 6** for sediment management functions.
Channel capacity upgrade (Storage & distribution)	• Increase storage • Distribute flows to down-slope channels	Mid catchment Cross-slope channels	• Widen channels where naturally flat grade to provide flood storage and intercept upstream flows. • Prioritise CD Farm Road & Midway. • Create new cross-slope channel on upstream side of Bruce Road. • Also refer **Table 6** for sediment management functions.
Culvert upgrade	• Improve conveyance	Mid catchment	• Upgrade culvert diameters to remove flow constrictions. • Prioritise culverts at Bruce Road and CD Farm Road.
Channel realignment	• Improve conveyance	Mid catchment Down-slope channels	• Realign channels to remove right-angled bends to improve hydraulic efficiency.

			• Prioritise Drains 1, 2, & 3 between Bruce Road and CD Farm Road.
Flood detention storage	• Attenuate flows	Upper catchment	• Construct detention devices at network constraints to reduce peak flow rates in mid catchment. • Prioritise existing ponding areas at State Highway 1 & Arapaepae Road.

6.5 Sediment and phosphorus actions

Sediment and phosphorus management actions apply at a range of scales to address the three primary pathways of sediment to the drainage network (**Section 3.2**). The actions encompass retention of sediment on the cropping surface, capture of mobilised sediment within the paddock, and capture of mobilised sediment outside the paddock (**Table 6**). Sediment capture is assumed to also target particulate phosphorus.

Table 6. Recommended actions to reduce generation and transport of sediment and phosphorus

Intervention	Function	Catchment zone	Activity and objective
Sediment trap (Vegetable wash)	• Sediment capture	Mid catchment	• Trap sediment washed from vegetables at processing facilities before it enters the network.
Channel capacity upgrade (Conveyance)	• Sediment capture	Mid catchment Down-slope channels	• Bench channels as two-stage to allow for sediment capture. • Also refer **Table 5** for drainage management functions.
Grass buffer	• Sediment retention	Mid catchment	• Filter runoff at down-slope paddock edge to retain sediment within paddock that has been mobilised from the cropping surface.
Silt trap with decanter	• Sediment capture	Mid catchment	• Construct on-paddock ponding device to capture runoff and allow settlement of suspended sediment. • Decant clean water to network and remove accumulated sediment.
Sediment trap (Offline)	• Sediment capture	Mid catchment	• Construct sediment trap offline to the network to receive diverted channel flows for settlement of entrained sediment.
Channel capacity upgrade (Storage & distribution)	• Sediment capture	Mid catchment Cross-slope channels	• Bench channels as two-stage to allow for sediment capture. • Also refer **Table 5** for drainage management functions.
Cover cropping	• Sediment retention	Mid catchment	• Plant non-productive crop during fallow periods to retain soil on cropping surface.
Contour cultivation	• Sediment retention	Mid catchment	• Orientate crop rows parallel to the contour to reduce concentration of

			runoff and high velocity flows scouring soil.
Sediment trap (Offline)	• Sediment capture	Lower catchment	• Maintain diversion structure of HRC sediment trap to ensure high flows enter Cell 1. • Reconfigure diversion structure to direct regular flows into trap to capture finer sediment.

6.6 Nitrogen actions

Effective nitrate management requires all catchment flows to pass through a treatment device. While this is most efficiently done in a distributed manner, with multiple wetlands located close to the source of flow where volumes and velocities are lower, the intermittent nature of flow throughout much of the network means that wetland plant communities cannot reliably be sustained. It is therefore recommended that denitrification focuses on a single large wetland at the downstream end of the catchment where all surface flows converge and permanent flow exists (**Table 7**). Nitrate-laden groundwater discharging to the Arawhata Stream can also be intercepted at this location for treatment.

Table 7. Recommended actions to reduce nitrogen discharge from the Arawhata Stream

Intervention	Function	Catchment zone	Activity and objective
Wetland (Offline)	• Nitrate (and DRP) removal	Lower catchment	• Construct an offline wetland with sediment forebay. • Configure and plant to provide conditions that support nitrate and DRP conversion and removal.

An optimum drainage water residence time of three days is required for effective nitrate removal (i.e. >70%). Based on the mean daily flow rates for the Arawhata Stream reported in **Figure 2**, a wetland of approximately 12 ha would be required to meet this condition.

It is critical for performance that this wetland has pre-treatment to remove bulk sediment. This must be considered as part of the design. Pre-treatment may be in the form of one or more sediment traps immediately upstream of the wetland, or distributed around the catchment. The sediment control options described in **Section 6.5** must be implemented before the wetland is commissioned.

6.7 Maintenance

A fundamental assumption underpinning the scoring of options and their recommendation for implementation is that each intervention is fully maintained so that it continues performing to its intended level of service.

- Grass buffer strips – Remove accumulated sediment to avoid formation of a bund at the down-slope and of the rows and consequent impoundment of runoff (**Figure 25**). Revegetate with grasses.
- Two-stage channel and other drains – Remove accumulated sediment to maintain capacity and re-vegetate with grasses. Monitor for bed and bank scour and provide rock protection as required.

- Culverts – Monitor for sediment accumulation and remove as required. Monitor for outlet scout and provide rock protection as required.
- Sediment retention devices – Remove accumulated sediment for redistribution on paddock.
- Wetlands (Nitrate) – Clear inlets and outlets to maintain operating levels. Periodically remove accumulated sediment from forebay.
- Wetlands (Phosphorus) – Remove phosphorus-containing sediment and periodically harvest plants to prevent phosphorus recirculation and release through plant decomposition.

6.8 Non-physical actions

While structural actions provide a fairly immediate and tangible benefit, other actions can contribute to more effective drainage and water quality management in the long-term. Specific actions are noted below.

6.8.1 Develop hydraulic model

The discordance between observed and estimated flow rates, and uncertainties in the distribution and direction of flow among network branches, highlights the importance of gaining a better understanding of system function under a range of flow conditions. A comprehensive 1D-2D hydraulic model that predicts water exchange between the channels and land surface would allow existing system performance to be quantified and network elements to be sized to meet the required level of service. A model would further allow the effects of proposed changes to be evaluated before committing to capital expenditure.

Good data already exists to support a model build, including high-resolution LiDAR, channel cross-sections, and culvert specifications.

6.8.2 Ongoing engagement with landowners

Landowners are the best-placed to observe the on-the-ground effects of proposed actions under the range of operational conditions for which they are designed. Maintaining good working relationships with, and providing information regarding on-farm options to, all parties is an important feature of a holistic approach to managing water quality in Lake Horowhenua.

6.8.3 Ongoing monitoring of water quality

The existing HRC water quality monitoring programme should be expanded to include multiple locations throughout the catchment so that the spatial variability in nutrient and sediment loading can be better understood. At a minimum, this should include event-based monitoring on the four main down-slope drains and the Hokio Beach Road drain at both the boundary with Kane Farm (priority 1) and immediately downstream of State Highway 1 (priority 2) (**Figure 27**). The priority 2 sites should include the southern-most branch (Drain 25) which the multi-site sampling maps show to have high TN and nitrate concentrations, and have a high proportion of TP present as DRP.

Performance monitoring of the proposed interventions should also be undertaken to ensure they operate to their design intent and to allow for adaptive management.

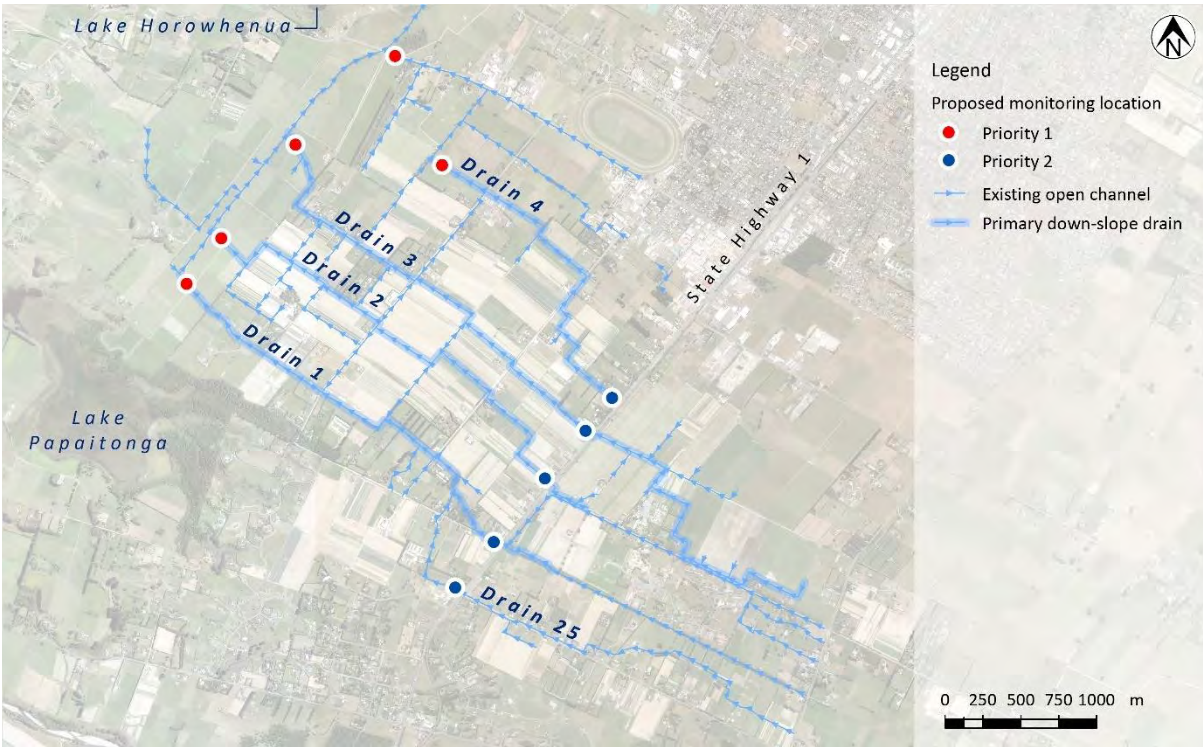

Figure 27. Proposed sub-catchment-scale water quality monitoring locations

7 Next steps

While the recommended actions are intended for implementation over the medium term, a number of more immediate steps could be undertaken in response to the timeline of the *Jobs for Nature* funding programme. These steps include:

- Formalise the connection between the interventions proposed in this project and the complementary wetland design project being undertaken by Jacobs. These projects are part of the same overall water quality improvement programme and need to be fully integrated to achieve the desired hydraulic and treatment objectives of each.
- Expand the existing water quality and flow monitoring programme to provide sub-catchment resolution of nutrient sources and improve understanding of temporal variability in nutrient concentrations.
- Include sediment monitoring in the expanded programme to confirm or otherwise that the assumed primary source of sediment is the vegetable cropping activity in the mid-catchment.
- Define the full Arawhata catchment extent and the sub-catchments of the four main down-slope drains to support accurate flow estimates for the sizing of interventions. This could be achieved using a direct rainfall ('rain-on-grid') hydraulic model or detailed GIS analysis, and would require additional feature (e.g. culvert and drain) surveys and that particular attention is paid to culvert positions and flow obstructions.
- Proceed with the implementation of key interventions under an *adaptive management*[6] framework. This recognises that limitations in existing catchment data exists but allows tangible progress to be made in parallel to the additional water quality and flow monitoring activity, and for interventions to be modified as new data becomes available.

[6] The Environment Court (*Golden Bay Marine Farmers v Tasman District Council* W19/2003 at [405]) has described adaptive management as an *experimental approach to management, or 'structured learning by doing'. It is based on developing dynamic models that attempt to make predictions or hypotheses about the impacts of alternative management policies. Management learning then proceeds by systematic testing of these models, rather than by random trial and error. Adaptive management is most useful when large complex ecological systems are being managed and management decisions cannot wait for final research results*. Sourced from http://www.environmentguide.org.nz/eez/purpose-and-principles/information-principles-and-adaptive-management/

8 Project risks

Proceeding with the recommended actions based on existing catchment knowledge presents several uncertainties and potential risks. While these uncertainties and risks can be at least partially mitigated through an adaptive management approach, as the project moves towards the implementation stage the following points could be considered for inclusion in an overall project risk register:

- A 5% AEP level of service has been assumed for network upgrades. Should a higher return period event occur soon after implementation, there is a risk that the upgrades are perceived by the community as being inadequate. While the channel network is not expected to manage extreme events, the example considered in **Section 4.5.2** indicated that the difference in channel width (+ 1.7 m) required to pass the 1% AEP event may not be much greater than that required for the 5% AEP event.
- When progressing to detailed design and implementation of the proposed interventions, it is acknowledged that all the information required to eliminate uncertainty does not currently exist. At least in the short to medium term, design and implementation will need to be progressed based on the 'best available information'. There is consequently a risk that devices constructed on this basis may not perform to their design standard. As noted in **Section 7**, a willingness to modify interventions after construction, where new data indicates that this would be prudent, will help to mitigate this risk.
- Ongoing uncertainty about the Arawhata catchment extent and the manner in which flows are distributed throughout the drainage network affects the basis for design of flow-based interventions. There is a risk that such devices will be under- or over-sized while catchment hydrology is not fully understood. As noted in **Section 7**, further assessment can be used to mitigate this risk.
- The interventions proposed in the report are aimed at improving water quality within the Arawhata catchment. While this may imply corresponding improvements to Lake Horowhenua water quality, this is not the project objective and no such claim is made due to the inherent complexity of the lake itself and the multiple surface water and groundwater inputs to the lake. How this report, proposed interventions, and potential outcomes is communicated to stakeholders and the community will be important to avoid misalignment of perceived outcomes.
- The wetland concept design has been undertaken on the basis of the flow regime associated with the existing drainage network. There is a risk that incremental improvements made to the network as proposed in this report will result in changes to channel flows and velocities such that the design basis for the wetland will be undermined. The short to medium term risk could be mitigated by integrating both projects under a single provider. In the longer term, for example after the wetland is constructed, the design of all interventions would need to consider the effect on the original wetland design assumptions and actual performance at that point in time.

9 Applicability

This report has been prepared for the exclusive use of our client Horizons Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:

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Reuben Ferguson

Water Resources Engineer

Authorised for Tonkin & Taylor Ltd by:

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Bryn Quilter

Project Director

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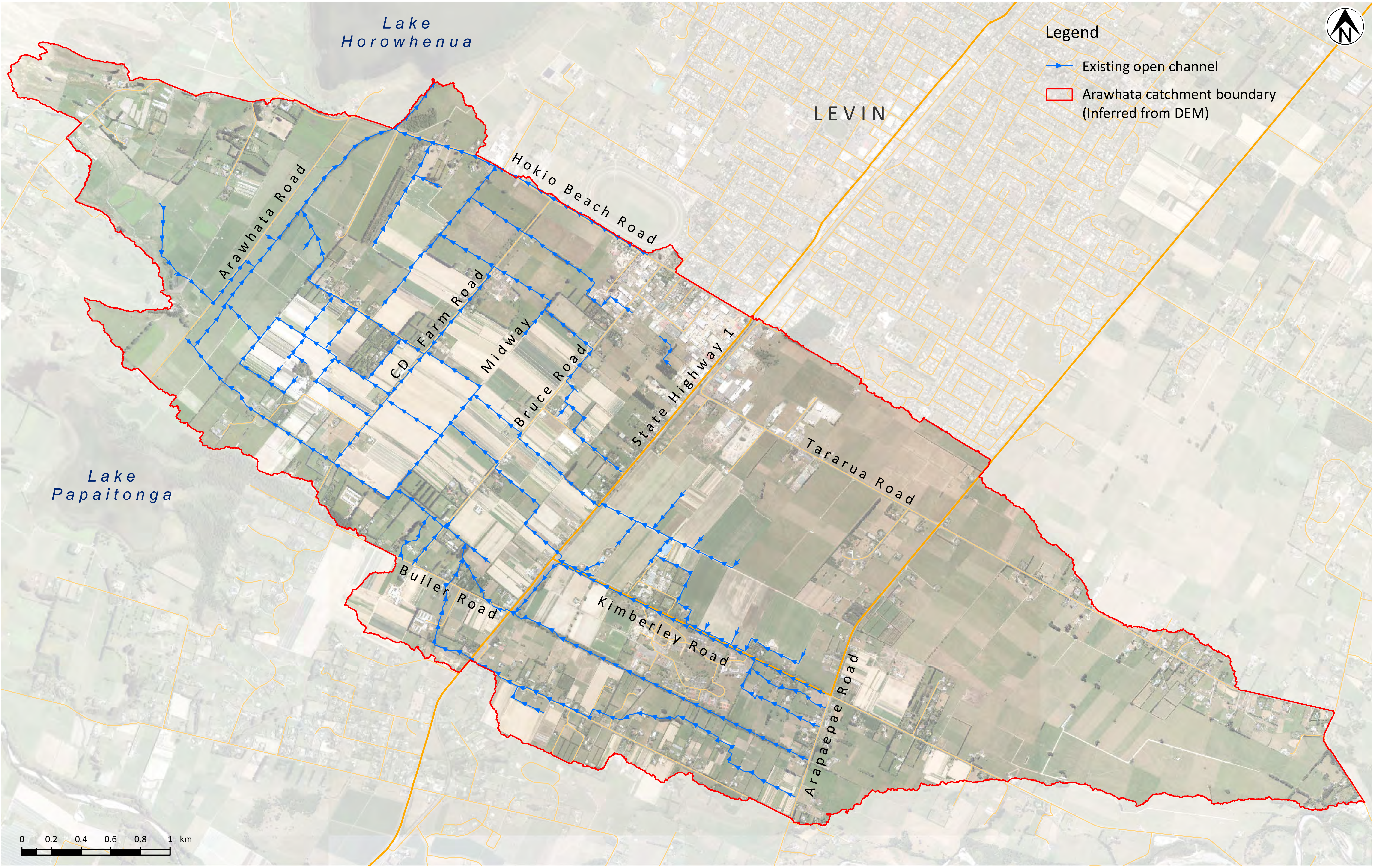
Appendix A1: Arawhata catchment extent



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NOTES:
Aerial photographs: LINZ (2015-2016)
Surveyed drainage network: Horizons Regional Council (2014)
Unsurveyed drainage network: Horizons Regional Council (2019)

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1	First version	REFE	BMQ	17/11/20

