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memorandum

TO	Simon Stewart, Anna Lewis	FROM	Alana Bowmar, Lenka Craft and Daryl Irvine
	Palmerston North City Council	DATE	31 August 2022
RE	Land Application Area of Interest – Soils Interpretive Report		

1.0 Introduction

As a result of an optioneering process, Palmerston North City Council (PNCC) has identified that the best practicable option (BPO) for the management of Palmerston North's wastewater is a high level of treatment and a dual discharge of treated wastewater via land application and discharge to the Manawatū River (a variation of Option 2).

Previously, PNCC relied on direct discharge to surface water (the Manawatū River) only, so now there is a need to find a suitable area of land for the discharge to land component. To better inform this decision, Pattle Delamore Partners (PDP) has carried out soil investigations across the recently refined area of interest (Figure 1).

This memorandum has been prepared by PDP to interpret the soil investigation results as they impact the ability to discharge to land. A factual summary is provided separately in PDP Memorandum No. A03109214M006.

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A	FINAL	AUG 2022	AS

SOURCE:
1. AERIAL PHOTO DERIVED FROM LINZ DATA.
2. PROPERTY BOUNDARY DATA
3. CADASTRAL/TOPOGRAPHICAL INFORMATION AND INSET DERIVED FROM LINZ DATA UPDATED JULY 19, 2022.

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FIGURE
FIG 1: LAND APPLICATION - AREA OF INTEREST

PROJECT
WHEN NATURE CALLS - PNCC WASTEWATER CONSENTING PROJECT

2.0 Best Practicable Option

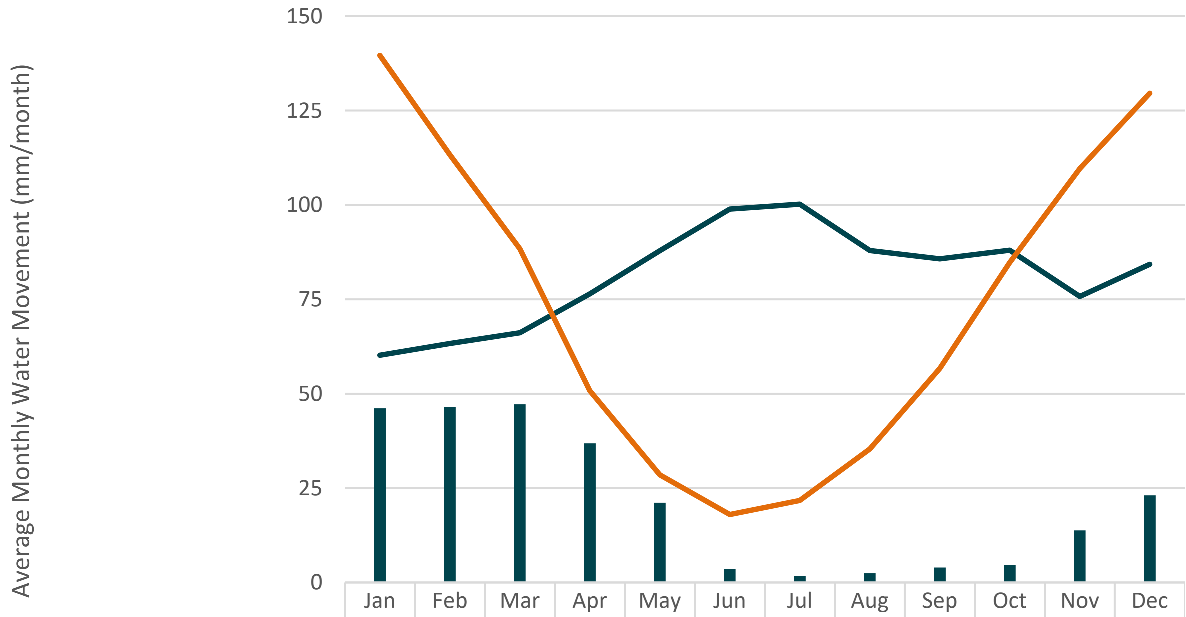
Optioneering processes to date have identified a best practicable option (BPO). In the context of the land application component, this option can be summarised as follows:

