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# Implications of the Geophysical Investigation for Water Resources

## Flaxbourne River, Marlborough

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# 1 Introduction

Cook Costello was engaged by the Flaxbourne Settlers' Association, through the Marlborough Research Centre Trust, to investigate the unconfined gravel aquifer adjacent to the Flaxbourne River Bridge on State Highway 1 (SH1). The aquifer supports the potable water supply for the Ward Community and a number of abstractions for irrigation.

A geophysical investigation comprising electrical resistivity tomography was previously used to determine the lateral extent and vertical thickness of the gravel aquifer (Sutter, 2019a). Given the positive nature of the results from the initial survey, a more detailed survey was undertaken to investigate:

- The gravel deposits in the vicinity of the existing Taimate well;
- The presence of paleochannels across the river terrace and their implication for a potential groundwater resource; and
- The groundwater level across the site.

This second phase of investigation used a range of geophysical methods including: electrical resistivity tomography, seismic refraction, and multi-channel analysis of surface waves. These techniques were used to investigate different aspects of the stratigraphy and hydrological sub-surface conditions. The methodology used for each of these methods, and the results of the investigations, are detailed in Sutter (2019b); presented in Appendix A.

This discussion reviews the results of the geophysical investigation from the perspective of improving understanding of the unconfined aquifer and groundwater resource in this area

# 2 Local Setting

A detailed description of the geological and hydrological setting of the wider area of the SH1 Flaxbourne River Bridge is provided in WSP Opus (2019). A summary is provided in the following sections.

## 2.1 Geological setting

The SH1 Flaxbourne River Bridge is located in southern Marlborough, approximately 2km north of the Ward township. The vicinity of the bridge is underlain by recent river gravel and sand which has been eroded to form a suite of degradational terraces. Local outcrops of Starborough Formation bedrock have also been mapped, which consists of poorly bedded sandstone and siltstone (Rattenbury *et al.*, 2006).

Intrusive investigations have previously been undertaken in the wider area of the SH1 Flaxbourne River Bridge. These include a borehole at each bridge abutment and a trench which was excavated to install an infiltration gallery. These investigations confirm the local geology of

- Minor upper layer (<2m thick) of surficial silt deposits. These are likely to be overflow deposits from the river, or fill deposits associated with the construction of the bridge and road infrastructure.
- 3m to 6m of gravel with a sand and silt matrix. These deposits are recent alluvial material and host a shallow unconfined aquifer.

- At the northern abutment, approximately 10m of silt was identified beneath the alluvial gravel. A similar layer, but significantly thinner (~2m) was also encountered at the southern abutment.
- Basement siltstone of the Starborough Formation.

### 2.2 Hydrological setting

All known groundwater in the Flaxbourne catchment is restricted to shallow alluvial gravel deposits associated with the Flaxbourne River; or its tributaries Tachalls and Needles Creeks. Very little information is available to quantify any permanent groundwater system in the catchment; however, it is thought that the relatively thin alluvial gravel deposits are recharged from rainfall and the Flaxbourne River. The gravel deposits act as unconfined riparian aquifers. The gravel deposits are generally thin i.e. less than 10m thick, and the storage capacity of the aquifers is likely to be limited (Davidson & Wilson, 2011).

## 3 Phase 1 Resistivity Investigations

As detailed in WSP Opus (2019), three north-south orientated electrical resistivity profiles (W1, W2 and W3) were measured in the vicinity of the SH1 Flaxbourne River Bridge (Figure 3.1). The profiles were aligned to allow interpretation of the sub-surface geology in both north-to-south and west-to-east directions.