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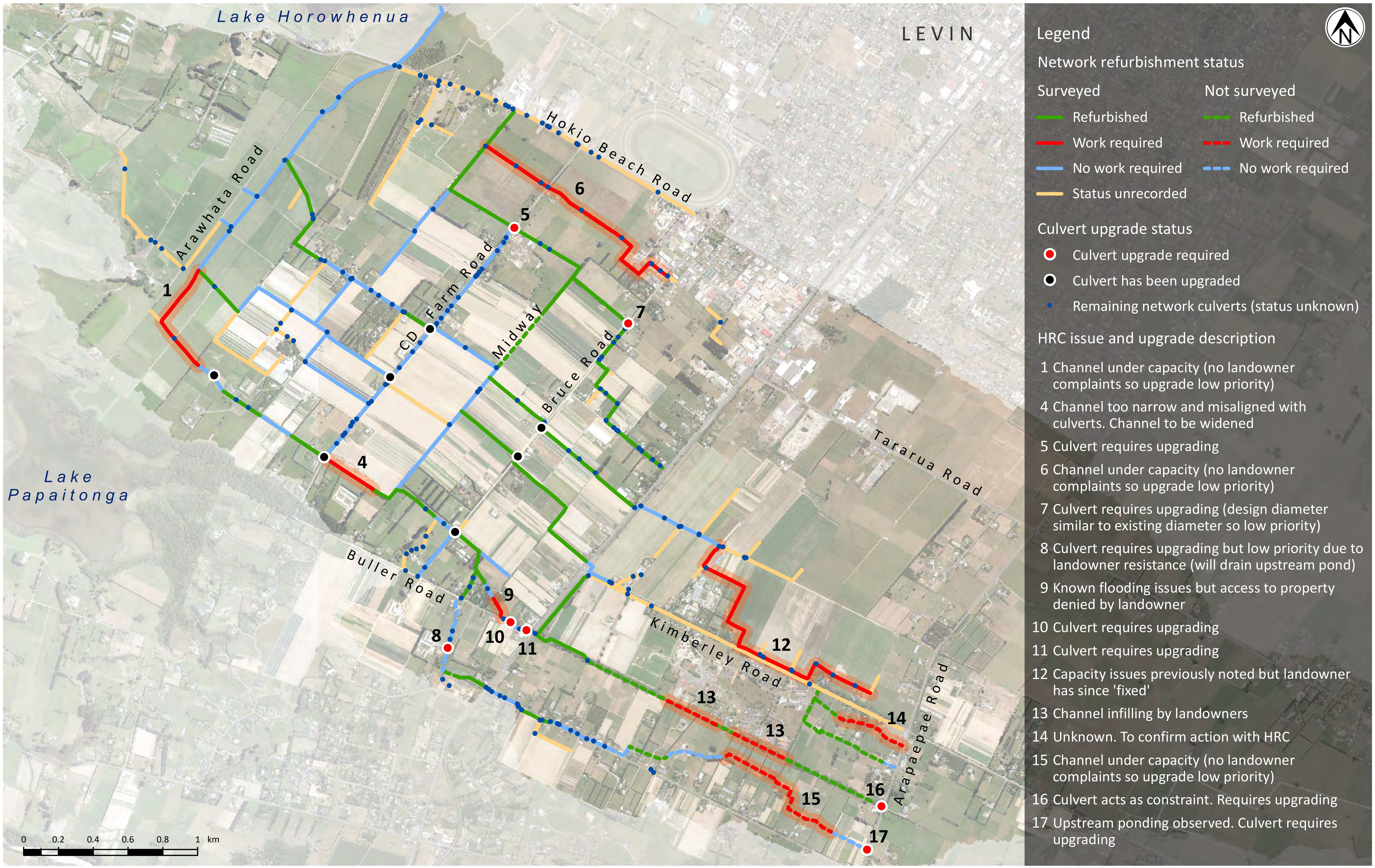
PROJECT ARAWHATA CATCHMENT ISNDMP
TITLE ARAWHATA CATCHMENT EXTENT

SCALE (A3) 1:23,500 FIG No. A1 REV 1

Appendix A2: Network refurbishment status



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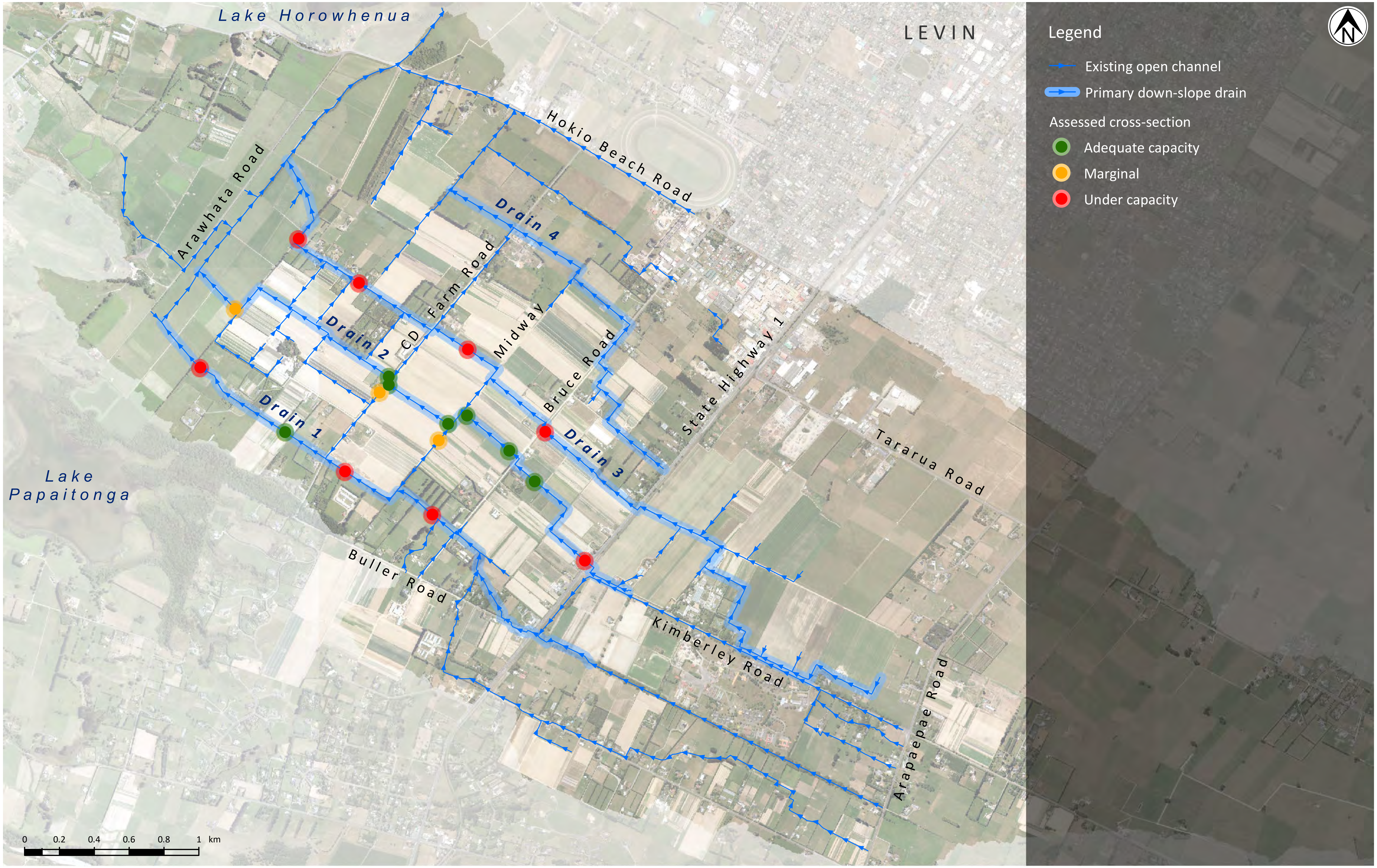
TITLE ARAWHATA DRAINAGE NETWORK REFURBISHMENT STATUS AND HRC PLANNED UPGRADES

SCALE (A3) 1:20,000 FIG No. A2 REV 1

Appendix A3: Cross-section capacity assessment



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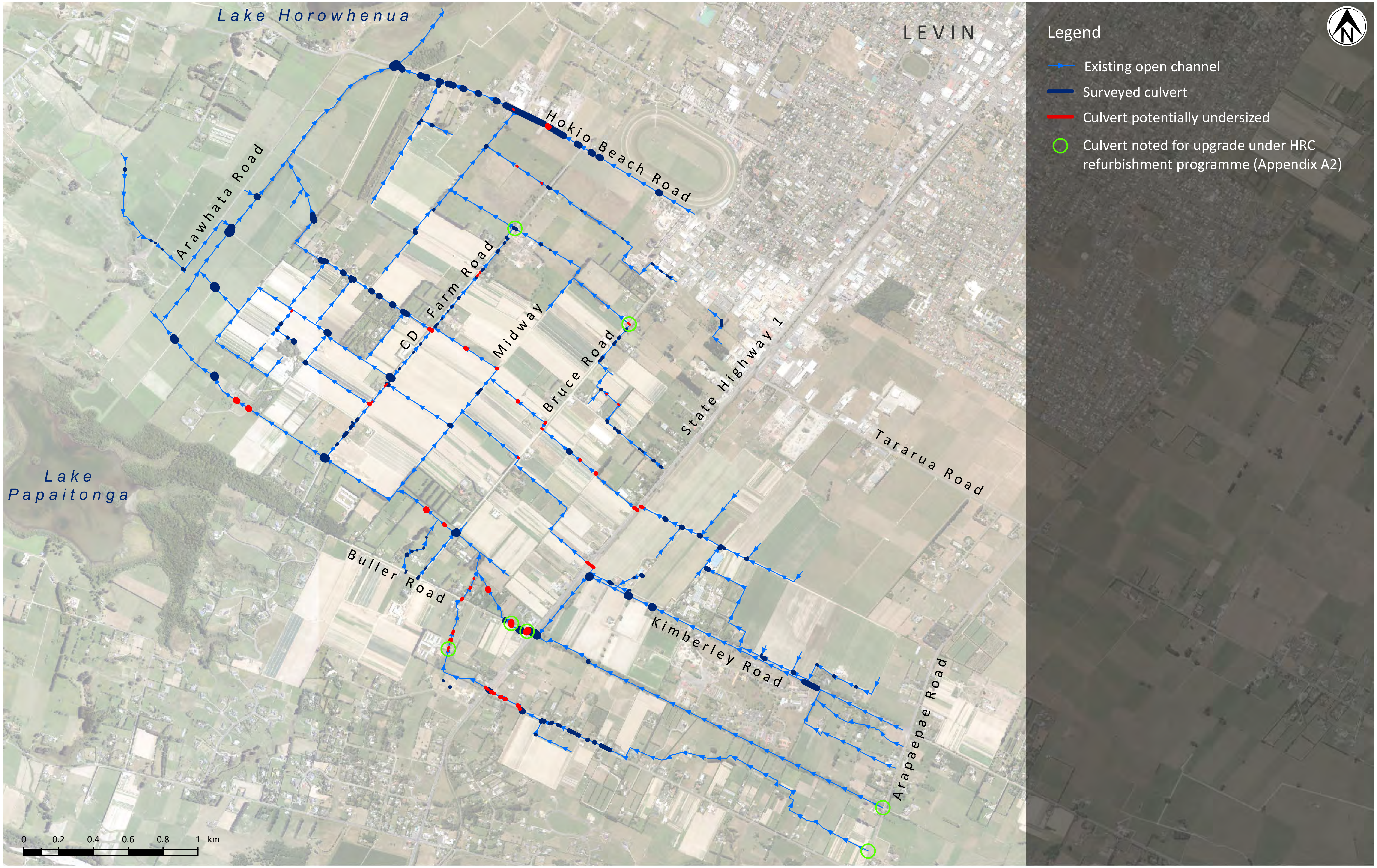
PROJECT ARAWHATA CATCHMENT ISNDMP
TITLE ARAWHATA DRAINAGE NETWORK REFURBISHMENT CROSS-SECTION CAPACITY ASSESSMENT
SCALE (A3) 1:20,000 FIG No. A3 REV 1

Appendix A4: Potentially undersized culverts



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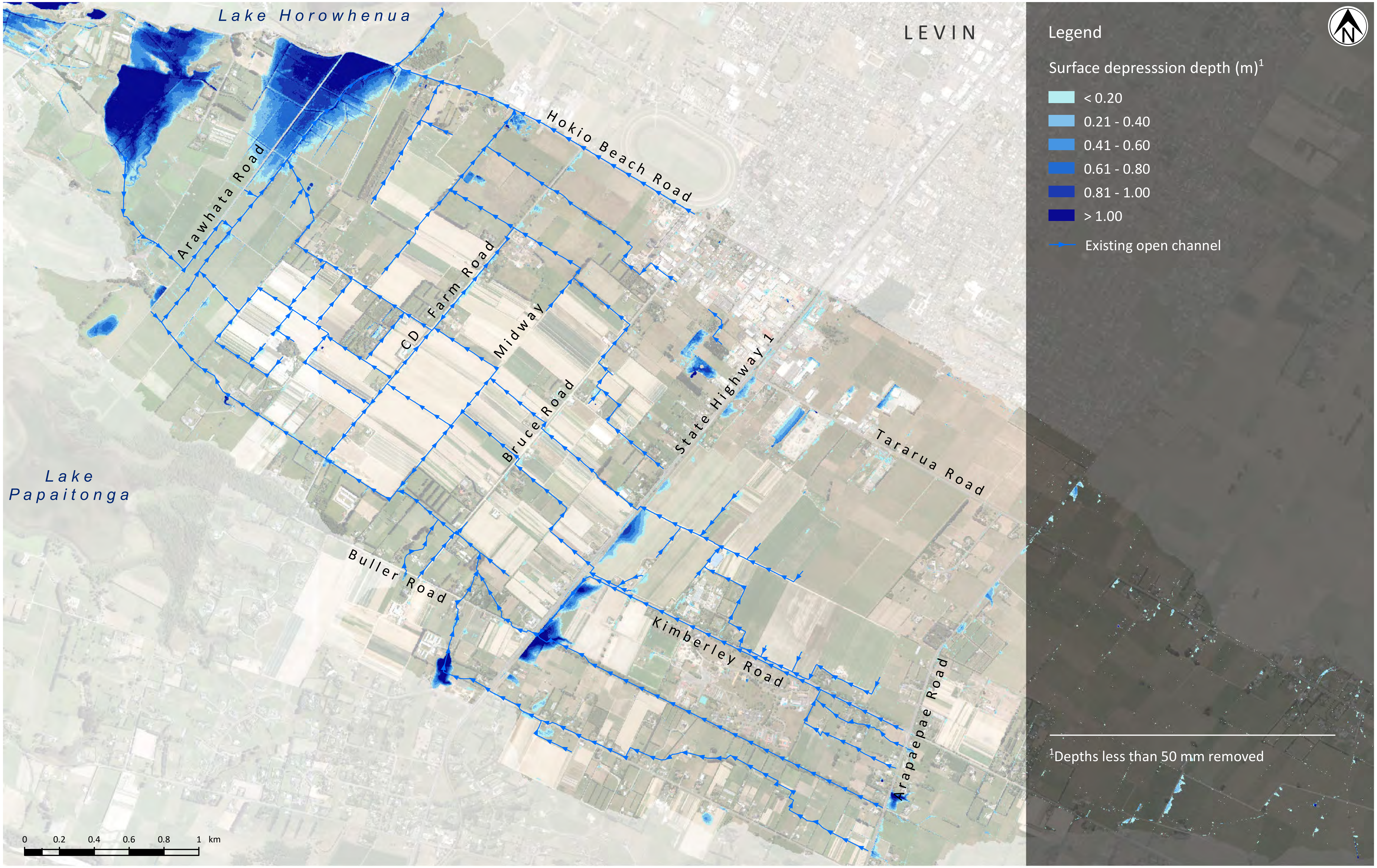
PROJECT ARAWHATA CATCHMENT ISNDMP
TITLE SURVEYED CULVERT DIAMETERS AND POTENTIALLY UNDERSIZED CULVERTS

SCALE (A3) 1:20,000 FIG No. A4 REV 1

Appendix A5: Maximum surface ponding



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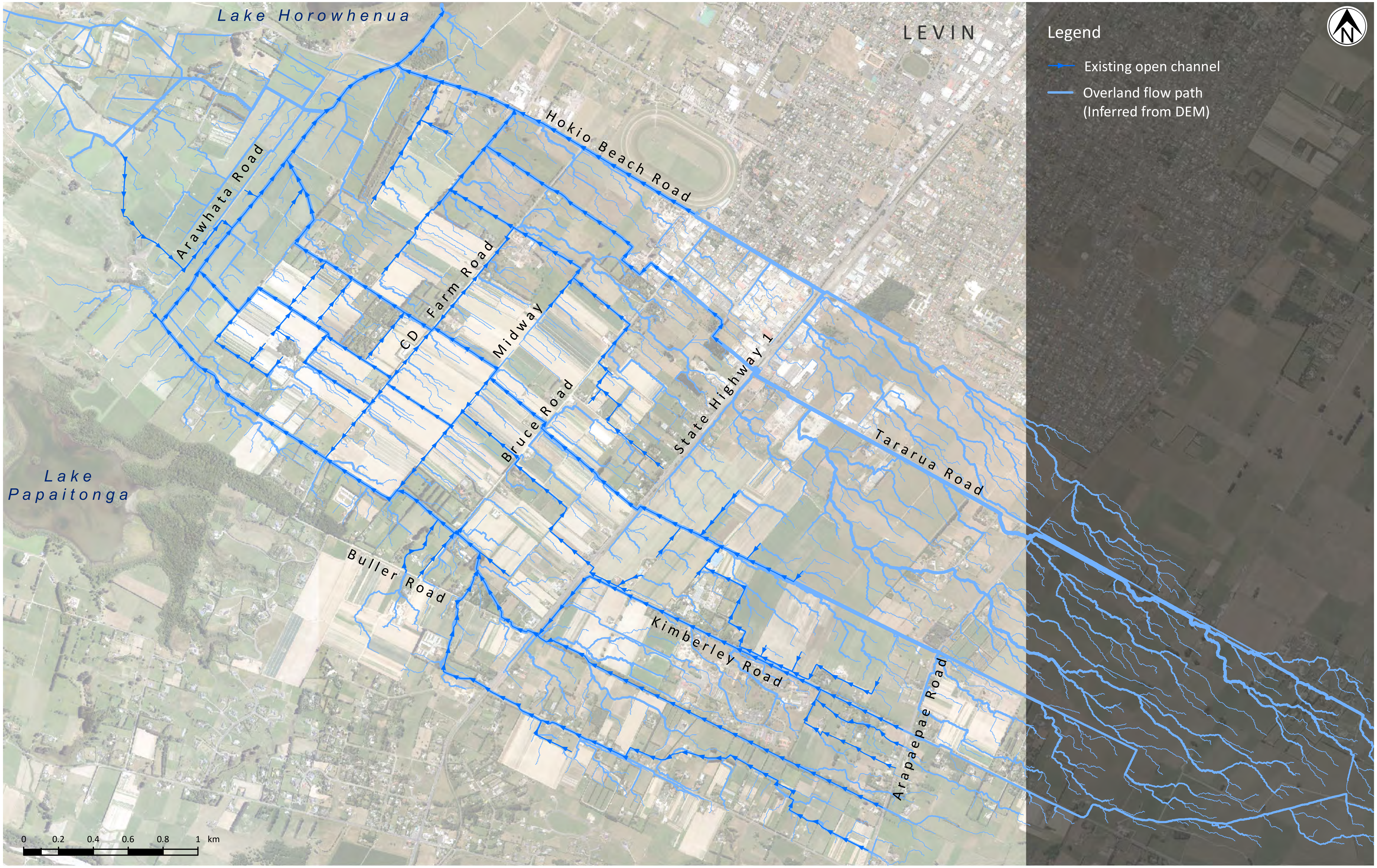
CLIENT: HORIZONS REGIONAL COUNCIL
PROJECT: ARAWHATA CATCHMENT ISNDMP
TITLE: OPPORTUNITIES ASSESSMENT
MAXIMUM POTENTIAL SURFACE PONDING