- High level of wastewater treatment.
- Discharge to land when the Manawatū River is less than half median flow (<37.5 m^3/sec).
- Discharge of up to 75% of the wastewater average dry weather flow (ADWF):
  - ADWF = 32,240 m^3/day (received from Aquanet 14 July 2022)
  - 75% of ADWF = 24,177 m^3/day

Based on flow records (2022) sourced from Horizons Regional Council for the Manawatū River at Teachers College flow monitoring station, the anticipated Option 2 average monthly irrigation distribution is summarised in Figure 2, based on an estimated long-term Land Application area of 530 ha.

Generally, the proposal results in greater irrigation depths when potential evapotranspiration (PET) exceeds rainfall. During these periods, much of the hydraulic load will contribute to additional biomass in the underlying farming system (i.e., pasture growth or other crop growth). This is because, without irrigation, water availability is expected to constrain growth at those times.

However, when irrigation would be required, it generally exceeds the hydraulic demand, and there are also times of year when irrigation and rainfall would exceed PET. At times of year when irrigation and rainfall exceed PET will be challenging to manage, requiring detailed consideration of the rainfall forecasting and potential storage. At certain times of the year, irrigation will contribute to increased drainage/infiltration to shallow groundwater (i.e. non-deficit). This will be especially true in late summer and autumn when rainfall increases but the river level is still low. This ultimately means that soil drainage will be a key factor in the sustainability of the land application system.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PNCC Wastewater Irrigation Supply	46	47	47	37	21	4	2	2	4	5	14	23
Rainfall	60	63	66	76	88	99	100	88	86	88	76	84
PET	140	113	88	51	29	18	22	35	57	85	110	130

Figure 2: Graph Showing Average Monthly Rainfall, PET, and Proposed Irrigation

3.0 Soil Types

For complete consideration of the soil types within the area of interest, this assessment has first considered the Manaaki Whenua's 'Fundamental Soil Layer - New Zealand Soil Classification' 2008 soil mapping. This spatial data is used as it spans the full area of interest and is shown in Figure 3. This information has been supplemented with Manaaki Whenua 'S-Map Online' factsheet data (accessed June 2022), Manaaki Whenua 'Soils Portal' classification data (accessed June 2022) and NZ Soils 'Soils of NZ: By Region' (accessed June 2022).

Table 1: Area of Interest Soil Summary

Soil Order	Soil Group	Area (ha)	Drainage	Water Logging Vulnerability	Nitrogen Leaching Vulnerability	Phosphorus Retention
Gley	Orthic Gley	5,306	Poorly Drained	High	Very Low - Medium	Medium (35 - 38%)
	Recent Gley	4,193				
	Sandy Gley	543				
Recent/Raw	Fluvial Recent	2,111	Imperfectly – Well Drained	Very Low - Moderate	Low - High	Very Low - Medium (3 - 33%)
	Sandy Recent	132				
Pallic	Perch-Gley Pallic	1,128	Poorly Drained	High	Very Low	Low (22%)
	Fragic Pallic	63				
Brown	Sandy Brown	455	Moderately Well – Well Drained	Low	High	Low
	Orthic Brown	181				

Gley Soils are present over a large majority of the area of interest (spanning over 10,000 ha). Gley Soils are characterised by saturated soil conditions caused by a rising water table (seasonally or continuously) that cause chemical reduction that appears as a light grey layer with brown mottles. They are typically poorly draining and impeded by shallow groundwater conditions.

- The Orthic Gley Soils (also referred to as Kairanga silty clay) within the area of interest are formed from fine textured sediment deposits washed down from the Ruahine and Tararua Ranges, and Quaternary to Miocene mudstones and sandstones, mostly uplifted from marine rocks, but also terrestrial silts, lignites and pumice in Pohangina and Dannevirke source areas. They are poorly drained and have shallow groundwater conditions. They have variable profile available water, but it is typically high in the top 300 mm.