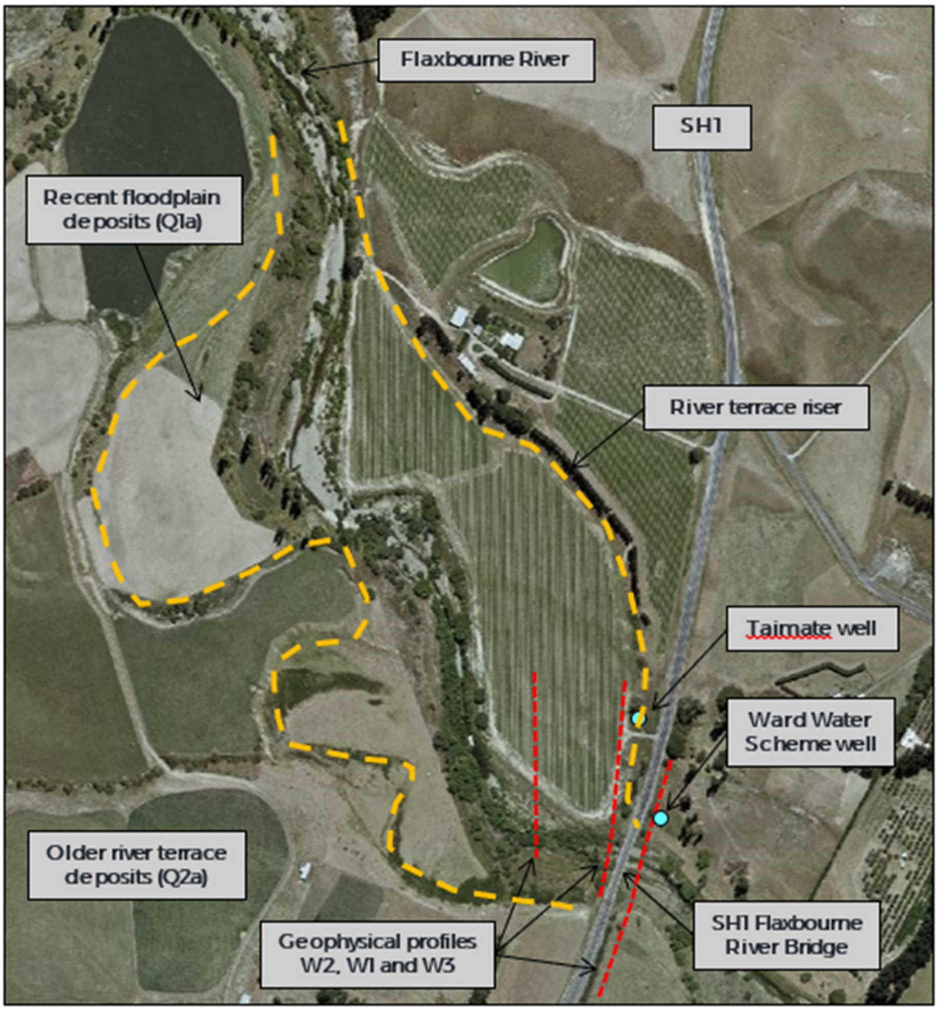


*Figure 3.1: Location of SH1 Flaxbourne River Bridge, geophysical and geotechnical investigations, and existing Ward Community and Taimate water supply bores.*

The initial investigations allowed the following conclusions (WSP Opus, 2019):

- There are three sub-surface layers, as defined by their resistivity (Figure 3.2).

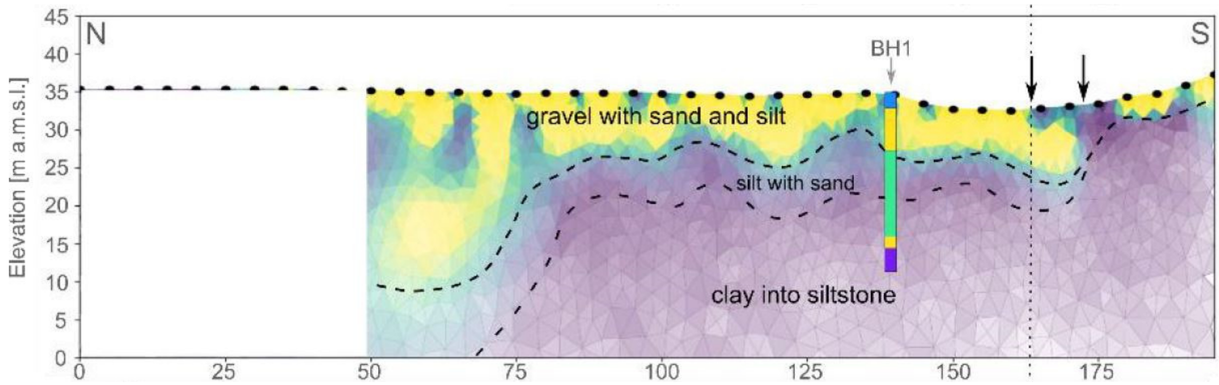


*Figure 3.2: Profile of W1 (Phase 1) with interpreted geology from bore (BH1) drilled on the northern abutment of the SH1 Flaxbourne River Bridge (Sutter, 2019a).*

- The surficial layer (yellow) is the most resistive with values of ~120Ωm. This layer is laterally extensive and represents the alluvial floodplain gravel. The resistivity value of these gravels is lower than normal for gravel. This may be because of the sand and silt within the gravel matrix and the presence of groundwater.