SCALE (A3) 1:20,000 | FIG No. A5 | REV 1

Appendix A6: Overland flow paths



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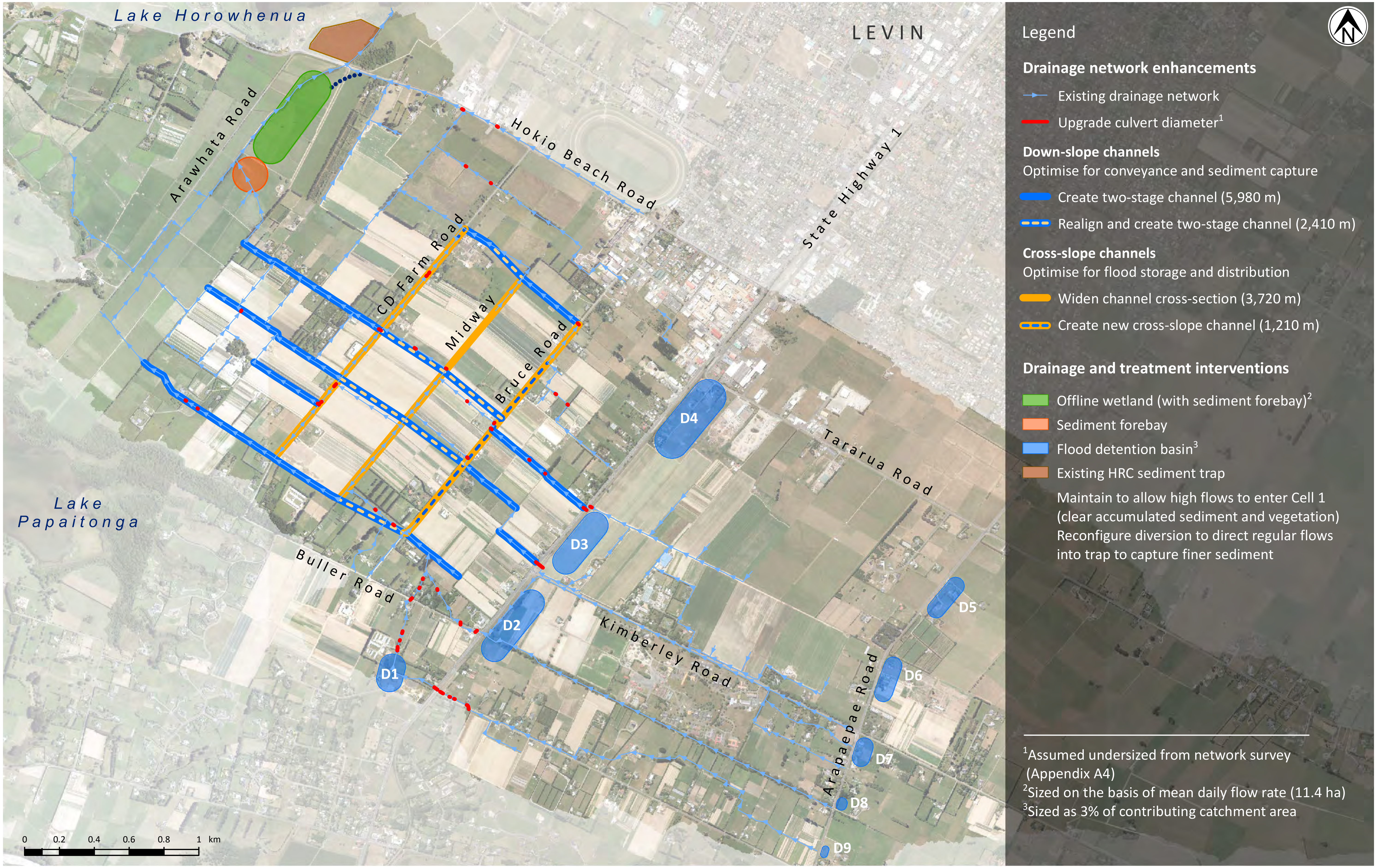
CLIENT: HORIZONS REGIONAL COUNCIL
PROJECT: ARAWHATA CATCHMENT ISNDMP
TITLE: OPPORTUNITIES ASSESSMENT
OVERLAND FLOW PATHS

SCALE (A3): 1:20,000 FIG No. A6 REV 1

Appendix A7: Catchment scale management options



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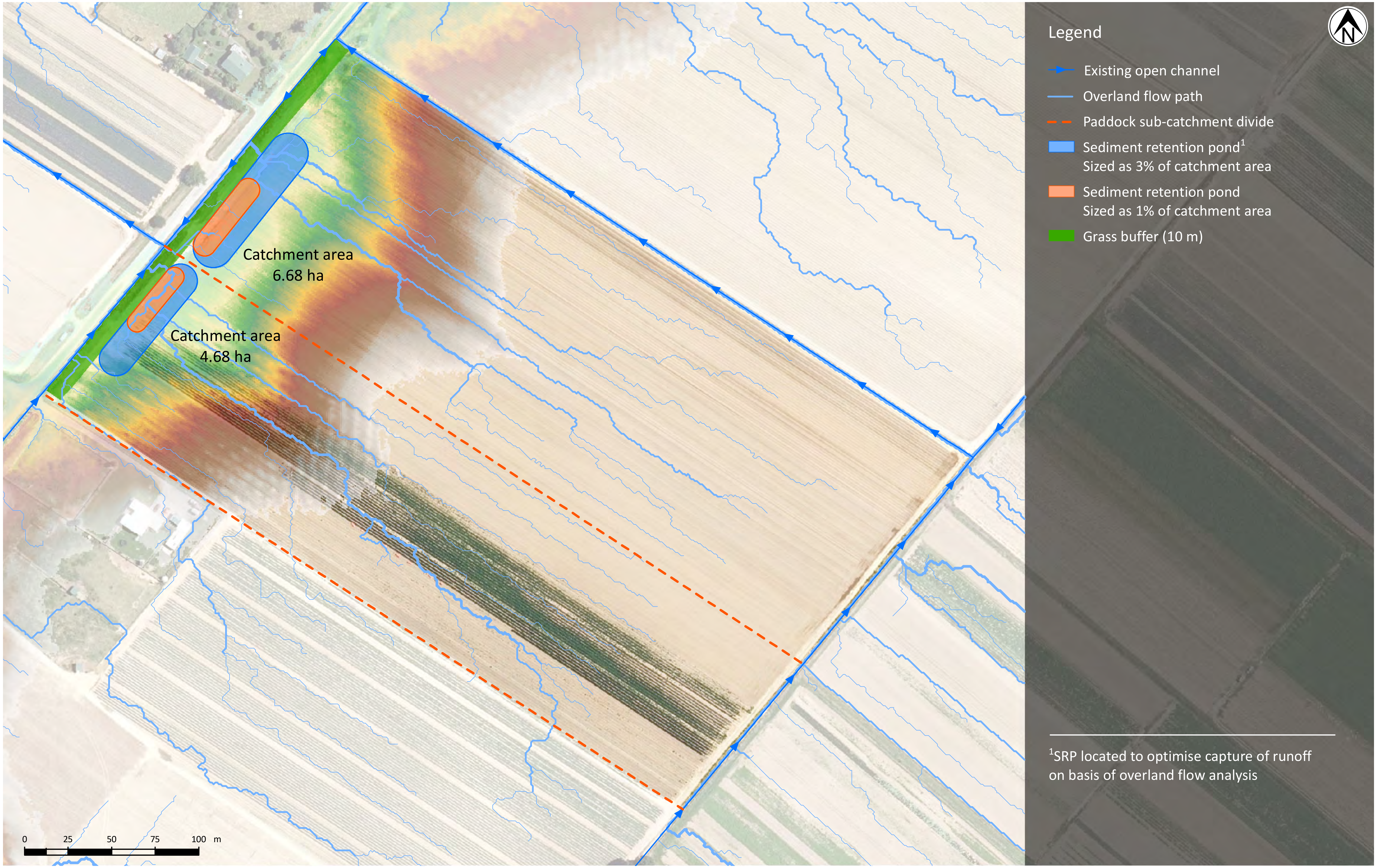
PROJECT ARAWHATA CATCHMENT ISNDMP
TITLE OPPORTUNITIES ASSESSMENT - POTENTIAL MANAGEMENT OPTIONS - CATCHMENT SCALE
SCALE (A3) 1:20,000 FIG No. A7 REV 1

Appendix A8: Paddock-scale management options



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NOTES:
Aerial photographs: LINZ (2015-2016)
Surveyed drainage network: Horizons Regional Council (2014)
Unsurveyed drainage network: Horizons Regional Council (2019)

REV	DESCRIPTION	GIS	CHK	DATE
1	First version	REFE	BMQ	17/11/20

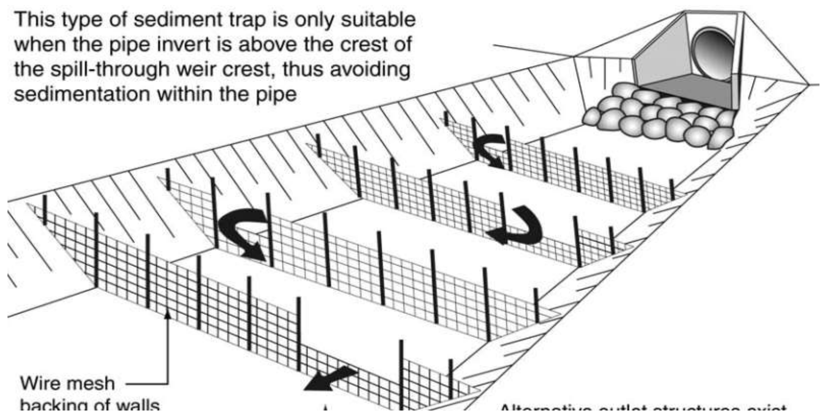
LOCATION PLAN

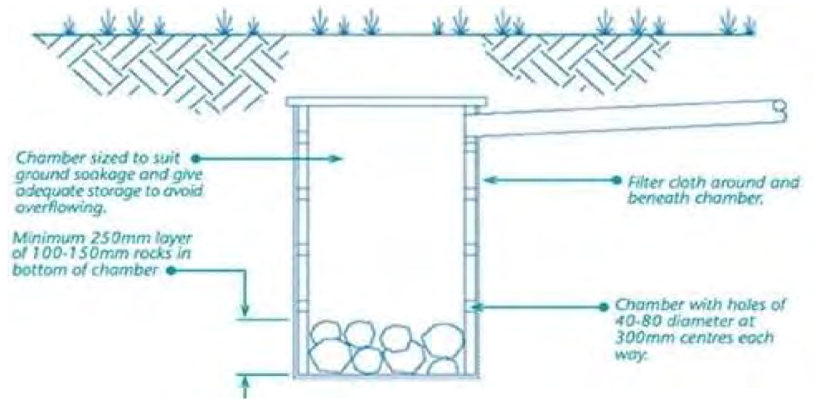
PROJECT No.	1011500	
DESIGNED	REFE	MAR 21
DRAWN	REFE	MAR 21
CHECKED	BMQ	MAR 21
APPROVED		DATE

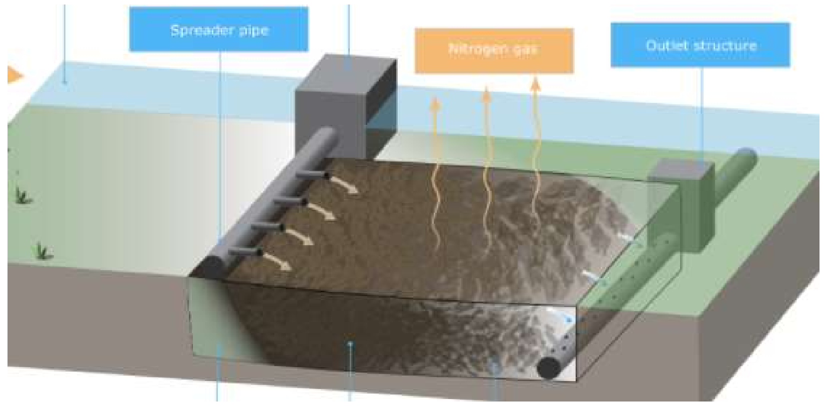
CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ARAWHATA CATCHMENT ISNDMP
TITLE OPPORTUNITIES ASSESSMENT - POTENTIAL OPTIONS - PADDOCK SCALE EXAMPLE

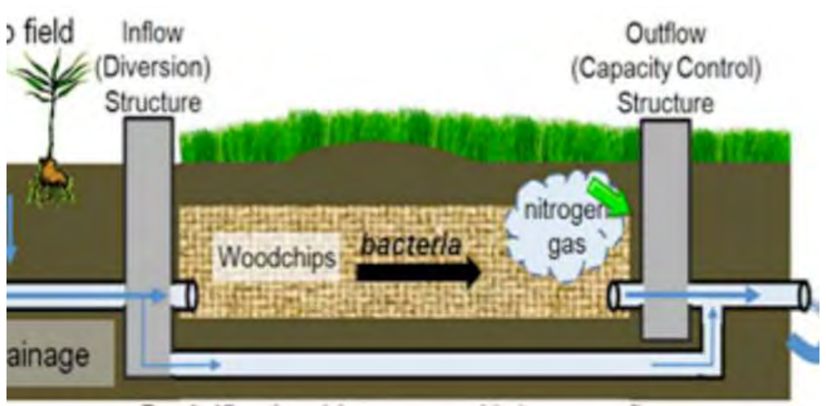
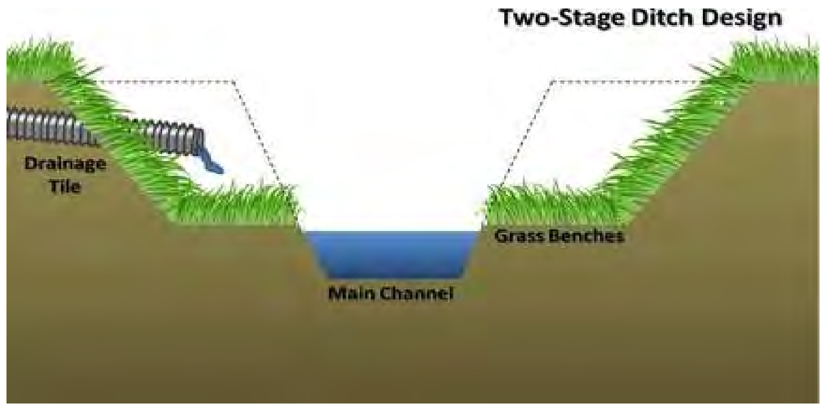
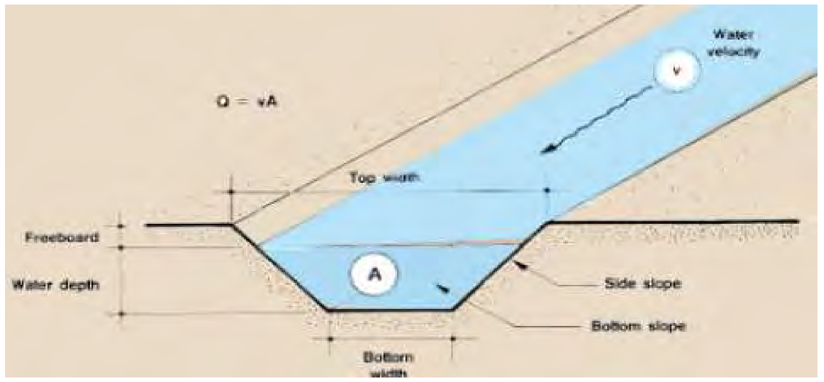
SCALE (A3) 1:2,000 FIG No. A8 REV 1

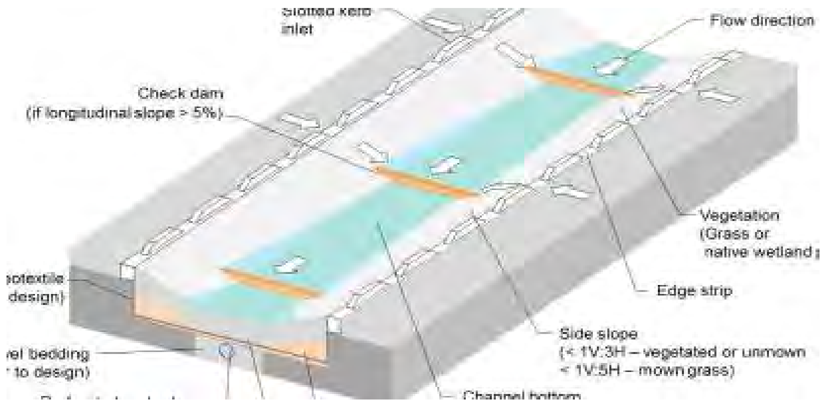
Appendix B: Summary of intervention options

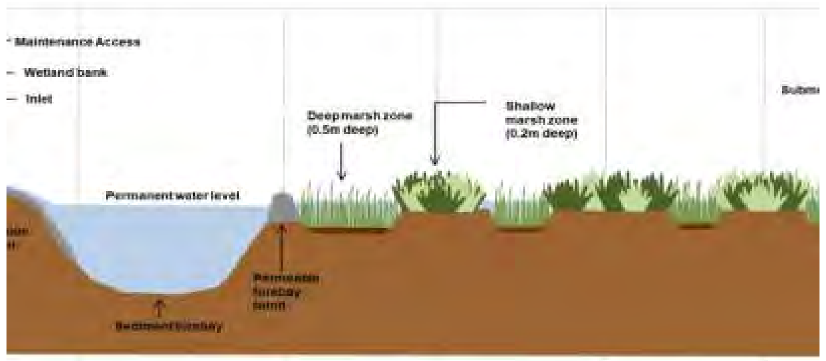
Scale	Intervention	Function	Activity and objective	Example
On-paddock	Riparian buffer	Sediment retention Channel bank stabilisation Channel shading (habitat function)	Plant strip of native vegetation along channel edges to filter sediment-laden runoff from croping surface Stabilise channel banks Provide channel shading and terrestrial habitat	
On-paddock	Grass buffer	Sediment retention	Establish grass margin at down-slope paddock edge to filter runoff that has been mobilised from the cropping surface	
On-paddock	Silt traps (With decanters)	Sediment capture	Construct on-paddock ponding device to capture runoff and allow settlement of suspended sediment Decant clean water to network and remove accumulated sediment.	
On-paddock	Sediment trap (vegetable wash)	Sediment capture	Trap sediment washed from vegetables at processing facilities before it enters the network	

On-paddock	Stabilised discharge point	Prevent sediment generation	Place rock at outlet to prevent scour and sediment generation by surface or piped flows discharging from paddock	
On-paddock	Soakage	Groundwater recharge Runoff reduction	Construct soakage trench / pit and direct hardstand runoff to this	
On-paddock	Land retirement (Revegetate)	Sediment source load reduction Nutrient source load reduction Groundwater recharge Runoff reduction Habitat creation	Resinstate natural condition (revegetate with native plants)	
On-paddock	Land use change (Dairy farming)	Sediment load reduction	Convert cropping land to dairy farming	

On-paddock	Land use change (Residential)	Sediment source load reduction Nutrient source load reduction (once mature)	Convert cropping land to residential development	
On-paddock	Cover cropping (When fallow)	Sediment load reduction	Plant crop during fallow periods to retain soil on paddock	
On-paddock	Contour cultivation	Sediment load reduction	Orientate crop rows parallel to the contour to reduce overland flow velocities	
On-paddock	Bioreactors - Pit (Surface water)	Nitrate reduction	Construct woodchip-filled pit to receive surface runoff from high nitrate areas	

On-paddock	Bioreactors - Trench (Groundwater)	Nitrate reduction	Construct woodchip-filled trench to intercept groundwater flows in high nitrate areas	
In-network	Culvert upgrade	Improve conveyance	Increase culvert diameters (or duplicate barrels) to provide 5% AEP level of service	
In-network	Channel capacity upgrade (Conveyance)	Improve conveyance Sediment capture	Widen and regrade channels to improve hydraulic efficiency Bench channels as two-stage to allow for sediment deposition in 1-2-year ARI flows	
In-network	Channel capacity upgrade (Storage & distribution)	Increase storage Distribute flows to down-slope channels Sediment capture	Widen channels where naturally flat grade to provide flood storage and intercept upstream flows Bench channels as two-stage to allow for sediment deposition in 1-2-year ARI flows	

In-network	Channel realignment	Improve conveyance	Realign channels to remove right-angled bends to improve hydraulic efficiency	
In-network	Flood detention storage	Attenuate flows	Construct detention devices at network constraints to reduce peak flow rates in mid catchment	
In-network	Check dams	Grade control Sediment capture	Install low dams in channel to reduce grade and velocity to encourage sediment deposition. Excavate captured sediment and return to paddock.	
In-network	Sediment trap (Online)	Sediment capture	Excavate directly into channel bed to allow deposition of coarse sediment entrained in flows Provides pre-treatment for downstream wetlands	