- Recent Gley Soils exist in and around the Orthic Gley Soils and can also be considered a part of the Kairanga silt clay complex. They are representative of the shallow groundwater conditions that cause the Gley Soils on a more recent alluvial deposit (i.e., on younger soils). Areas of Recent Gley Soils loosely align with the extents and spill paths of the Taonui Basin and are likely a result of the prolonged ponding that can occur in this area when the rivers have large flood events, overtopping their stop banks. It is therefore reasonable to assume that the parent fluvial material is finer in nature (prolonged ponding allows for finer sediments to deposit). Although, some coarser textured soils are present in this area, for example, the Parewanui Recent Gley Soil is a sandy loam.

- Sandy Gley Soils are formed in the low-lying areas between older dune complex of the sand country on the western side of the Manawatū River. They are formed (in part) from a different parent material (being the wind deposited sandy dune material from the coast), and also crevasse splays from the Manawatū River overtopping the channel. These soils have shallow rising ground water conditions, typical of Gley Soils. S-map soil data is not available in this area, it is expected with the sandy soil texture that these soils have good permeability but are poorly draining due to shallow groundwater conditions.

Recent/Raw soils (also referred to as Manawatū silt loam and Manawatū fine sandy loam) are the next most dominant soil type across the area of interest, spanning over 2,200 ha. These are all fluvial deposits on the flood plains of the Manawatū and Oroua Rivers. These soils are highly variable consisting of multiple fluvial deposits from various flood events. These soils are imperfectly drained to well drained, due to the variable textured deposits, although typically coarser (sandy) than the surrounding Gley complexes. Over time, these soils will become influenced by the position of the flood banks changing the deposit of new sediment layers.

Pallic Soils span almost 1,200 ha of the area of interest and are in the loess (wind-blow dust), colluvium and alluvium that forms the foothills of the Tararua Ranges. J. D. Cowie (1973) describes the Pallic Soils in this area, stating that they vary between the lower areas (the Ohakea series, which are underlain by gravels at 90 to 150 cm below the surface), through to the thicker loess deposits (in the Tokomaru and Milton series), and the oldest thin loess deposits (Marton series). The Pallic Soils are poorly drained, with high to moderate profile available water. Pallic Soils have a compact subsoil (fragipan) that restricts drainage.

All of the above soils are reported by Manaaki Whenua (2022) soil reports to have a high to very high structural vulnerability. This could limit potential land use under irrigation operation to light weight animals (i.e. sheep) or cut and carry operations, where pugging risk is limited or removed.

Sandy Brown soils makes up 455 ha of the area of interest. They are formed in older dune complex of the sand country on the western side of the Manawatū River, on higher areas. They are formed from the wind deposited sandy dune material from the coast. S-map soil data is not available in this area, it is expected with the sandy soil texture, elevated well above groundwater, that these soils are well draining, but hydraulically limited by shallow groundwater conditions. Due to the inability to access land in this area, and the areas being relatively small, steep, and far away from the WWTP, this soil type has been unable to undergo site specific sampling.

Orthic Brown soils makes up only 180 ha of the area of interest, running in a narrow strip next to the Kahuterawa Stream, where property sizes are generally small. For these reasons, this soil type has not undergone site specific sampling.

Please note, that the proposed discharge is to be highly treated wastewater, this summary has focused on the hydraulic properties of soils, rather than the potential for nitrogen loss and soil phosphorus retention.

4.0 Soil Investigation Results by Soil Order

The soil investigations focused on classifying the three dominant soil orders across the area of interest: Gley, Recent/Raw and Pallic. The number of samples in each soil type was selected based on the aerial coverage of each soil type. While more samples will be preferable for site specific investigations and detailed design, this data should allow for region specific verification of the key soil types in question. The main purpose of this assessment is to provide a greater understanding of the drainage properties of the soil types, and therefore provide a more accurate estimate of the land area required, and better quantify the relative value of each soil type in terms of the flux of highly treated wastewater that can potentially be sustainably applied.