In-network	Sediment trap (Offline)	Sediment capture	Create offline excavation with associated diversion and bypass structures Low velocity environment enable settlements of entrained sediment Provides pre-treatment for downstream wetlands	
Whole-of-catchment	Sediment trap (Offline)	Sediment capture	Create offline excavation with associated diversion and bypass structures Low velocity environment enable settlements of entrained sediment Provides pre-treatment for downstream wetlands	
Whole-of-catchment	Wetland (Offline)	Nitrate and DRP removal	Construct an offline wetland with sediment forebay Configure and plant to provide conditions that support nitrate and DRP conversion and removal	
Whole-of-catchment	Land retirement (Revegetate)	Sediment source load reduction Nutrient source load reduction Groundwater recharge Runoff reduction Habitat creation	Resinstate natural condition (revegetate with native plants)	

Whole-of-catchment	Land use change (Dairy farming)	Sediment load reduction	Convert cropping land to dairy farming	
Whole-of-catchment	Land use change (Residential)	Sediment source load reduction Nutrient source load reduction (once mature)	Convert cropping land to residential development	

Appendix C1: MCA evaluation criteria

Evaluation criterion	Weight	Score	Scoring guide	Explanation
Sediment reduction Potential to reduce sediment generation at source or to capture sediment that becomes mobilised.	22.5%	0	No reduction in sediment mobilisation or capture	Refers to the ability of the intervention to reduce sediment generation and mobilisation within paddocks or, where sediment does become mobilised, to capture that sediment. Capture may occur either within the paddock, in a modified section of channel, or in a device that is offline to the channels.
		1	Small reduction in sediment mobilisation or capture	
		2	Moderate reduction in sediment mobilisation or capture	
		3	Large reduction in sediment mobilisation or capture	
Nitrogen reduction Potential to reduce nitrogen loading to the drainage network and to capture nitrogen that becomes mobilised.	22.5%	0	No reduction in nitrogen capture or transformation	Refers to the ability of the intervention to reduce the load of nitrogen discharging from the Arawhata Stream through capture or transformation. Based on a review of supplied monitoring data, the scoring assumes that 95% of total nitrogen is in the form of nitrate.
		1	Small reduction in nitrogen capture or transformation	
		2	Moderate reduction in nitrogen capture or transformation	
		3	Large reduction in nitrogen capture or transformation	
Phosphorus reduction Potential to reduce phosphorus loading to the drainage network and to capture phosphorus that becomes mobilised.	22.5%	0	No reduction in phosphorus capture or transformation	Refers to the ability of the intervention to reduce the load of particulate and dissolved phosphorus discharging from the Arawhata Stream. Based on a review of supplied monitoring data, the scoring assumes that 75% of total phosphorus is in particulate form and 25% is present in soluble form.
		1	Small reduction in phosphorus capture or transformation	
		2	Moderate reduction in phosphorus capture or transformation	
		3	Large reduction in phosphorus capture or transformation	
Network performance Potential to improve hydraulic efficiency, attenuate flood flows, or reduce frequency of channel overtopping.	22.5%	0	No improvement in channel conveyance or reduction in overtopping	Refers to the ability of the intervention to enhance network function through improved conveyance or storage capacity to reduce frequency of overflows. The score relates to effects in the immediate channel reach and does not take account of wider network constrictions that may continue to cause overflows.
		1	Small improvement in channel conveyance or reduction in overtopping	
		2	Moderate improvement in channel conveyance or reduction in overtopping	
		3	Large improvement in channel conveyance or reduction in overtopping	
Co-benefits Potential to improve water quality through reduction of non-target contaminant, specifically faecal pathogens.	5.0%	0	No improvement in water quality	Refers to the ability of the intervention to have a positive effect on water quality by reducing the load or concentration of non-target contaminants. In particular, the ability to reduce the load of faecal pathogens which are shown by monitoring data to be present in the Arawhata Stream in high concentrations.
		1	Small improvement in water quality	
		2	Moderate improvement in water quality	
		3	Large improvement in water quality	
Co-benefits Potential to enhance biodiversity value through provision of aquatic or riparian habitat.	5.0%	0	No additional environmental enhancement	Refers to the ability of the intervention to have a positive effect on the natural environment in addition to the core sediment, nutrient, or drainage management effect it is designed for. This would typically mean the provision of in-channel or riparian habitat.
		1	Small additional environmental enhancement	
		2	Moderate additional environmental enhancement	
		3	Large additional environmental enhancement	
Cost to HRC Combined capital and operating cost of the intervention (without consideration of opportunity cost or lost productivity).	50%	-3	High capital and ongoing costs	Refers to the capital and operating costs of implementing the intervention. This is the direct cost to HRC and does account for the opportunity cost of lost productivity due to the implementation. While some costs may be shared between HRC and HDC or private landowners, this is not accounted for.
		-2	Moderate capital and ongoing costs	
		-1	Low capital and ongoing costs	
		0	No cost	
Land requirement Loss of productive land to accommodate intervention.	50%	-3	Large footprint with high loss of productive land	Refers to the spatial footprint the intervention occupies. This is assumed to have a commensurate loss of productive land. For interventions that are located entirely within the channel, the score is zero.
		-2	Medium footprint with moderate loss of productive land	
		-1	Small footprint with low loss of productive land	
		0	No productive land required for intervention	

Appendix C2: MCA scores for management options

Catchment scale	Intervention	Benefits (100%)						70%	Costs (100%)		30%	Total score	Rank
		Sediment reduction	**Nitrogen reduction**	**Phosphorus reduction**	**Network performance**	**Co-benefits (water quality)**	**Co-benefits (environmental)**	**Benefits score**	**Financial cost**	**Land requirement**	**Costs score**	**Total score**	**Scale specific**
		22.5%	22.5%	22.5%	22.5%	5.0%	5.0%		50%	50%			
		0-3	**0-3**	**0-3**	**0-3**	**0-3**	**0-3**		**-3-0**	**-3-0**			
On-paddock Interventions and practices	Riparian buffer	1	1	1	0	1	2	0.8	-1	-1	-1.0	0.3	12
	Grass buffer	3	1	3	0	1	0	1.6	-1	-1	-1.0	0.8	3
	Silt traps (with decanters)	3	1	3	1	1	0	1.9	-2	-2	-2.0	0.7	5
	Sediment trap (vegetable wash)	3	1	3	1	1	0	1.9	-1	-1	-1.0	1.0	2
	Stabilised discharge point	1	0	1	0	0	0	0.5	-1	0	-0.5	0.2	13
	Soakage	1	1	1	1	1	0	1.0	-1	-1	-1.0	0.4	8
	Land retirement	3	3	3	2	3	3	2.8	-2	-2	-2.0	1.3	1
	Land use change (dairy farming)	2	0	2	1	0	0	1.1	-1	-2	-1.5	0.3	9
	Land use change (residential)	2	3	3	1	3	1	2.2	-3	-2	-2.5	0.8	4
	Cover cropping (when fallow)	1	1	1	1	0	0	0.9	-1	0	-0.5	0.5	6
	Contour cultivation (parallel)	1	1	1	1	0	0	0.9	-1	0	-0.5	0.5	6
	Erosion control bund	1	1	1	1	0	0	0.9	-1	-1	-1.0	0.3	10
	Bioreactors (pit - surface water)	1	2	1	0	0	0	0.9	-1	-1	-1.0	0.3	10
	Bioreactors (trench - groundwater)	0	2	0	0	0	0	0.5	-1	-1	-1.0	0.0	14
In-network Interventions	Culvert upgrade	1	0	1	3	0	0	1.1	-2	0	-1.0	0.5	4
	Channel capacity upgrade (conveyance)	2	1	2	3	0	2	1.9	-2	-1	-1.5	0.9	1
	Channel capacity upgrade (distribution & storage)	1	1	1	3	0	0	1.4	-2	-1	-1.5	0.5	3
	Channel realignment	1	0	1	3	0	0	1.1	-2	0	-1.0	0.5	4
	Flood detention storage	1	1	1	3	0	0	1.4	-2	-2	-2.0	0.3	6
	Check dams	1	0	1	0	0	0	0.5	-1	0	-0.5	0.2	8
	Sediment trap (online)	2	0	2	1	0	0	1.1	-2	-1	-1.5	0.3	7
	Sediment trap (offline)	2	1	2	2	1	0	1.6	-2	-2	-2.0	0.5	2
Whole-of-catchment Interventions	Sediment trap (offline)	2	1	2	2	1	1	1.7	-2	-3	-2.5	0.4	4
	Wetland with forebay (offline)	2	3	2	2	3	3	2.3	-3	-3	-3.0	0.7	3
	Land retirement (revegetate)	3	3	3	3	3	3	3.0	-3	-3	-3.0	1.2	1
	Land use change (dairy farming)	2	0	2	2	0	1	1.4	-1	-3	-2.0	0.4	5
	Land use change (residential)	2	3	3	2	3	1	2.5	-3	-3	-3.0	0.8	2

Appendix D: Literature review

Tonkin+Taylor

Memo

To:	**Staci Boyte**	**Job No:**	**1011500**
From:	**Reuben Ferguson**	**Date:**	**8 March 2021**
Subject:	**Integrated Sediment, Nutrient, and Drainage Management Plan for the Arawhata Catchment - Literature Review**		

1 Introduction

Ongoing monitoring by Horizons Regional Council (HRC) shows that the loss and transport of sediment and nutrients from horticultural land in the Arawhata catchment has had a detrimental effect on the Lake Horowhenua receiving environment, as well as affecting the productivity of farmland. It is understood that impacts continue to accrue due to a combination of land use practices and deficiencies in the network of channels that drain the catchment. A number of studies have sought to understand the mechanisms for sediment mobilisation in the catchment, the quality of surface water and groundwater, catchment water budgets, functioning of the drainage scheme, and efforts that have been made to mitigate these impacts. A review of these studies and related data has been undertaken to provide background to the remainder of this project.

1.1 Literature review objectives and outline

This literature review has been prepared for HRC[1] to summarise current understanding of the historical environmental context, water quality patterns, mechanisms for sediment and nutrient mobilisation, the locations and drivers of flooding, and hydraulic performance of the drainage network within the Arawhata catchment. It summarises efforts that have been made by HRC and landowners themselves to manage the drainage network and modify land use practices to reduce sediment and nutrient loss.

The review is intended to identify what additional measures may be required and sets the direction for the development of a catchment-wide Integrated Sediment, Nutrient and Drainage Management Plan (ISNDMP). The review also takes into account comments provided by HRC on an earlier draft.

1.2 Review methodology

The review is based on 16 reports and associated spatial and monitoring datasets provided to Tonkin & Taylor Ltd (T+T) by HRC. The reports and datasets cover water quality and groundwater systems in the catchment, performance of the Arawhata drainage scheme, and the investigation of physical measures to reduce sediment and nutrient loss from farms and subsequent transport to Lake Horowhenua via the Arawhata Stream. Additional reports have been referred to where these are cited in the reports provided or otherwise deemed relevant to the project. Further information about on-farm interventions and improvements to the drainage network has been gleaned through discussions with HRC engineering officers and other practitioners who have worked in the catchment.

[1] The review forms Task 2 of the HRC/T+T Contract 2019/01: Developing an Integrated Sediment & Drainage Management Plan for the Arawhata Catchment, dated 27 September 2019.

2 Review findings

2.1 Water quality

The Arawhata Stream was shown to be the dominant source of sediment, total nitrogen, and total phosphorus inflows to Lake Horowhenua from sampling in 2013-2014 [16]. Vegetable cropping is reported to be the primary source of sediment and nutrients within the Arawhata catchment [10]. A review of monitoring data against the NPS-FM national objectives framework showed the Arawhata Stream to be below the national bottom line for nitrate toxicity [16]. The total nitrogen and total phosphorus concentrations in the stream were shown to exceed One Plan targets (as they apply to lakes).

An understanding of the concentration of sediment and nutrients in their various forms in the catchment is important because the management response to these contaminants must be tailored to their particular characteristics.

Observed concentrations of sediment and nutrients in the catchment can be compared to default guideline values from the National Policy Statement for Freshwater Management 2020 (NPS-FM) national bottom line limits and Horizons' One Plan targets (**Table 1**). The One Plan targets are Horizons' response to the NPS-FM requirements and apply to the 'Hoki_1' Water Management Zone. The One plan targets are used as the reference value for the concentrations reported in the following sections.

Table 1. Guideline values for sediment and nutrients in the Arawhata catchment

Constituent	Guideline / target value (g/m^3)	
	NPS-FM National bottom line[2]	Horizons One Plan[3]
Total suspended solids (TSS)	-	-
Total Nitrogen (TN)[4]	0.800	0.490
Nitrate	2.400[5]	0.167[5]
Ammoniacal nitrogen	0.240[5]	0.400[5]
Total phosphorus (TP)[5]	0.050	0.030
Dissolved reactive phosphorus (DRP)	>0.018[6]	0.015

2.1.1 Sediment

The Arawhata Stream is acknowledged as the largest contributor of sediment to Lake Horowhenua, accounting for up to 75% of all contributions in the last five years [11], [18]. Sediment loading is closely associated with high rainfall events during which drainage channels may overtop and wash soil from cropland into the drainage system [13]. Soil is also mobilised by runoff generated within the farms themselves by direct rainfall, and by flows entering from adjacent properties, including the road reserve [6],[8],[9],[10]. Vegetable-washing operations at the grower processing facilities also discharge sediment to the drainage network.

[2] Annual median
[3] Annual average
[4] Total nitrogen and total phosphorus values apply only to lakes.
[5] For protection against toxicity effects
[6] Median for ecological communities impacted by substantial DRP elevation above natural reference conditions

State of the Environment (SoE) sampling at roughly monthly intervals from 2016-2019 shows the concentration of total suspended solids (TSS) in the Arawhata Stream at Hokio Beach Road to range from <3 g/m^3 to 318 g/m^3 with a mean of 23 g/m^3 [32]. The single monthly samples belie the spikes in TSS concentration that may occur during high-flow events between sampling periods. When daily and event-based sub-daily records within this period are included[7], greatly elevated TSS concentrations (up to 3,920 g/m^3) are apparent (**Figure 1**).

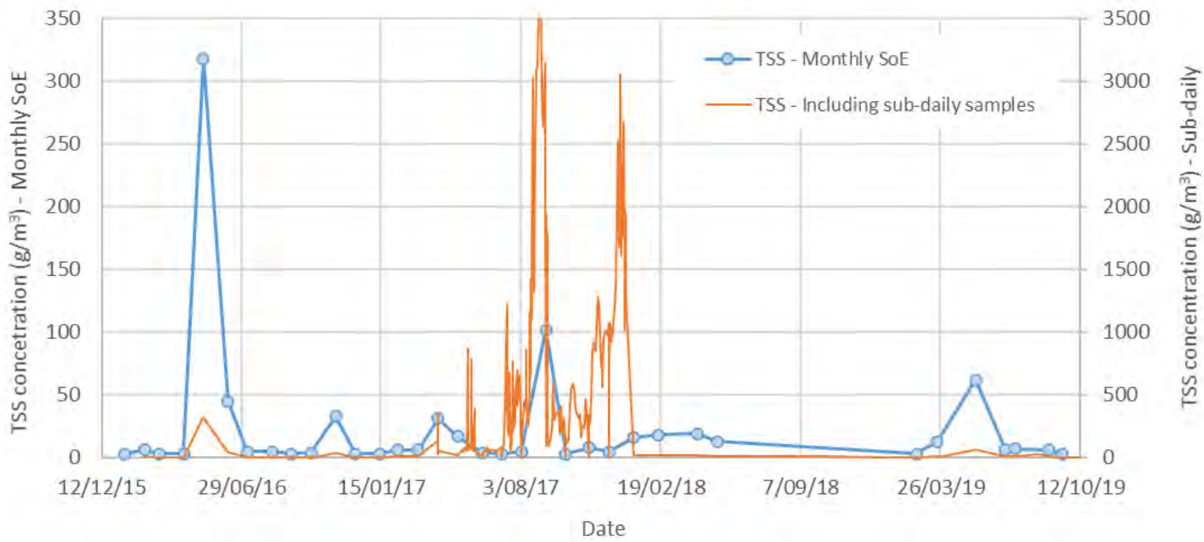


Figure 1. Monthly SoE and sub-daily TSS concentrations at Hokio Beach Road (note separate y-axes)

The Hokio Beach Road sampling only describes water quality at a whole-of-catchment scale. One-off water quality sampling was undertaken by HRC at 22 sites within the drainage network during a high flow event on 13 August 2019 to better understand sub-catchment-scale patterns. This sampling showed TSS concentrations to range from 6 g/m^3 to 161 g/m^3 across the sites with a mean of 51 g/m^3 (**Figure 2**).

A lack of understanding about the source of sediment within the catchment a finer spatial scale was acknowledged during a Horizons-led workshop aimed at developing a monitoring programme for the Horowhenua Freshwater Management Unit in August 2020 [34]. In particular, uncertainty about the quantity of sediment entering the drainage system from above the horticultural area was recognised as an information gap. This gap limits the confidence with which targeted sediment management options can be developed.

Sediment grain size analysis undertaken to support the design of the HRC-designed sediment trap in the lower catchment (assumed to be a sample taken from the water column rather than channel substrate) showed particle sizes to be skewed towards the fine end of the spectrum [31]. Specifically, 89% of the sample occupied the medium silt to clay particle size range. The sample had a mean particle size of approximately 10 µm, i.e. very fine silt, with a range of diameters from 0.1 µm to 100 µm. Particles in this range may require disproportionately large devices to allow sufficient residence time for particle settlement.

[7] Data collected under separate HRC turbidity monitoring programme.

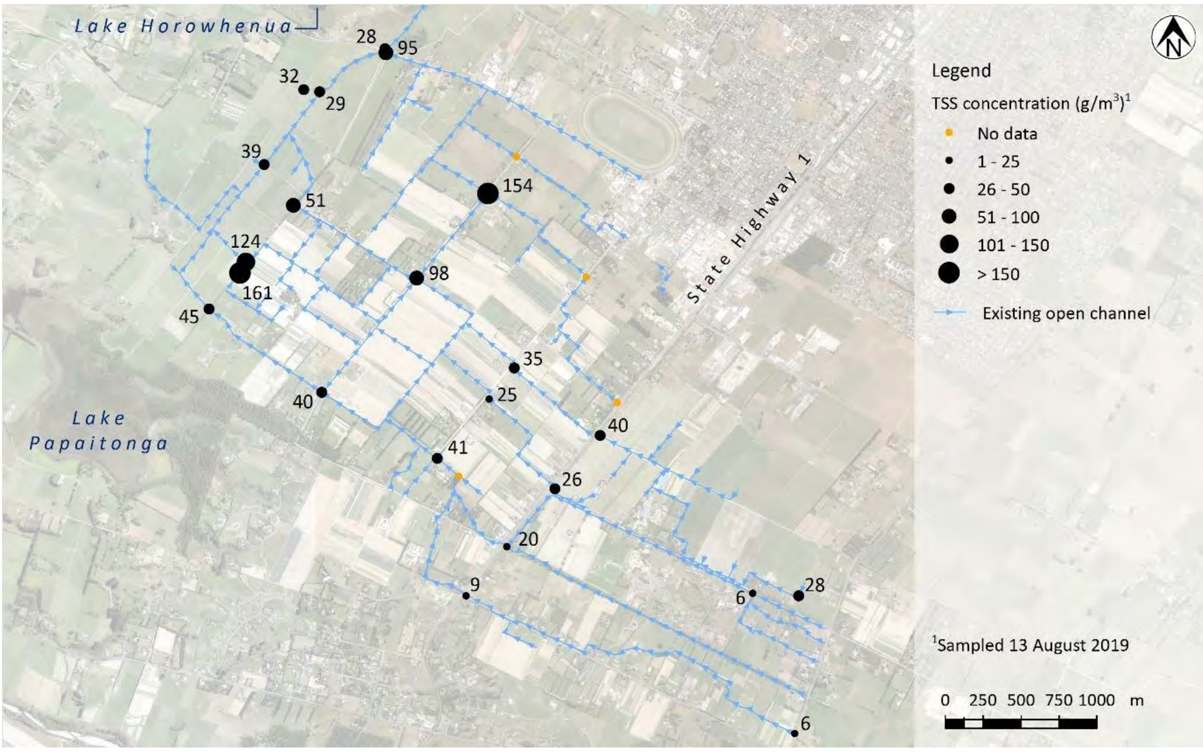


Figure 2. Observed TSS concentrations from one-off multi-site sampling (13 August 2019).