Three key elements of the investigation will assist with classifying the hydraulic capacity of each soil order:

- **Hydraulic Cores**: a laboratory test to determine K_{sat} and K_{-40} on an undisturbed sample, at each site undisturbed samples were collected at 0 – 100 mm and 300 – 400 mm. These samples are also processed to determine wilting point, field capacity, and porosity as well as bulk density to assist in better defining the soil water storage properties.
- **Geulph Permeameter Test**: an insitu infiltration test in pre-soaked conditions to obtain K_{fs}, each site took insitu test at 150 mm and at 300 mm depth.
- **Hand Augers:** to identify the presence of low permeability layers and the depth of the vadose zone/depth to groundwater on the day of augering.

4.1 Hydraulic Conductivity

Saturated hydraulic conductivities (K_{sat}) of the different soils for application should be considered an upper bound of potential hydraulic application rates. These conductivities are typically not achievable in the field, where air entrainment will restrict water flow. However, K_{sat} is a good measurement to assist with soil classification. Consistent applications at or above these rates will result in ponding and runoff of the treated wastewater, especially in winter where there is limited storage capacity within the soil.

Unsaturated hydraulic conductivities (K_{-40}) is a better indication of soil permeability at near-saturated conditions (that are more typical of field saturation levels). K_{-40} is used to indicate a sustainable hydraulic loading rate, which allows for drainage through smaller pores, with larger pores air-filled to assist with soil and plant health, soil structure, and void space to provide for storage of rainfall.

Field infiltration rates (K_{fs}) also give a good indication of soil permeability at near-saturated conditions, that better measure the effects that farming practices (i.e. how recently was the area grazed) can have on infiltration rates.

All conductivity results for each soil order are summarised in Table 2.

Table 2: Hydraulic Conductivity Results by Soil Group

		Recent/Raw		Gley		Pallic	
Number of Samples		4		9		2	
Parameter	**Method**	**Average [Median] (Range)**		**Average [Median] (Range)**		**Average (Range)**	
Sample Depth		150 mm	260 - 320 mm	150 mm	260 - 320 mm	150 mm	260 - 320 mm
K_{fs} (mm/d)	Insitu	151 [151] (27 - 275)	119 [82] (39 - 275)	66 [66] (27 - 87)	21 [11] (1 - 58)	71 (66 - 77)	13 (13 - 14)
Sample Depth		Surface	300 mm	Surface	300 mm	Surface	300 mm
K_{sat} (mm/h)	Laboratory	236 [214] (60 – 455)	35 [25] (5 – 87)	155 [107] (11 – 370)	74 [46] (2 – 300)	26 (18 - 34)	9 (1 - 18)
K_{-40} (mm/h)	Laboratory	14 [12] (3 - 28)	14 [12] (1 - 30)	8 [4] (1 - 25)	15 [14] (1 – 43)	2 (1 - 4)	3 (0 - 6)

Notes:

1. *In-situ test methods were via the Guelph Permeameter, and Laboratory test methods were from undisturbed core samples processed at the Manaaki Whenua Soil Physics Laboratory.*
2. *Based on onsite observations samples F20N has been interpreted as Recent/Raw and H1 has been interpreted as Gley (PDP technical memorandum A03109214).*

The soils with the highest hydraulic loading rate potential are the Recent/Raw soils, which are almost two times higher than the Gley Soils and four to five times higher than the Pallic Soils. The field results for hydraulic conductivities for these soil types are highly variable. This is consistent with the mapping and formation of the Recent/Raw soils that can result in significant variability between the different fluvial deposit layers with different particle sizes. These soils vary rapidly spatially, so it is reasonable to expect that within an individual property with Recent/Raw soils there will be a mixture of very high permeability and low permeability formations and that a median result is reasonable for an assessment of the likely average application rates. It should be noted that for specific design of a land application system, more detailed site specific soil mapping and measurements of soil hydraulic conductivities should be carried out.

Pallic Soils have lower variability between sites, with very restrictive conductivities. This is expected with the shrinking and swelling that occurs in the Pallic subsoil. For sustainable operation, the Pallic Soils will require a very low average hydraulic loading rate.

Gley Soils have high variable hydraulic conductivities between sites. The Gley subsoil is not as restrictive as the Pallic subsoil however, the Gley Soils in areas will be restricted by the low permeability topsoil as well as shallow groundwater that can rise and fall quickly (discussed further below).

4.2 Soil Water Storage

Soil storage is best defined by the following three measures:

- **Wilting Point:** maximum soil moisture (as a depth of soil depth, or percentage of soil volume) below which plants cannot access the soil water.
- **Field Capacity:** maximum soil moisture (as a depth of soil depth, or percentage of soil volume) that does not drain. Also often defined as the maximum water content held in the soil, 2 days after saturation.
- **Porosity:** maximum soil moisture content (as a depth of soil depth, or percentage of soil volume) above which ponding, and runoff start to occur.

These variables are key to understanding how water within the soil profile behaves, and they better define how much irrigation of the land will increase runoff, additional evapotranspiration, and additional drainage. These variables also indicate the available storage within the soil profile when instantaneous application rates exceed hydraulic conductivities during various seasonal conditions.

Table 3: Profile Available Water Results by Soil Group

		Recent/Raw		Gley		Pallic	
Number of Samples		4		4		2	
Sample Depth		Surface	300 mm	Surface	300 mm	Surface	300 mm
Parameter	**Method**	**Average (Range)**	**Average (Range)**	**Average (Range)**	**Average (Range)**	**Average (Range)**	**Average (Range)**
Wilting Point (%)	Laboratory	18 [19] (15 - 21)	19 [19] (14 - 24)	21 [21] (20 - 21)	20 [20] (18 - 22)	19 (18 - 19)	20 (20 - 21)
Field Capacity (%)	Laboratory	46 [46] (39 - 51)	38 [38] (34 - 44)	46 [46] (45 - 46)	42 [41] (40 - 44)	46 (45 - 47)	36 (36 - 37)
Porosity (%)	Laboratory	57 [57] (53 - 60)	49 [49] (46 - 54)	54 [55] (53 - 55)	50 [51] (46 - 53)	55 (55 - 56)	47 (46 - 48)

Notes:

1. *Laboratory test methods were from undisturbed core samples processed at the Manaaki Whenua Soil Physics Laboratory.*
2. *Based on onsite observations samples F20N has been interpreted as Recent/Raw and H1 has been interpreted as Gley (PDP technical memorandum A03109214).*
3. *All values are the percentage of the soil volume.*

For all the soil samples collected the results were consistent, and generally similar between the soil orders, this is likely due to the organic matter present in the surface topsoil layers.

4.3 Hand Auger Results

Hand augers were used at each soil sample site to identify the depth to groundwater and to indicate whether shallow groundwater could impede soil drainage. They were also used to identify if there were any layers present at greater depths below ground level (BGL) than where our samples were collected (i.e., 0.4 mBGL) that were likely to be low permeability (i.e. clay layers) that may impact the soil depth or permeability assumptions.

Table 4: Hand Auger Key Results by Soil Gro up

	Recent/Raw Average (Range)	Gley Average (Range)	Pallic Average (Range)
Number of Hand Augers	4	9	2
Groundwater (mBGL)	1.6 (1.2 – 1.8) (30 May – 1 Jun 22)_	1.7 (0.5 – 2.7) (30 May – 1 Jun 22)	> 2.5 (16 Jun 22)
Lower Permeability Layer (mBGL)	1.4 (1.2 - 1.7)	1.7 (0.9 - 2.7)	1.9 (1.4 – 2.5)

Generally speaking, groundwater levels were on average >1.5 mBGL, at the time sampled (early winter), and therefore less likely to restrict drainage rates (subject to site specific groundwater mounting potential assessment). However, there were some very shallow groundwater levels identified in the Gley Soils, as well as evidence of gleying and mottling at very shallow depths. Therefore, it is expected that some areas of Gley soil types will be restricted by shallow groundwater levels during winter.