2.1.2 Nitrogen

The Arawhata Stream contributes approximately 50% of the surface water nitrogen load to Lake Horowhenua, with vegetable cropping and intensive dairy farming being the main contributors [17]. The other primary contributor of nutrients to the lake is groundwater which has a high nitrate concentration in particular (but low dissolved reactive phosphorus) [4] which is attributed to over use of fertiliser and dairy farming [17]. Groundwater is reported to be the dominant source of nitrogen to the lake [4].

The presence of nitrate in particular is important when considering mitigation options due to its solubility in water and multiple pathways to the catchment outlet via runoff and leaching. This means that interventions that rely on physical settling alone, such as the HRC sediment trap already constructed (**Section 2.5.4**), are unable to reduce loads of an important nutrient source for the lake.

The Arawhata Stream was shown to be the dominant surface water source of total nitrogen (TN) during sampling of Lake Horowhenua tributaries in 2013-2014 [16]. Monthly SoE monitoring at Hokio Beach Road shows consistently high TN in the Arawhata Stream, ranging from 3.6 g/m^3 to 13.8 g/m^3 with a mean of 10.3 g/m^3 (**Figure 3**). The proportion of TN present as nitrate over this period ranged from 26% to 100% with a mean of 96%[8]. The concentration of nitrate ranged from 2.15 g/m^3 to 14.7[6] g/m^3 with a mean of 9.9 g/m^3.

[8] Some of the nitrate proportions are recorded as being greater than 100% of TN (as high as 114%). These are set to 100% for graphing purposes in Figure 3.

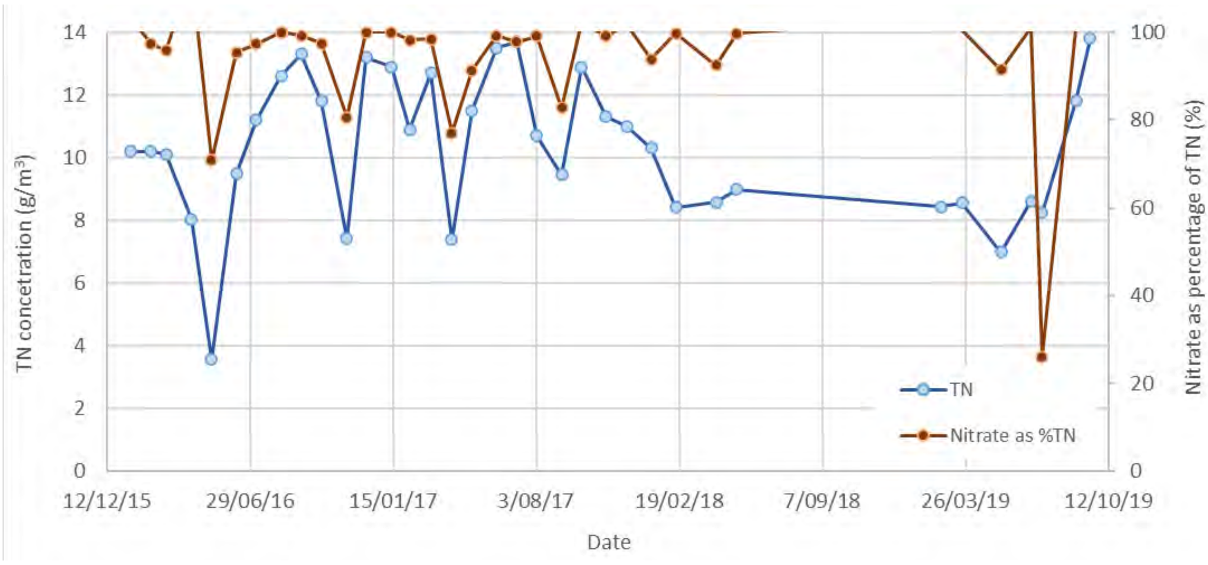


Figure 3. TN concentration and the proportion of TN present as nitrate at Hokio Beach Road[9]

The one-off multi-site sampling showed TN concentrations to range from 1.2 g/m^3 to 12.3 g/m^3 with a mean of 3.7 g/m^3. Nitrate concentrations ranged from 0.33 to 11.9 with a mean of 2.7 g/m^3 (**Figure 4**). The proportion of TN as nitrate ranged from 27% to 97% with a mean of 64% (**Figure 5**).

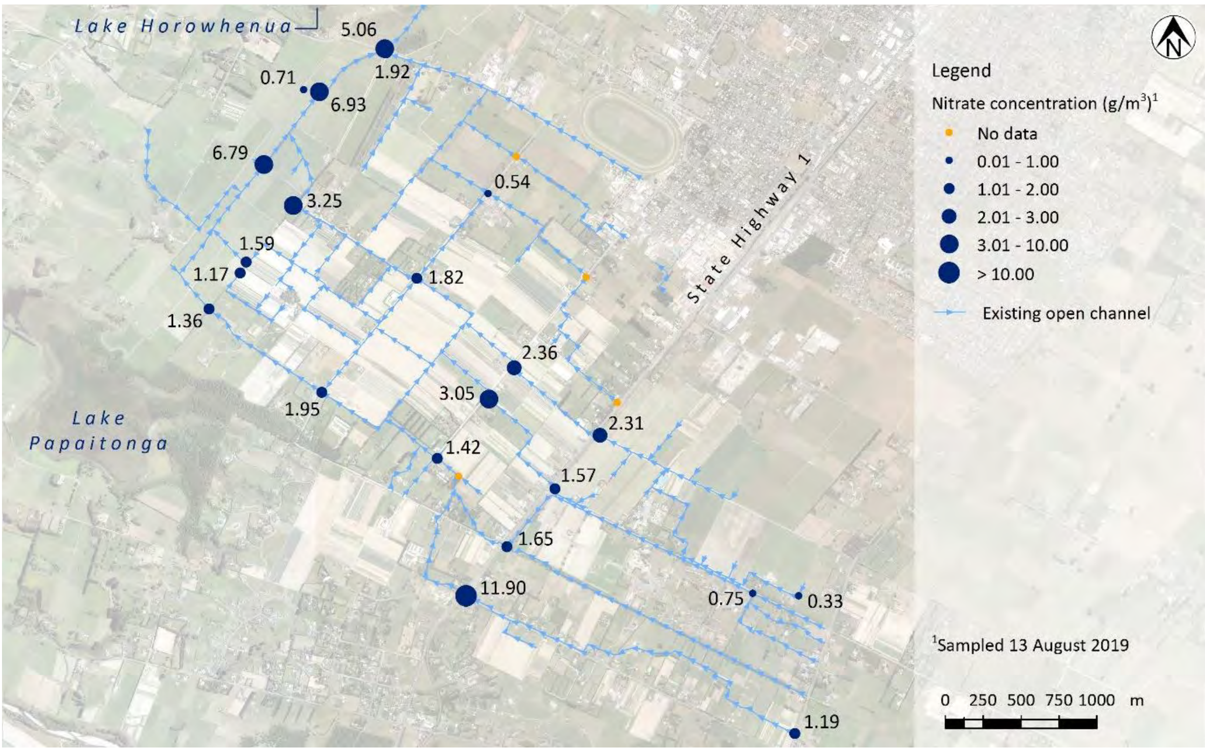


Figure 4. Observed nitrate concentrations from one-off multi-site sampling (13 August 2019).

[9] Some nitrate proportions shown as greater than 100% of TN due to reported nitrate concentrations exceeding TN concentrations in monitoring data.

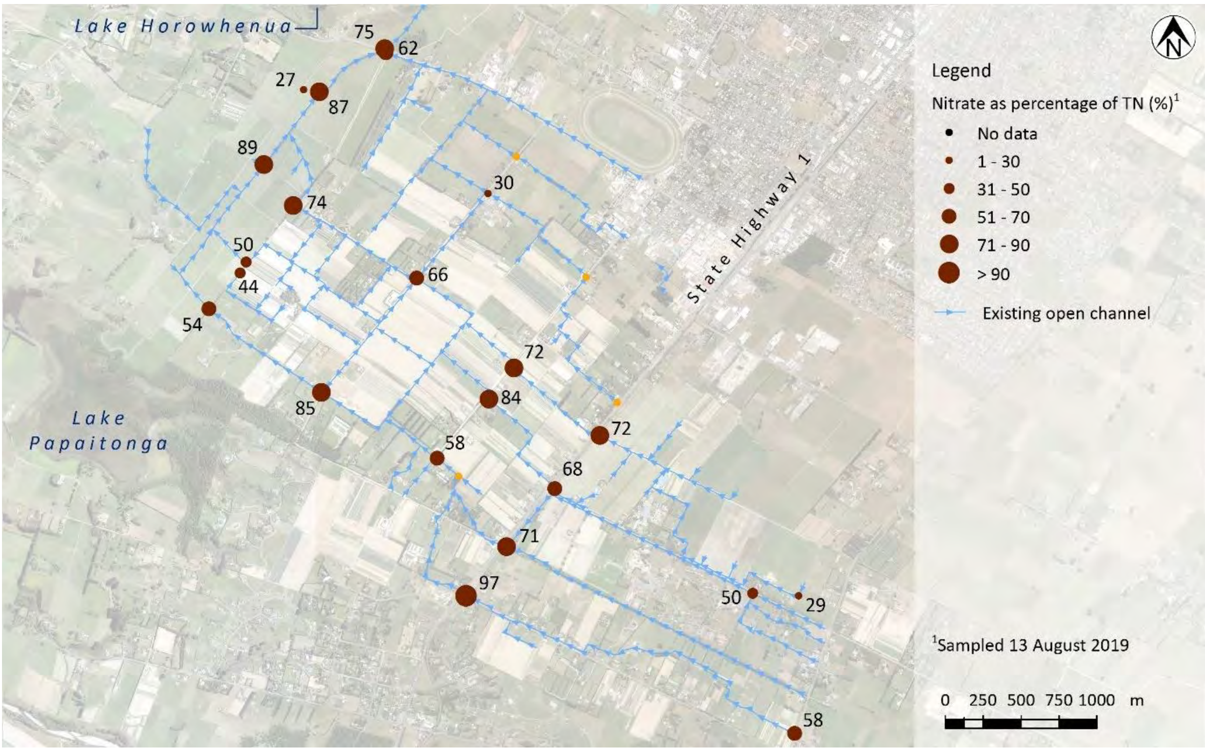


Figure 5. Nitrate as proportion of TN from one-off multi-site sampling (13 August 2019).

2.1.3 Phosphorus

Phosphorus is predominantly lost from cultivated horticultural land in the form of particulate phosphorus attached to sediment in overland flow [21]. This association means that phosphorus is readily captured through settlement-based methods that target sediment [35]. Monthly SoE monitoring data from Hokio Beach Road confirms that this relationship exists between TSS and total phosphorus (TP) for the Arawhata catchment (**Figure 6**).

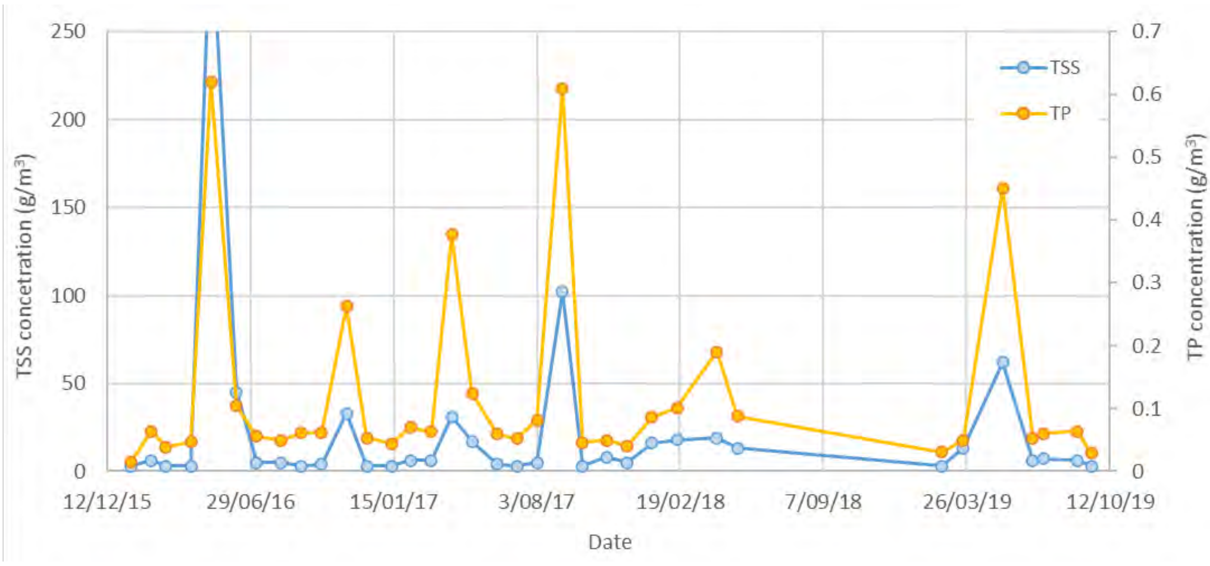


Figure 6. Monthly SoE concentrations for TSS and TP at Hokio Beach Road (y-axis truncated)

Monthly SoE monitoring at Hokio Beach Road shows TP concentrations ranging from 0.02 g/m^3 to 0.62 g/m^3 with a mean of 0.12 g/m^3. A high of 2.78 g/m^3 is reported when event-based sub-daily records are included. The multi-site sampling shows a range of 0.10 g/m^3 to 1.34 g/m^3 with a mean of 0.49 g/m^3 (**Figure 7**). The concentration of dissolved reactive phosphorus (DRP) ranges from 0.01 g/m^3 to 0.11 g/m^3 for the Hokio Beach Road SoE samples, and is as high as 0.23 g/m^3 in the sub-daily record. In the multi-site samples the range is 0.04 g/m^3 to 0.23 g/m^3.

The fraction of TP present as DRP is relatively high at approximately 25% for both the SoE samples and the multi-site data, and is inversely related to the concentration of TP (**Figure 8**). This figure compares to 5% for cropping land elsewhere in New Zealand [35].

The DRP fraction ranges from 9% to 96% in the Arawhata Stream samples, and from 10% to 54% in the multi-site data. This observation is important because it indicates the presence of a significant proportion of phosphorus that is not able to be removed through sediment retention devices and so must be addressed specifically. This is likely to take the form of heavily vegetated wetlands in which DRP is taken up by plants [30].

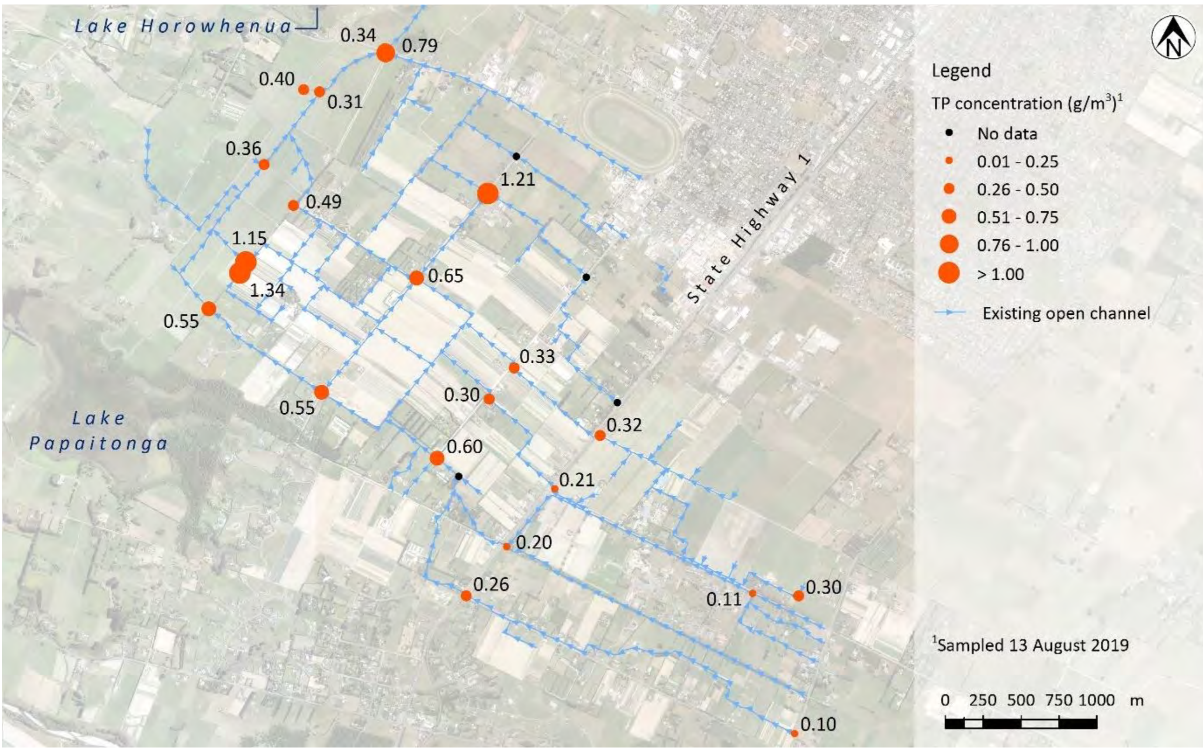


Figure 7. Observed TP concentrations from one-off multi-site sampling (13 August 2019).

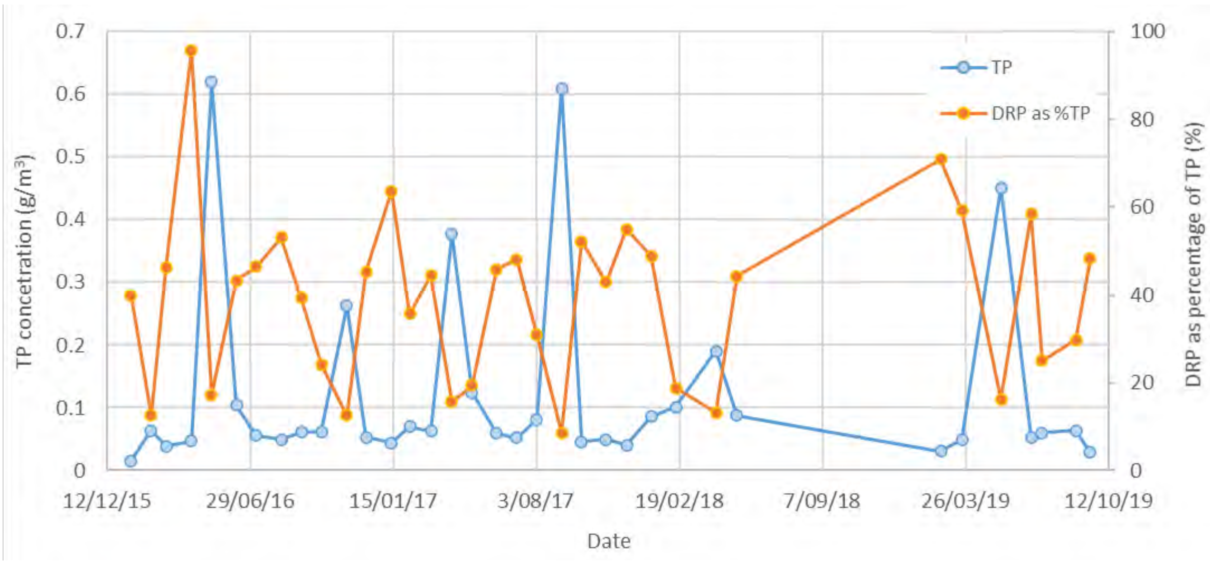


Figure 8. Relationship between TP concentration and the proportion present as DRP at Hokio Beach Road

2.2 Groundwater

Several studies have investigated the age and quality of groundwater, and the extent of groundwater-surface water connectivity in the catchment. A high degree of connectivity exists between groundwater and surface water in the Horowhenua Groundwater Management Zone (HGWMZ) [1], [4], [5], [7]. This connectivity indicates ready transmissibility of nutrients from surface activities to groundwater for conveyance to Lake Horowhenua via the drainage network.