There were no consistent low permeability layers identified for each soil order within the hand auger logs at untested depths (>0.4 mBGL). Generally, the most restrictive soil textures (clays, silty clays) were present just below the topsoil layers and at or near the phreatic surface. Samples of the lower permeability layers were collected in the subsoil hydraulic conductivity and infiltration testing.

Note, it is expected that if more hand augers were carried out in the Pallic Soils, the low permeability fragipan would become more evident. It is also expected that in higher seasonal groundwater conditions, you would encounter a perched shallow groundwater above the fragipan that could restrict the available soil depth for irrigation storage.

5.0 Parameters Selected for Soil Moisture Modelling Updates

Based on the above field results, PDP has modified the soil moisture model assumptions. We have selected typical results, based on median drainage results for the lowest permeability horizon, and median profile available water results, averaged between each horizon (Table 5).

Table 5: Soil Moisture Model Inputs

	Recent/Raw	Gley	Pallic
TYPCIAL SUMMER CONDITIONS			
Soil Depth (mm)	600	500	600
Maximum Infiltration Rate[1] (mm/d)	289	84	58
TYPCIAL HIGH-GROUNDWATER WINTER CONDITIONS			
Soil Depth (mm)	600	200	600
Maximum Infiltration Rate[1] (mm/d)	289	84	58
PROFILE AVAILABLE WATER			
Wilting Point (%)	19	21	20
Field Capacity (%)	41	45	41
Porosity (%)	53	53	51

Notes:

1. *Based on unsaturated hydraulic conductivity (K_{-40}) results.*

PDP has also considered worst-case results, based on the minimum soil sampling result for the lowest permeability horizon and the most restrictive profile available water results (i.e. highest wilting point, lowest available water capacity and lowest capacity between porosity and field capacity) (Table 6).

Table 6: Soil Moisture Model Worst-Case Inputs

	Recent/Raw	Gley	Pallic
WORST-CASE SUMMER CONDITIONS			
Soil Depth (mm)	600	500	600
Maximum Infiltration Rate[1] (mm/d)	36	16	2
WORST-CASE HIGH-GROUNDWATER WINTER CONDITIONS			
Soil Depth (mm)	600	200	600
Maximum Infiltration Rate[1] (mm/d)	36	16	2
WORST-CASE PROFILE AVAILABLE WATER			
Wilting Point (%)	24	22	20
Field Capacity (%)	39	41	36
Porosity (%)	46	46	46

Notes:
1. *Based on unsaturated hydraulic conductivity (K_{-40}) results.*

These assumptions set the maximum drainage rates of the soils based on the unsaturated hydraulic conductivities (K_{-40}) through the soil profile as determined by Manaaki Whenua Soil Physics Cores. This allows for sustainable loading rates, which allow for drainage through smaller pores, maintenance of air-filled voids for soil and plant health, and maintenance of void space to provide for storage of rainfall. Based on PDP's experience the in-situ saturated hydraulic rates measured by the Guelph are considered to be too conservative and may have been overly influenced by smearing due to the saturated soils conditions.

The soil depths are proposed to be reduced in Gley Soils, especially during winter. Shallow groundwater was encountered during the field investigations at several of the Gley soil sample sites. Further to this, there was mottling and gleying at even shallower depths, indicating that the soil has experienced periodic waterlogging at shallow depths during its formation. On this basis, PDP expects that the Gley Soils will be further constrained when groundwater levels are elevated.

6.0 Updated Soil Moisture Modelling

A soil moisture model (SMM) was run for each soil type based on the soil assessments above and the following set of assumptions. These assumptions have been prepared carefully, based on the best information available at this time. If these assumptions are to change, it should be expected that the resulting land area outputs will change.

- Daily climate data, rainfall (mm/d) and PET (mm/d), from the NIWA virtual climate network at Opiki for the period 1987 to 2018;
- Daily Manawatū River average flow data for the period 1987 to 2018, sourced from Horizons Regional Council (19 May 2022);
- A wastewater volume of 24,177 m^3 is received by the land application system when river flow is <37.5 m^3/sec, based on forecasted wastewater flows until 2058;
- The maximum irrigable soil moisture is halfway between field capacity and porosity;
- Runoff only occurs when soils are at saturation and rainfall interception is negligible; and
- Soil storage parameters based off field investigations, outlined in Table 5 and Table 6.

The SMM model provides an indication of the required irrigation areas, storage volumes, and likely daily and weekly loading rates. These results are summarised Table 7. The total area required has been calculated assuming a 30% buffer for non-irrigable areas such as buffer zones from property boundaries, set-backs from waterways, access roads etc.

Table 7: SMM Required Irrigation Area

Soil Order	Daily Irrigation Limit (mm/d) [1]	Weekly Irrigation Limit (mm/week) [1,2]	Irrigation Storage Volume (m^3)	Irrigation Area (ha)	Total Area (ha)
Recent/Raw	10	45 – 54	75,000	420 - 500	600 - 710
Gley	5	25 - 32	100,000	765 - 970	1,090 - 1,390
Pallic	5	20	100,000	1,300	1,860
Worst Case Scenario					
Recent/Raw	10	45	75,000	560	800
Gley	5	25	100,000	970	1,390
Pallic	5	20	150,000	4,400	6,290

Notes:

1. *The irrigation limits are spatially averaged across the whole irrigation system and therefore account for rotation practices. For example, a spatial average of 10 mm/d in practice could be achieved with a 50 mm/d application rotating daily between 5 equal sized paddocks over 5 days, so that on any given day the average loading across the 5 paddocks would be 10 mm/d.*
2. *Range based on other known sustainable land application loading rates for similar soil types.*