Groundwater inflows are known to be a major source of nutrients to the lake [4]. All groundwater outflow from the Lake Horowhenua groundwater catchment flows into Lake Horowhenua and does so via surface flow, including the Arawhata Stream and drains [2]. Under baseflow conditions, the Arawhata Stream is thought to be entirely groundwater-fed (Logan Brown, pers. comm.).

The shallow bores of the HGWMZ, while not well represented within the Arawhata catchment itself, show 'hotspots' of high nitrate concentration [5]. High recharge rates in the HGWMZ bores are also consistent with high nitrate concentrations in the area [1]. Surface water samples at low flows (i.e. baseflow with groundwater contribution to or from surface water) show very similar water quality characteristics to samples from shallow groundwater bores [5], further illustrating the connectivity.

The spatial representation of groundwater nitrate is discussed further in **Section 3.5**.

2.3 Monitoring

Water quality monitoring in Arawhata Stream is necessary to detect changes in response to land use activity and mitigation measures, and to identify locations for targeted placement of specific interventions. The importance of long-term monitoring to allow for adaptive management is also stressed so that actions can be refined where a goal is not achieved [12], [17]. Performance monitoring was proposed for the HRC sediment trap [13] and would apply equally to any interventions resulting from the present project. Monitoring also enables early intervention when a problem is first detected [17] as the basis for adaptive management.

Water quality in the catchment is currently only recorded in the Arawhata Stream at Hokio Beach Road, i.e. just upstream of the catchment outlet, at monthly intervals, with the exception of the one-off distributed sampling described in **Section 2.1**. This makes it difficult to discern patterns at a finer spatial scale throughout the catchment which may be required to inform targeted placement of drainage water treatment measures. A lack of understanding about nitrate 'hotspots' in the catchment, for example, has been noted as an impediment to the installation of bioreactors [15].

It has previously been noted that significant gaps exist in water quality data that make it difficult to identify trends, measure the effectiveness of interventions, or to separate natural from human influences [12], [17]. The inconsistency of previous HGWMZ water balances with each other has been attributed in part to the lack of monitoring data on lake inflows [4]. A lack of reliable flow statistics for deriving nutrient budgets in the catchment has been noted, as some One Plan water quality targets are only relevant under particular seasonal and flow conditions [16].

Monitoring gaps and the limitations they impose on management decisions have been recognised by HRC and are being progressively addressed. Flow, turbidity, temperature, and dissolved oxygen are now recorded continuously at Hokio Beach Road, although TSS and nutrients are still sampled monthly. The limitations of 'snap shot' sampling in the catchment was also acknowledged during the recent HRC-led monitoring workshop [34].

Recommendations from the monitoring workshop that are aimed at improving the spatial and temporal resolution of flow and water quality information in the catchment include:

- Continuous monitoring of flow, turbidity, and nitrogen in the drains between the cropping land and the proposed wetland site (i.e. Kane Farm property). This is assumed to mean the four main network branches that run perpendicular to the contour.
- Monitor water quality in the Hokio Beach Road drain upstream of the confluence with the Arawhata Stream to separate urban sources of nitrogen and phosphorus from farming sources.
- Monitor nitrogen in tile drains to understand where and when nitrate is being lost from the soil profile to the drainage network.
- Development of a groundwater model with high resolution around Lake Horowhenua to better understand flow and contaminant transport from groundwater to the lake.
- Continuous monitoring of shallow groundwater levels to relate to continuous flow monitoring in Arawhata Stream.
- Monitor chemistry within the main Arawhata Stream channel to understand surface water-groundwater interactions to inform design of wetland within Kane Farm.

2.4 Arawhata drainage network

The network of channels that drain the Arawhata catchment (a subset of the larger Hokio drainage scheme) is understood to be central to the environmental issues in the catchment, acting both to mobilise soil from farms and to transport sediment to Arawhata Stream. The drainage network (as surveyed – discussed further in **Section 3.1**) is shown in **Figure 9**.

Undersized culverts and other constrictions [10] in the drainage network cause high flows to overtop the channel banks at discrete points and scour soil from farmland which is then transported downstream via the network of channels [9]. The frequency with which this occurs is not known but the network is understood to currently be unable to pass the level of service flows without overtopping [13]. The level of service is understood to be the 5% annual exceedance probability (AEP) event [20]. Infilling of some of the old water races that comprise the upstream sections of the network is understood to have driven many of the drainage issues in the past [8], particularly the cross-slope interceptor drains [6]. The configuration and refurbishment status of the drainage network is discussed further in **Section 3.1**.

[10] Historic infilling of channels, weed growth, slumping, etc.

An annual inspection of the scheme's assets noted that they are generally in good condition (as at 30 June 2017), and that there is currently no community desire for increased levels of service [8]. Performance charts indicate 100% of assets meet their drainage, erosion, and flooding performance levels of service, requiring only minor maintenance such as clearing channels, unblocking culverts, and maintaining the gradient. This sentiment is somewhat at odds with other sources of information [e.g. 9], and a programme of culvert upgrades and channel realignment works within the scheme has nevertheless been proposed as part of the capital works plan, specifically to reduce sediment and nutrient runoff from farms [8].

The network upgrade program has not been seen as part of this review, and the asset maps referred to are not included in the asset management plan. However, it is assumed to be the upgrade referred to in Arawhata stream sediment trap Lake Horowhenua – Resource Consent Application [13] which states that HRC will provide an outlet for all on-farm drainage systems, upgrade eight road culverts, enlarge or regrade 6 km of drains, and increase drain maintenance by spraying and machine cleaning. The source of this information, and whether or not the work has been undertaken, is not clear from the reports but at least some of it is understood to have been completed as part of HRC's ongoing network refurbishment (Paul Arcus, pers. comm.). Network refurbishment is discussed further in **Section 3.1**.

A 2008 review of the Hokio drainage scheme noted that no significant improvements were required, and that little more could be done to improve water quality [6]. Water quality effects were attributed to land use rather than scheme drainage practices. However, subsequent reports highlight the relationship between scheme performance and water quality, and the clear need for further network upgrades. The 2008 review concluded that little justification existed for extending the scheme further upstream in the Arawhata catchment to incorporate the old water race sections but, paradoxically, went on to recommend that this happen [6]. It is understood that the scheme was indeed expanded to service the entire Arawhata catchment and that is the network that exists today.

Improving the hydraulic performance of the network has been described as the single most effective way to reduce sediment impacts in the catchment [9]. While observations support this, we note that improving performance for drainage purposes may also enhance the efficiency with which any entrained sediment is transported downstream. Ongoing conflict is also reported to exist between the standard of drainage that Horowhenua District Council provides for roads in the area and the higher drainage expectations of adjoining landowners [6].

2.5 Sediment and nutrient management

It has long been recognised that "turning off" the sediment and nutrient sources from the catchment is the highest priority in restoring Lake Horowhenua [11], [17]. To this end, the Lake Horowhenua Accord Action Plan outlines 15 management actions aimed at restoring Lake Horowhenua [18]. Of these, two – creating drainage and sediment control plans for the cropping farms [9] and constructing a sediment trap and treatment wetland [14] – are directly relevant to this project. Both of these actions have been completed.

A number of additional actions have been implemented or recommended throughout the catchment to reduce sediment loss and transport. Collectively, these loosely follow a 'treatment train' approach, comprising a suite of 'at-source' measures to minimise the mobilisation of soil from individual farms, amendments to the drainage network to reduce channel overtopping and surface flooding, and an end-of-catchment sediment trap to capture sediment that has become mobilised.

2.5.1 Drainage and Erosion Management Plans

A series of farm-specific Drainage and Erosion Management Plans (DEMPs) have been developed to manage sediment and nutrient issues associated with productive land as part of the Fresh Start for Freshwater Clean-up Fund [9]. The DEMPs assessed erosion risk within individual paddocks and described actions required to manage drainage and reduce sediment loss to waterways. Farmers are reported to have generally been receptive to the recommendations and have carried out many of the proposed activities, often with anecdotally positive outcomes (Dan Bloomer, pers. comm.).

This work assessed drainage patterns using terrain modelling to understand how flooding and soil loss could be reduced by reshaping the land surface and changing farming practices [9]. Recommended source control measures included reshaping headlands to slow runoff velocities, changing crop row orientation to run down rather than across slopes to enable free discharge from furrows, lowering downslope headlands to allow free discharge of runoff to drainage channels, and removing raised traffic lanes and other impediments to surface flows. These measures are intended to prevent water accumulation and subsequent 'blow-outs' which can liberate large quantities of sediment to the network. Vegetating headlands to bind soil and intercept any mobilised sediment was also suggested. Where these measures are not feasible, remaining options are to implement downstream sediment traps or retire land from production.

A key recommendation of the DEMPs was to allow for drainage from farm blocks to the network. While positive outcomes of this work have been reported, some contradictory advice exists. For example, orientating crop rows downslope is recommended so that water can drain freely from furrows [9], while, conversely, orientating rows across the slope is encouraged elsewhere so that high velocity runoff down furrows is not able to mobilise sediment [12]. However, the relatively flat terrain in the Arawhata catchment may not generate the highly erosive velocities seen elsewhere, and Woodhaven have indicated they will only ever run their rows down-slope (Jay Clarke, pers. comm.).

Additionally, some farmers have constructed stop banks to keep flood flows in channels to prevent flooding of farmland [9]. The specific location of these actions are not recorded in the DEMPs. Stop banks may be locally effective but may also push the problem elsewhere and, if the banks do overtop, flood flows may be prevented from freely draining from farms back into the channels. These examples highlight that the 'answer' to one problem may make another problem 'worse'. In our view this dichotomy needs to be explicitly addressed for any proposed management actions, and is a driving factor in developing a catchment-wide response.

2.5.2 Water quality interventions

The installation of grass buffers along drain edges to intercept mobilised sediment, and silt ponds at the bottom of each property, have long been recommended [6]. Even narrow buffer strips adjacent to drains have been shown to be effective at intercepting sediment-laden runoff [9]. Recent trials in the Arawhata catchment found that no sediment was transported beyond grass buffer strips [21] although it was noted that no large storm events occurred during the trial period. Accumulated sediment within the strips at the lower edge of the paddock may eventually form a barrier which acts to impound flows and inundate cropland [35]. Deliberate breaching of such an impoundment, and the impact this has on network water quality, is shown in [35]. For this reason it is important that the headlands are reshaped to be lower than row furrows [9], [35].

Trials of sediment retention pond (SRP) performance on Pukekohe cropland showed that a pond volume of 0.5% of the contributing catchment area was very effective, detaining more than 95% of eroded sediment from paddocks [35]. As phosphorus is largely attached to sediment in the form of particulate phosphorus on cropland, SRPs were also found to reduce phosphorus losses beyond the pond by more than 98%. The use of floating decant systems further improved the sediment reduction efficiency. This finding contrasts with typical New Zealand guidance on the construction of SRPs which recommends a pond volume of 3% [25], [26], [27].

The smaller pond size recommendation is due to the relatively low volumes of runoff generated on cropland compared to an equivalent area of compacted construction site for which erosion and sediment control guidelines are strictly intended (Andrew barber, pers. comm.). This point illustrates the importance of context-specific design, particularly where pond construction displaces productive land and there is an imperative to reduce device size without compromising performance.

SRPs may be less effective in the flatter terrain of the Arawhata catchment where adequate grade between the dead storage level and the drain to which decanted flows are discharged may not always be available (Andrew Barber, pers. comm.). Even in situations where SRPs are appropriate, it may be necessary to break larger paddocks into smaller catchments, each with their own trap [25]. Vegetated buffer strips are expected to be more effective in the Arawhata catchment given the generally lower runoff volumes and velocities generated.

Strip-cropping, in which remaining crops retain sediment during harvest of adjacent rows, has also proven effective (Dan Bloomer, pers. comm.). Binding of tilled soil on cropped land with an anionic polyacrylamide to reduce erosion during irrigation and heavy rainfall has also been suggested [11].

In managing the effects of erosion, a distinction can be made between sources of flow, i.e. whether erosive runoff is generated within the paddock itself, or whether flows enter a paddock from an adjacent property or the road reserve. Farmers have commented that they are generally able to manage the effects of rainfall within their blocks but that problems arise when concentrated flows enter from overtopping channels or the neighbouring property [9], emphasising the importance of intercepting surface flows at the upslope edge of paddocks. This observation highlights the need to separate the core project objectives of effective drainage and reduction of sediment loss when considering management options. It is this effect that calls for a catchment-wide, rather than farm-specific, assessment of the issues.

2.5.3 Downstream mitigation measures

The philosophy behind the DEMPs was that it is best to have cropping practices that prevent sediment generation in the first place (Dan Bloomer, pers. comm.). Then, if sediment does become mobilised, traps on cross-drains can be used to retain sediment on farms, and, if those also fail, the end-of-catchment sediment trap is expected to capture much of the remaining sediment load.

Downstream measures proposed have included on-paddock drains to capture sediment-laden runoff prior to it entering the main drainage network, with captured sediment returned to paddocks [[9]. Sand-bagging within the drains has been used to flatten grades and reduce velocities to encourage sediment deposition. It is noted, however, that sediment accumulating in this way could reduce storage capacity in the drains such that the risk of flooding and sediment remobilisation may increase unless regular excavation of captured sediment is undertaken.

Installing sediment retention ponds on the down-slope side of cropland and returning trapped sediment to the paddock has also been suggested to reduce nutrient loading to the main network [12] (although this would only be effective against particulate phosphorus). Where on-paddock silt traps or wetlands are large, however, they can be viewed as a waste of productive land. This has been cited in at least one case for not proceeding with a proposed wetland in the catchment (Dan Bloomer, pers. comm.).

As noted in **Section 2.4**, refurbishment of the drainage network by HRC is continuing to improve channel capacity through enlarging and regrading drains and upsizing culverts. Using sprays instead of mechanical means to control weeds has been suggested to reduce in-channel sediment generation [12]. While drainage improvement is a core objective of this project, we note that it may work against the sediment retention objective by more effectively transporting sediment to the catchment outlet. In-channel interventions aimed at capturing entrained sediment, whilst maintaining flood conveyance, are therefore likely to be a part of future actions.

2.5.4 HRC sediment trap

A sediment trap and associated diversion structure were constructed at the downstream end of the Arawhata Stream by HRC in 2017 as part of the Fresh Start for Freshwater Clean-Up Fund. The trap is intended to remove sediment and nutrients from the stream that have not been retained by source-control measures [13], [14]. The trap was designed to retain sediment mobilised during extreme rainfall events, with smaller flows bypassing the device for direct discharge to Lake Horowhenua. Pre-construction modelling indicated that up to 80% of the Arawhata Stream flow would be diverted into the device during high-flow events, and that 65% of all sediment entering the trap would be removed under these conditions [13]. During smaller events (of unstated return period), up to 50% of sediment is expected to be removed.

The design premise for the trap is that most sediment is mobilised during extreme storm events. The trap is therefore currently configured to only remove relatively coarse sediment given the relatively short residence times and velocities associated with flood flows. Finer sediment will continue to discharge to the lake either via the main channel or by passing through the trap. This is important because fine sediment is the major vector for phosphorus [11], [18] and 80% of phosphorus enters the lake in particulate form attached to soil [12]. Fine sediment is also conveyed during normal channel flows (Dan Bloomer, pers. comm.).

While stated in the sediment trap resource consent application [13] that the trap will also have benefits for reducing phosphorus and nitrogen, it is noted that no specific mechanism for nitrogen removal is described and the trap, as currently configured, is unlikely to reduce the load of this important contaminant due to its solubility in water. The system is also described at times as a wetland [10], [13]. However, it does not strictly function as a treatment wetland due to the lack of permanent standing water, wetland plant communities, and associated treatment pathways.

A monitoring programme was proposed for the sediment trap over the first year of operation to measure its effectiveness [13]. It is not known if this has occurred, if any performance data to verify the modelling exists, or if a programme of ongoing monitoring has been established. The consent application does, however, acknowledge that the trap may be modified over time to improve its sediment removal performance if monitoring indicates this should happen [13]. Modifications are understood to be scheduled for 2021, including removal of vegetation that currently impedes diversion of flows into the trap from Arawhata Stream (Logan Brown, pers. comm.). HRC are investigating opportunities for the sediment trap to be engaged more frequently so that a higher proportion of fine sediment can also be removed.

2.5.5 Nutrient management

Nutrients can be effectively managed using well-designed wetlands [30]. While it has been reported that a number of wetlands are either under construction or planned within some farms in the catchment [19], it is understood that none have in fact been constructed, at least partly due to concerns about loss of productive land (Dan Bloomer, pers. comm). A concept design is being developed, however, for a wetland within the Kane Farm property that is specifically geared towards nitrate management (Logan Brown, pers. comm.). The high nitrate levels reported in groundwater, and the close hydraulic connection between groundwater and surface water in the catchment, means that any wetland constructed in the lower catchment should be optimised to account for both water sources.

The planned construction of a bioreactor within the network to strip nitrate from drainage water has also been reported [15], [19]. To be effective at reducing nitrate loads, a bioreactor must be located in an area of high nitrate concentration and low flow [19]. However, no information on nitrates or channel flow currently exists at a sufficiently fine spatial and temporal scale in the catchment to support targeted placement of bioreactors [15].

3 Data Review

3.1 Drainage network

Limitations in the Arawhata drainage network have been identified as a critical driver of sediment loss from farms and subsequent transport to Lake Horowhenua via the Arawhata Stream [9]. Long-term management of the drainage system is therefore important, but this relies heavily on having accurate and up-to-date spatial representation of the network elements, features which affect hydraulic performance, and functional status.

The alignment and grade of major channels and culverts were surveyed in 2014. A CAD file of the network was provided to T+T for review (**Figure 9**). This comprises 38,038 m of channel and includes 215 culverts. Channel cross-sections and invert levels were defined at points along the network and provided separately in spreadsheet form. This information can be used to estimate channel capacity and ultimately to develop a hydraulic model if required. It is noted that a MIKE 11 model was previously conceived by HRC but was subsequently not progressed [20].