7.0 Interpretation

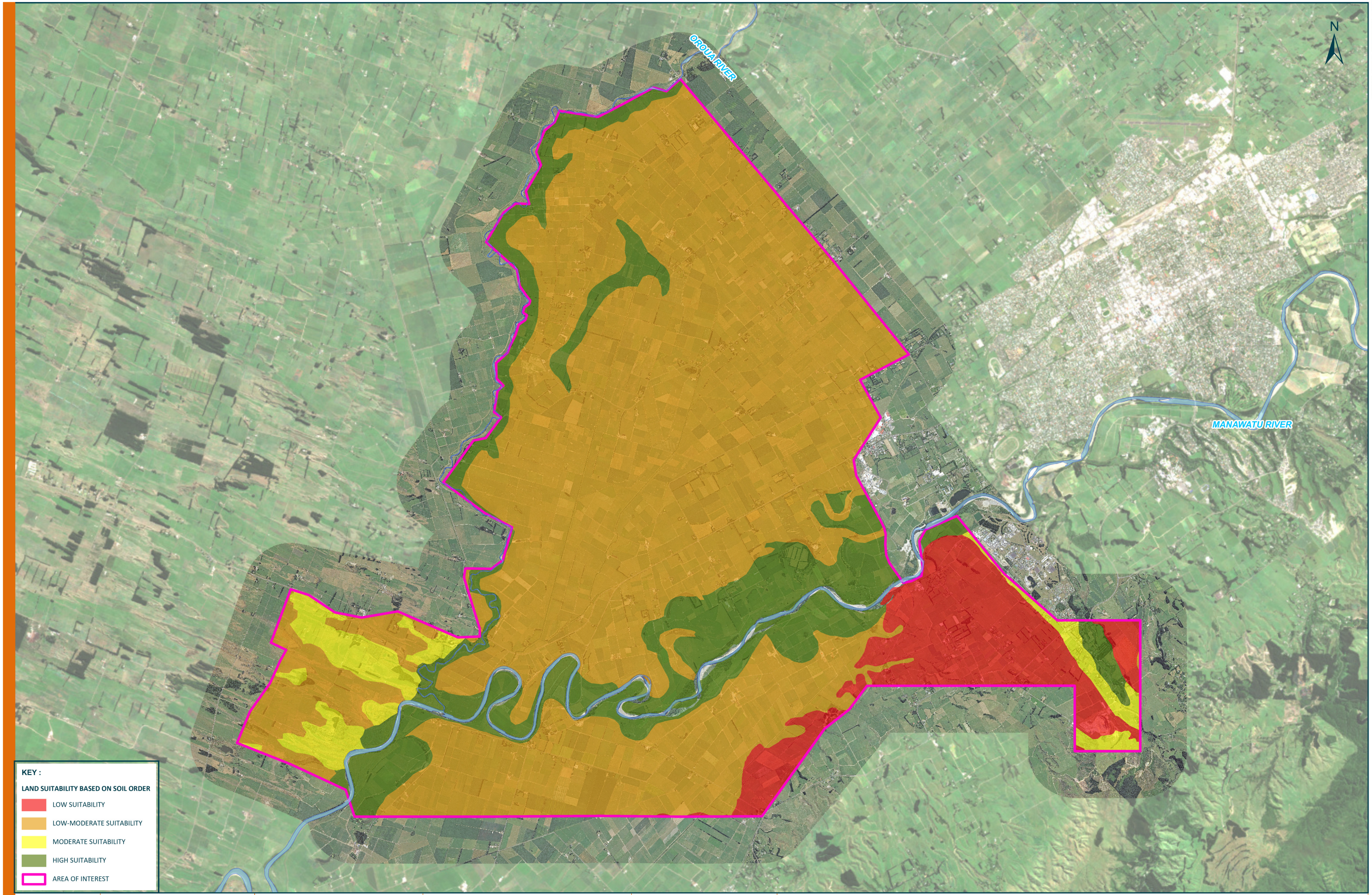
The soil sampling programme collected various analyses across the three dominant soil classes across the area of interest, being the Raw/Recent Soils, Gley Soils, and Pallic Soils.

The best drainage rates were identified in Raw/Recent Soils. These can be sustainably loaded at higher rates than other soil types. A theoretical land application system located on the Raw/Recent Soils will require approximately 600 - 710 ha of land and 75,000 m^3 of effective storage.

The Gley Soils are the next most effective soil types for land application based on drainage rates. These have a significantly lower sustainable loading rate, requiring additional land area (52% as effective as the Raw/Recent Soils).

The Pallic Soils are the least effective soil type for land application based on drainage rates. These have the lowest sustainable loading rate. They are typically 38% as effective as the Raw/Recent Soils. The worst-case Pallic soil drainage characteristics are extremely restrictive. Therefore, land application schemes on a Pallic soil type have a high risk of significant cost escalation.

The effectiveness of each soil type is summarised in Figure 4, as a heat map showing high suitability, moderate-low suitability, and low suitability.



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SOURCE:
1. AERIAL IMAGERY (FLOWN 2021), PROVIDED UNDER LICENCE FROM HORIZONS CITY COUNCIL.
2. SOIL CLASSIFICATION DERIVED FROM SMAP 2008.
3. CADASTRAL/TOPOGRAPHICAL INFORMATION AND INSET DERIVED FROM LINZ DATA.

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FIGURE
FIG 4: SUITABILITY FOR LAND APPLICATION BY SOIL ORDER

PROJECT
PHASE 1 SOIL INVESTIGATIONS

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8.0 Limitations

This memorandum has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Palmerston North City Council, Stantec Ltd, Landcare Research and Hill Laboratories. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the memorandum. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This memorandum has been prepared by PDP on the specific instructions of Stantec Limited, for the limited purposes described in the memorandum. PDP accepts no liability if the memorandum is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

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