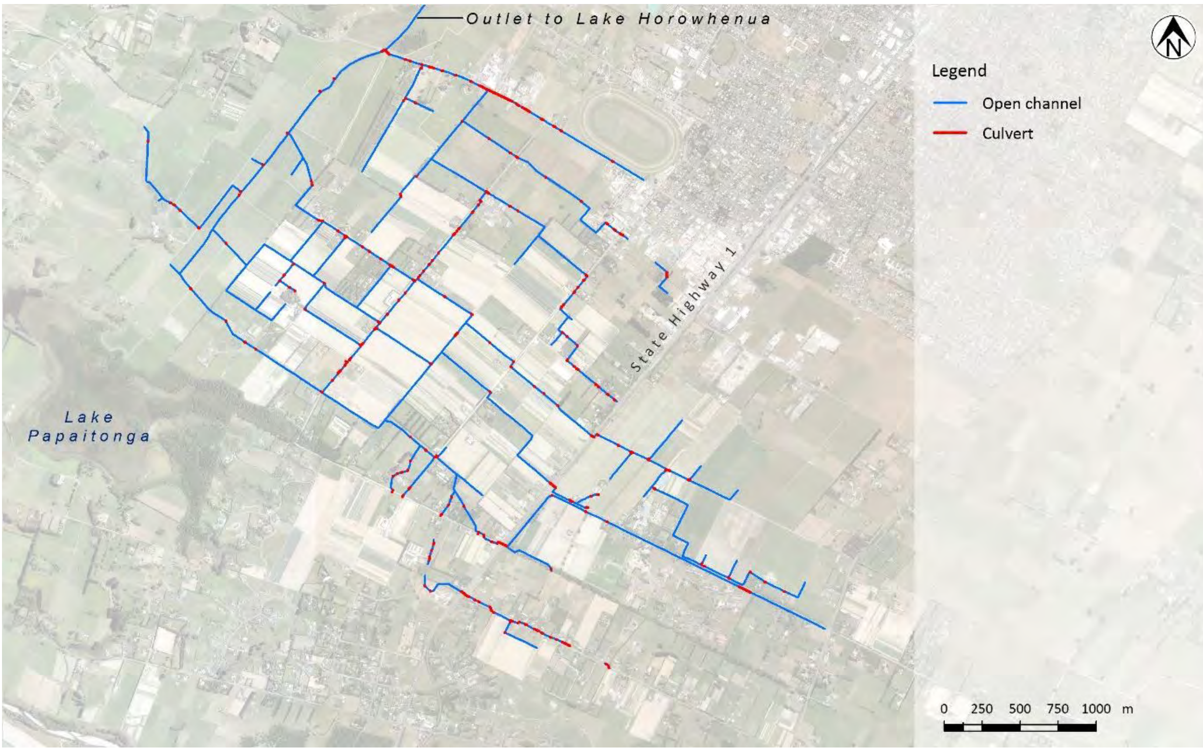


Figure 9. Hokio drainage network as defined by the 2014 survey. Total channel and culvert length 38,038 m.

The total number of culverts is likely to be greater than the survey indicates as parts of the network that appear to be culverts from the aerial photographs are not classified as such in the CAD file. The location and nature of specific flow constrictions [11] (other than undersized culverts) – information that is critical to understanding wider system performance – were not captured during the survey.

An earlier survey of the scheme conducted by MWH in 2007 is referred to in [6]. This information was not reviewed as part of this project but is understood to have defined areas where flow was

[11] Historic infilling of channels, weed growth, slumping, etc.

impeded. The survey report concluded that the four main races surveyed were in reasonable condition and required only relatively minor works to improve capacity and alignment.

Additional channels that are clearly discernible on aerial photographs and the DEM have also not been captured. It is understood that the scope of the survey was to capture "major" drains only, although no definition for "major" was established (Quentin Gilkerson, pers. comm.). The remaining drains are considered "minor" in that they only drain a single paddock.

A second dataset of the drainage network was provided to T+T following a meeting with John Foxall and Paul Arcus of HRC on 2 March 2020 (**Figure 10**). This network differs from the 2014 surveyed data in terms of total channel length (33,924 m) and the alignment of some of the channels. Each network contains channels that do not feature on the other such that the collective length of both networks is approximately 46,100 m. The second dataset provides information on channel upgrades that have been undertaken since the 2014 survey to improve conveyance function (as at February 2019). Specifically, while not noting the nature of the upgrade, it shows sections of network that have been refurbished (19,259 m), sections for which further work is considered to be required (6,857 m), and the remaining areas for which no landowners have apparently raised concerns (7,808 m).

It is understood that the remaining sections of drain to be refurbished are based on feedback from landowners [9] and field observations by HRC staff. For example, some road crossings are thought by HRC to be acting as inadvertent sediment traps at points where existing culverts constrict flow (Paul Arcus, pers. comm.). The location of proposed and completed culvert upgrades are not included in the dataset but are recorded elsewhere graphically [13]. It is assumed that channels marked as having been refurbished (and culverts within those channels) now operate to design capacity and require no further work.

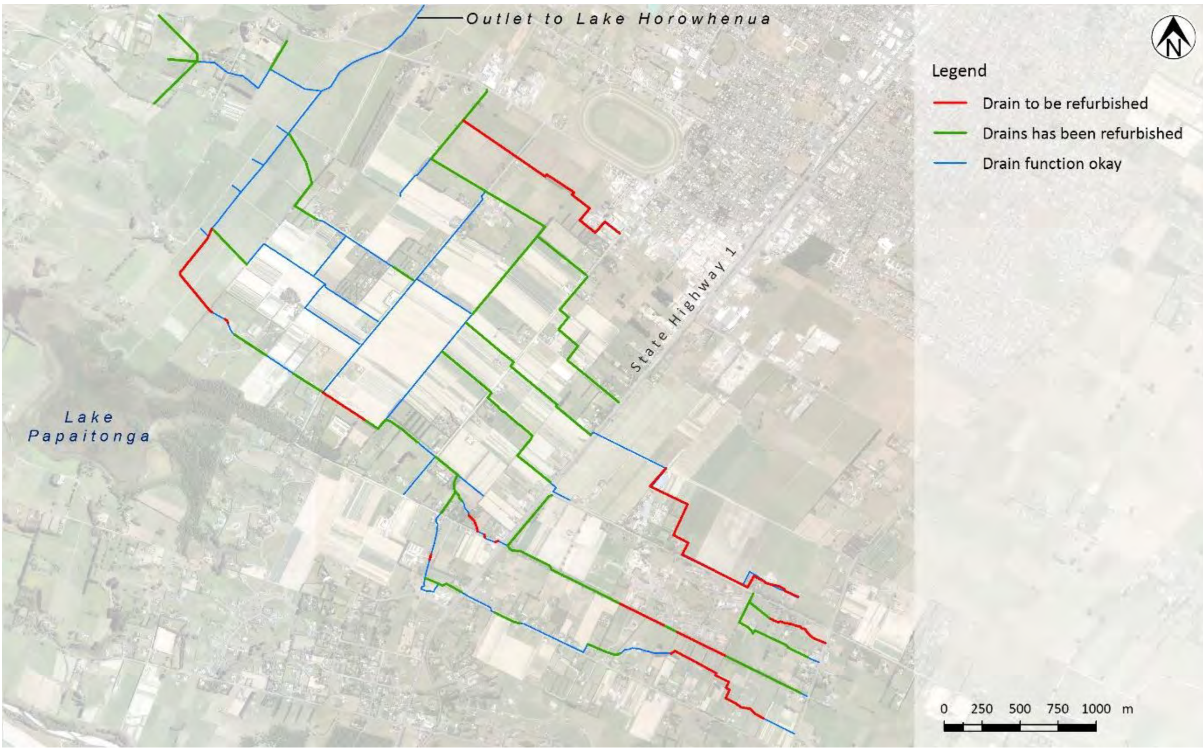


Figure 10. Hokio drainage network showing channel refurbishment status as at February 2019. Total channel length 33,924 m.

An internal HRC memorandum (26 March 2015) outlines the design approach to channel and culvert upgrades, stating that the design standard for the 'main drains' is to pass flows associated with a 5%

AEP event [20]. Calculations to support culvert upgrades are included, showing the 5% AEP discharge and culvert size required to pass these flows. These calculations were not reviewed as part of the data review but it is understood upgrades were undertaken on this basis.

No definitive extent of the Arawhata catchment is known to exist. Analysis of terrain data in GIS (refer **Section 3.2**) can be used to delineate the catchment but this would also require information on the position of any culverts upstream of the network, particularly at Arapaepae Road and Tararua Road. Channel capacity calculations will depend on knowledge of full flow contributions into the upstream end of the network.

3.2 Terrain data

Terrain data was provided as a 1 m resolution LiDAR-derived digital elevation model (DEM) covering the entire Arawhata catchment and surrounds. Provisional checks have shown the DEM to be suitable for various GIS-based analyses that will support later stages of the project, including overland flow path definition, catchment delineation, and identification of surface depressions that may inform the placement of sediment traps, wetlands, or other detention structures. Example DEM derivatives produced during these checks are shown in **Figure 11**.

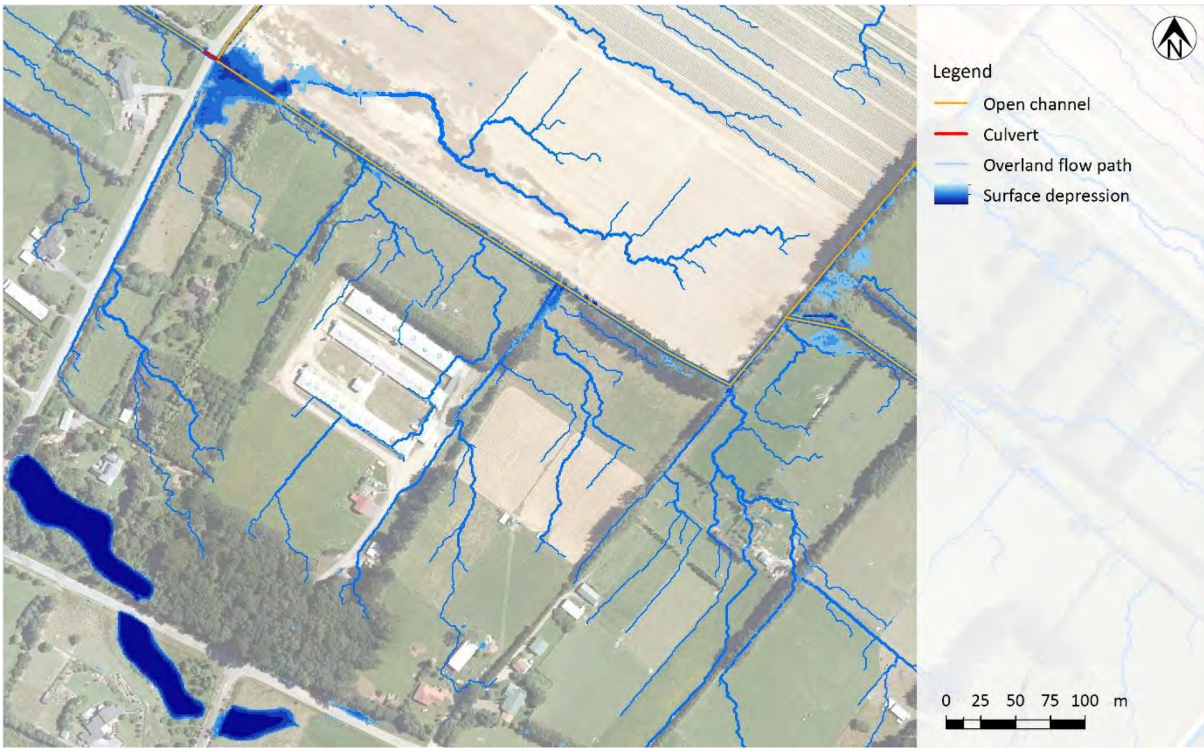


Figure 11. Examples of overland flow paths and surface depressions that can be extracted from the DEM.

3.3 Surface water data – flow

Flow in the Arawhata Stream is now gauged continuously at the Hokio Beach Road monitoring site. A three-year period (2017-2020) of mean daily flows was distilled from the continuous record to observe general flow conditions (**Figure 12**). Mean daily flow rates range from 46 L/s to 2,645 L/s over this period, with an average of 219 L/s.

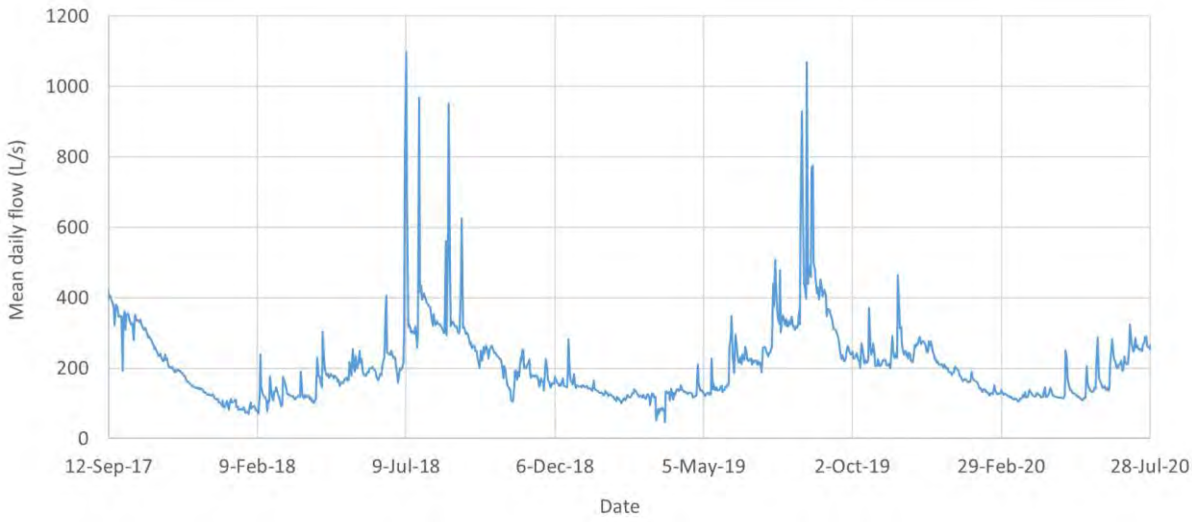


Figure 12. Mean daily flow in the Arawhata Stream at Hokio Beach Road (2017-2020)

While mean daily flows do not allow instantaneous peak flow rates to be identified (which are important for understanding network capacity), they do provide an indication of the seasonal variability of flow and are suitable for informing the sizing of wetlands for nutrient removal purposes.

While stream flow in the main Arawhata Stream is permanent (sustained by groundwater), the remainder of the drainage network remains dry outside of rainfall events (Logan Brown, pers. comm.). This is noted as a significant constraint for the implementation of wetlands at a sub-catchment scale due to the inability to sustain wetland plant communities.

Event-based flows were gauged in a one-off series of measurements at 22 sites throughout the catchment in relation to a single rainfall event on 13 August 2019 (**Figure 13**). While this data was collected over a three-hour period, and therefore does not describe the same part of the hydrograph at each site, it does provide a broad indication of flow allocation across the drainage network. The data reveals that the majority of flows are concentrated in the southern-most 'Drain 1' branch of the network. Possible flow attenuation effects are apparent in the other branches at State Highway 1 where the flow rate is shown to decrease in the downstream direction. Contemporaneous gauging at the two Drain 3 locations either side of the highway may support this.

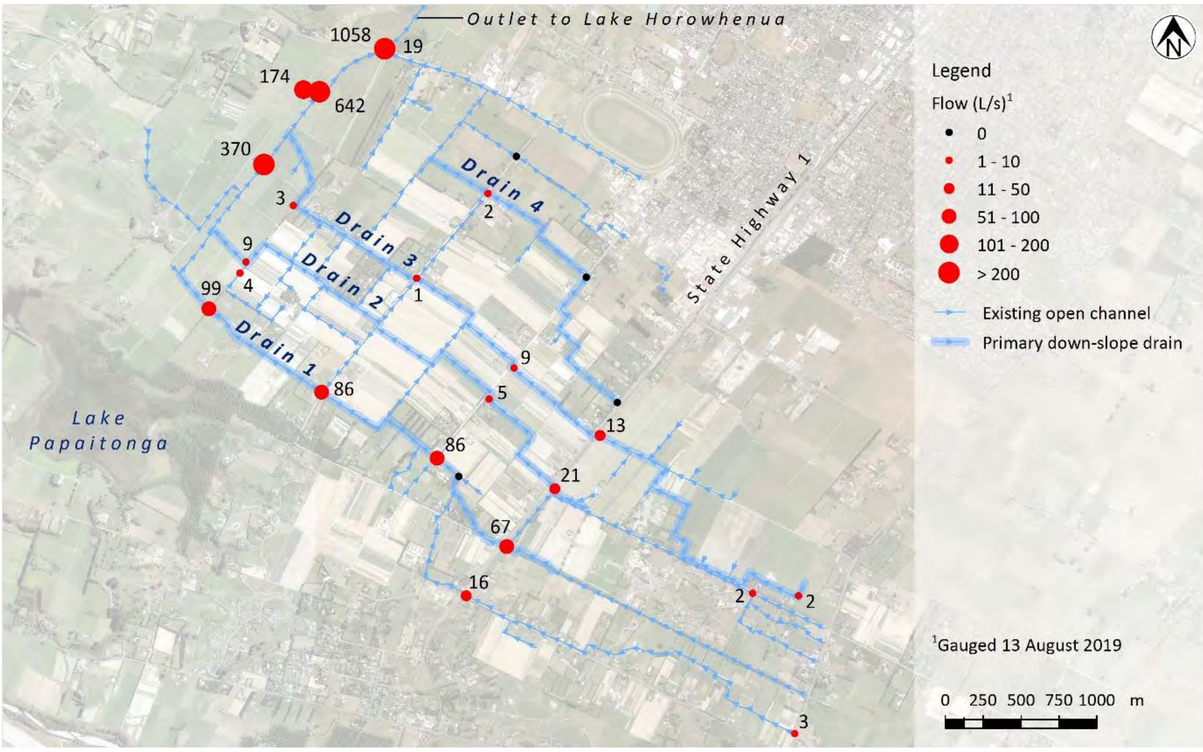


Figure 13. Gauging locations and observed flow rates during rainfall event of 13 August 2019

3.4 Surface water data – water quality

Water quality samples were collected at the same 22 locations noted in **Figure 13**, during the same event. The samples include TSS, total nitrogen, total phosphorus, and their constituent forms. The concentrations of key constituents have been mapped to provide spatial context to the sampling. Constituents in addition to those discussed in **Section 2.1** are shown in **Figure 14** (TN), **Figure 15** (nitrite), **Figure 16** (DRP), and **Figure 17** (DRP as a proportion of TP).

While limited conclusions can be drawn from a single dataset, this information provides a broad indication of sub-catchment variability in nutrient patterns during channel flows.

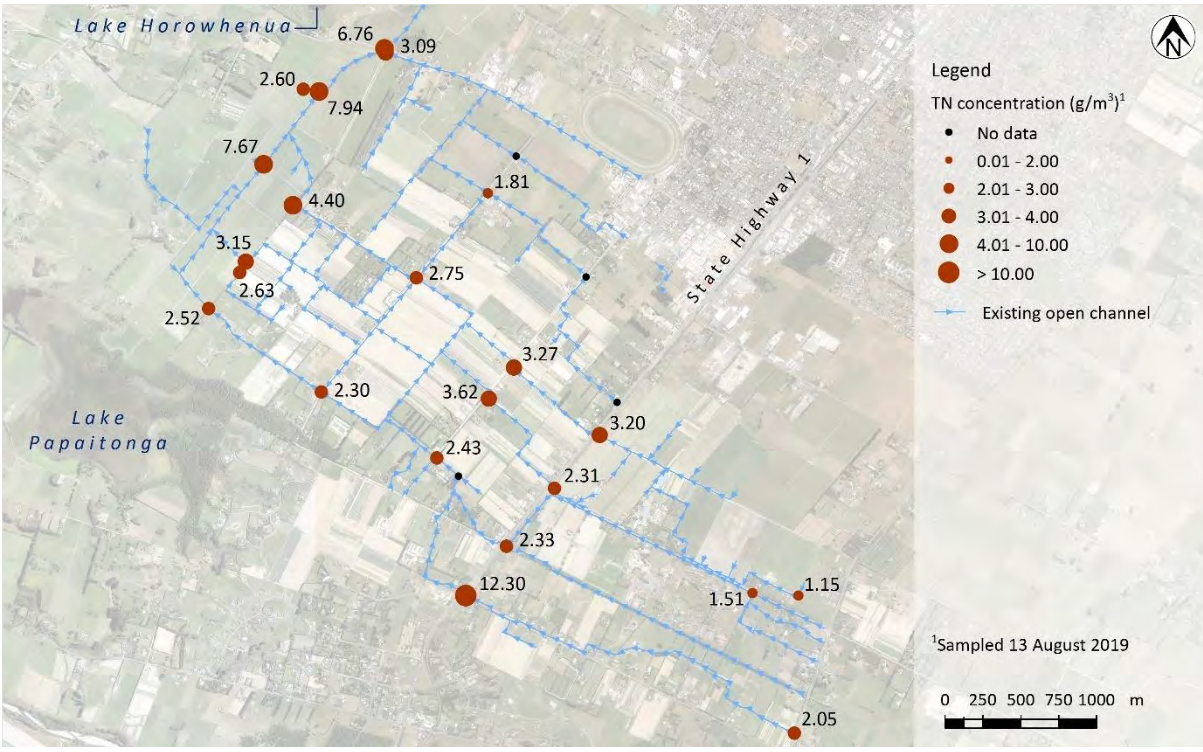


Figure 14. Observed TN concentrations from one-off multi-site sampling (13 August 2019).

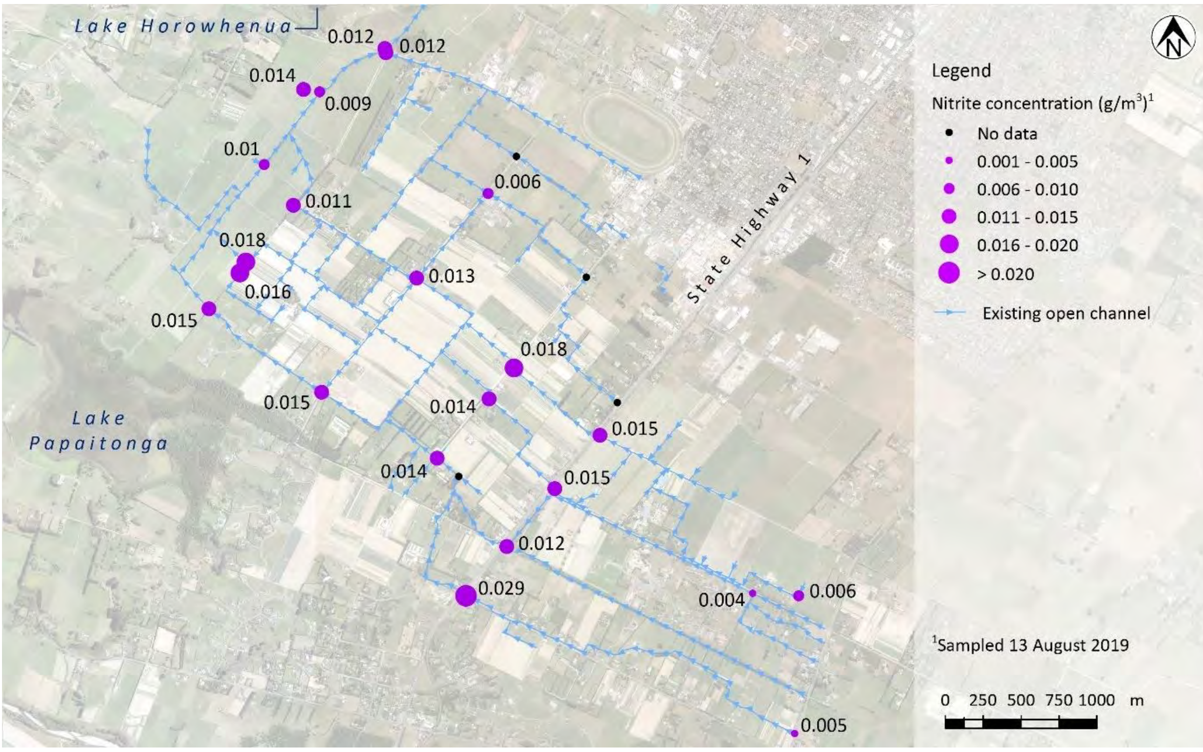


Figure 15. Observed nitrite concentrations from one-off multi-site sampling (13 August 2019).

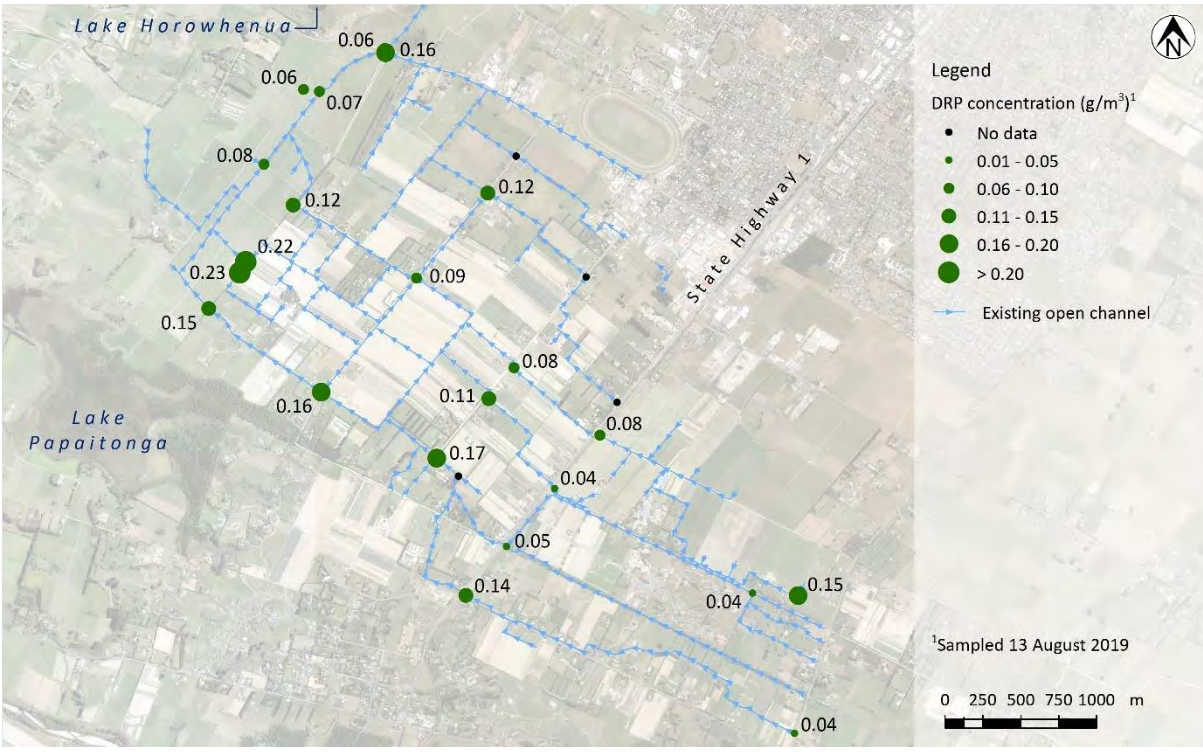


Figure 16. Observed DRP concentrations from one-off multi-site sampling (13 August 2019).

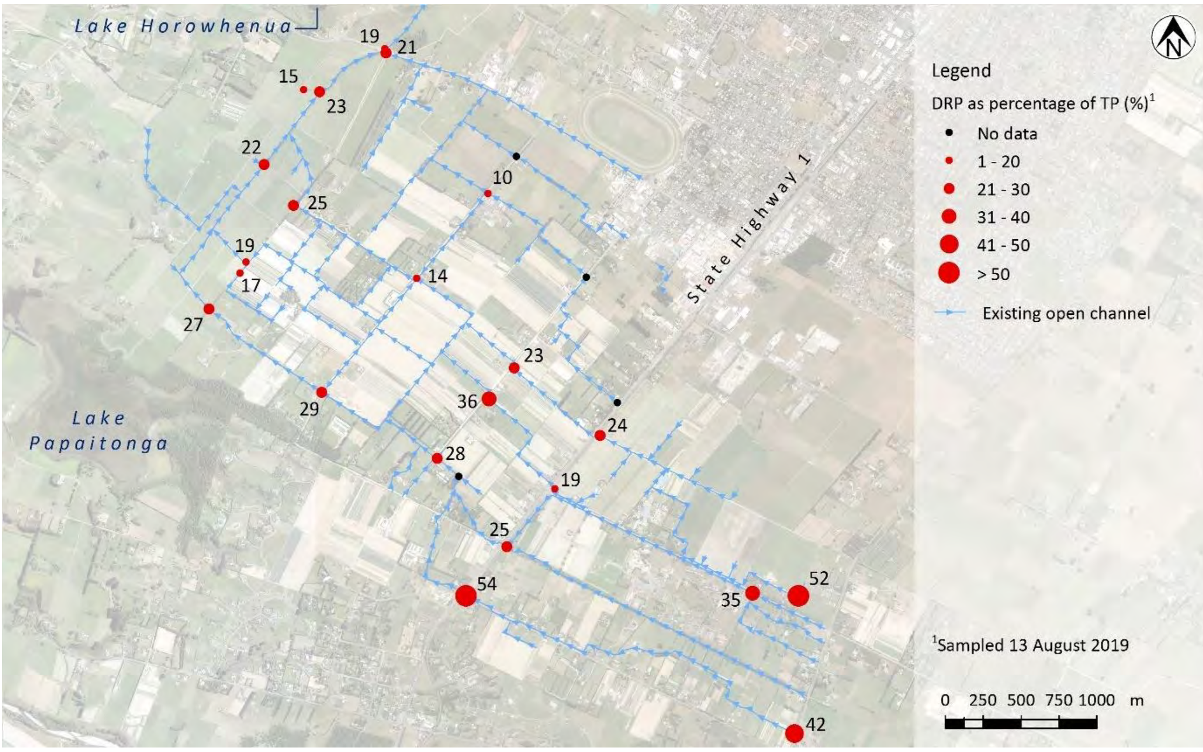


Figure 17. DRP as a percentage of TP from one-off multi-site sampling (13 August 2019).

3.5 Groundwater data

Groundwater quality data from wells within (and outside) the Arawhata catchment was provided in spreadsheet form [36]. Of the 121 wells represented, 42 are located within the Arawhata catchment. The sampling period within the Arawhata wells ranges from 1995-2016, with 1-6 samples recorded at each well over that period. The mean nitrate concentration at each well is shown spatially in **Figure 18**.

Over the sampling period represented, nitrate concentrations in the catchment ranged from 0.005 g/m^3 to 23.0 g/m^3 with a mean of 5.4 g/m^3. Other nutrient constituents are sparsely represented in the dataset and not reported here. The depth of sampling was not noted in the spreadsheet. A separate dataset [37] contains groundwater levels at two wells within the catchment (**Figure 18**). Approximately monthly samples from 1991-2019 show depths to groundwater ranging from 16.5 m to 32.4 m and 21.1 m to 27.7 m for the western and eastern wells, respectively.

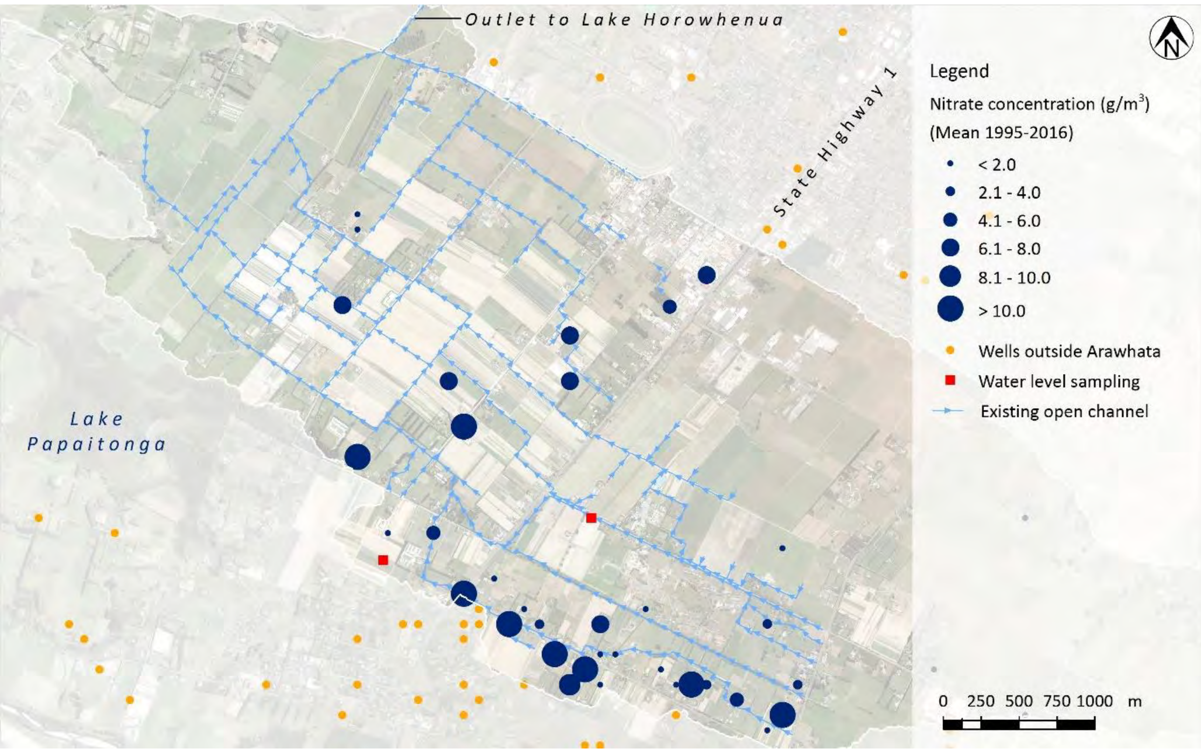


Figure 18. Mean groundwater nitrate concentrations in the Arawhata catchment (1995-2016)

3.6 Recommendations

Many of the reviewed datasets contain geographic identifiers, either as georeferenced spatial layers or spreadsheets in which sampling records have coordinates. It is recommended that a spatial database be created that brings all these datasets together into a common geographic framework so that spatial relationships among catchment features can be readily identified and spatial analyses may be performed. While much of this has been done in the course of completing the literature review, additional activities would further enable network improvements and other management activities to be visualised and tracked.

Key tasks include amalgamating the two drainage network datasets (i.e. surveyed and unsurveyed) into a single definitive reference, and attributing network elements with geometry and maintenance data. Geometry attributes aid network visualisation, such as the variability in culvert size throughout the catchment, and make the dataset more amenable to implementation in a hydraulic model, should that be a future consideration.

Key network attributes to include are:

- Culvert diameters and channel and culvert invert levels
- Target and actual levels of service

- Completed and planned upgrade and maintenance works
- Channel and culvert condition ratings

Additional spatial information to collate for the database could include:

- The location of specific issues within the network where these are known from field observations or communications with landowners.
- The location of planned, constructed, and rejected interventions, where these are gleaned from the DEMPs or conversations with farmers.
- Interventions that are proposed as part of this project.
- Surface water and groundwater quality parameters in addition to those mapped for this project.

4 Summary

This review indicates that the key mechanisms of sediment and nutrient generation and transfer in the Arawhata catchment are well understood in general terms (qualitative, perhaps semi-quantitative), but that sub-catchment-scale processes and water quality patterns are less well understood in a quantitative sense. An historic lack of long-term monitoring data that is collected in a consistent and coordinated manner has impeded the extent to which evidence-based decisions can be made. This is important because mitigation options should be designed to respond to the range of flow and water quality conditions expected, and management actions implemented on the basis of a general understanding only may lack the two, strongly inter-connected, objectives of flood reduction and improved water quality.

However, these limitations are recognised by HRC and are being progressively addressed through the planning and implementation of continuous flow and water quality monitoring programmes to improve understanding of the temporal and spatial patterns of flow and water quality in the catchment. These changes, once implemented, will help to expand the evidential basis for deploying physical management interventions and understanding the performance of significant capital works. More spatially and temporally comprehensive monitoring will also identify where additional interventions could most optimally be located, allow for adaptive management to improve the outcomes of existing actions where they have not met their design intent, and verify the anecdotal reductions in soil loss achieved through enacting the recommendations of the DEMPs.

While much work has been done in the catchment, the spatial record of the location and nature of interventions and maintenance activities, and how successful they have been, is somewhat inconsistent. The specific locations of flow impediments and other problem areas have also not been apparent in the documents reviewed, and the issues and recommendations of the DEMPs are not spatially explicit. It would therefore be beneficial to spatially reference this information and amalgamate it into a centralised spatial database.

Key information on network condition appears to be held by individuals or in ‘silos’ both within and outside HRC. Further discussions with HRC engineering staff, as well as landowner input, will be required to define problem areas and record these spatially so that specific responses can be developed. It is likely that other agencies, such as HDC and Waka Kotahi, whose assets continue to impact adjacent crop land through uncontrolled runoff, will also need to be consulted.

The combined effect of on-farm measures and channel upgrades to date has anecdotally been to reduce the incidence of surface flooding and soil loss from cropping land. The objective of the present project is to build on this work by identifying issues that remain and developing consistent interventions to address those issues. It is also important that any proposed interventions are appropriate to the local context. The proposal to install bioreactors, for example, must acknowledge the impact that a high sediment environment may have on the functional lifespan of these devices, despite successes elsewhere. Contradictory recommendations on optimum row orientation further emphasises the need to develop bespoke rather than generic measures that respond to specific circumstances.

Further scope exists to develop in-channel methods to capture sediment that continues to be mobilised, and to possibly modify the existing sediment trap to capture finer sediment and associated phosphorus. It is understood that HRC are currently investigating changes to the sediment trap to improve its performance, within the terms of the resource consent (Ramon Strong, pers. comm.). Nevertheless, it is important that the sediment trap continues to be seen as a final control measure and not a replacement for distributed upstream interventions. It is likely that multiple small interventions located close to the sediment source will be preferable to a smaller number of large downstream measures, both in terms of cost and performance. We understand that this approach aligns with HRC expectations. Because such interventions are inherently farm-based, landowner input is invaluable and it is imperative that their involvement continues.

A high degree of connectivity is expected between groundwater and surface water within the catchment and this adds a layer of complexity that does not appear to be explicitly addressed in current water quality interventions. This aspect of water quality and appropriate management actions will need to be further investigated. The discharge of groundwater to the drainage network does, however, create opportunities for the construction of denitrifying wetlands to intercept flows upstream of Lake Horowhenua. This is understood to be the reasoning behind the proposed Woodhaven wetland (Logan Brown, pers. comm.).

The DEMP source-control work was conducted on a farm-by-farm basis in the context of “the world starts at the edge of the paddock” (Dan Bloomer, pers. comm.). In doing so, it placed less emphasis on catchment-wide processes and the interactions between neighbouring properties. Although this approach makes it possible for an individual landowner to move forward, this review has highlighted that it may be resulting in missed opportunities and tends to focus on only one of the twin project objectives, i.e. flood reduction and water quality improvement. For this reason, a whole-of-catchment approach with a hierarchy of interventions – structural and non-structural – is likely to be the most effective way to further reduce sediment and nutrient flux to Lake Horowhenua. This notion aligns with HRC’s aspirations to move away from piecemeal interventions towards a more comprehensive approach (Jon Roygard, pers. comm.) and should form the basis of future work.

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