- The floodplain gravel deposit is generally less than 8m thick and extends laterally both north and south of the river. This water-bearing unit is associated with the youngest river terrace of the Flaxbourne River, which extends significantly further on the north side of the river than the south.

- There is generally little variation in thickness of the alluvial deposits, with the exception of an area approximately 100m north of the river within the adjacent alluvial terrace, where the gravel appears to be up to 25m thick. The increased thickness of gravel is thought to be a paleochannel of the Flaxbourne River. Historic (and current) aerial images indicate the presence of a paleochannel at this location. The resistivity of this material is similar to that of the Flaxbourne River, which may indicate a larger groundwater resource.

- Historic aerial photographs of the site show a number of paleochannels across the river terrace on the north side of the river. The largest channel can be seen immediately north of profiles W1 and W2; which aligns with the thicker gravel deposit identified in the survey profiles.

- The static groundwater level (i.e. top of the saturated zone) could not be distinguished in the results, but the alluvial gravel deposit hosts a shallow unconfined aquifer.

- The resistivity of the stratigraphic layers underlying the surficial alluvial deposits decreases rapidly with depth. These layers are expected to consist of clay and silt deposits followed by basement siltstone. These units are likely to be relatively impermeable and contain little, if any, groundwater.

The results of investigations led to the following conclusions regarding water resources in the area:

- The surficial alluvial gravel deposits are the only potential source of groundwater in the vicinity of the SH1 Bridge.

- While the alluvial deposits indicate a potential groundwater resource, at a catchment level these deposits are limited. The deposits are constrained to the contemporary floodplain of the Flaxbourne River.

- The limited extent of deposits that could host an unconfined riparian aquifer suggests a limited storage capacity, and a reliance on ongoing recharge from the Flaxbourne River to support the groundwater system.

- Surface flows within the Flaxbourne River are ephemeral and so there is limited groundwater recharge during dry summer periods. Any groundwater resource hydraulically-connected to the river is likely to experience low levels during prolonged dry periods.

- The nature and limited availability of groundwater in the shallow unconfined aquifer adjacent to the Flaxbourne River has implications for water resource management. These include:

  - A direct hydraulic connection between the Flaxbourne River and the groundwater resource;

  - Limited availability of groundwater;

  - Rapid recharge during periods of higher flow in the Flaxbourne River;

  - Limited groundwater storage to buffer periods of sustained low flow in the Flaxbourne River; and

  - No aquitard to prevent contamination of the groundwater from the ground surface.

- These constraints relating to the nature of the groundwater resource impact the potable water supply for the Ward Community, Taimate and any other abstractions.

- These constraints could potentially be mitigated if a new bore was drilled within the paleochannel identified on the river terrace on the north side of the river. The paleochannel is likely to be hydraulically-connected to the Flaxbourne River and therefore act as a preferential flow path for shallow groundwater flow. A bore in this location would therefore potentially provide a more reliable, higher yielding, and more resilient groundwater source. It would, however, still be affected by low flows in the Flaxbourne River.

- It was recommended that the potential of this paleochannel, and the associated gravel deposit, to provide a resilient groundwater supply be investigated further. This could include:

  - Additional resistivity profiles to better define the boundaries of the paleochannel;

  - Exploratory drilling; and

  - Pump testing of the aquifer if a significant groundwater resource is located in this area.

# 4 Phase 2 Geophysical Investigations

As stated, the recent geophysical investigations were undertaken to further investigate:

- The nature of the gravel deposits in the vicinity of the existing Taimate well;
- The presence of paleochannels across the terrace to the north of the Flaxbourne River; and
- The groundwater level across the river terrace.

This investigation used a range of geophysical methods including: electrical resistivity tomography, seismic refraction, and multi-channel analysis of surface waves. These techniques were used to investigate different aspects of the stratigraphy and hydrological sub-surface conditions. The methodology used for each of these methods, and the results of the investigations, are detailed in Sutter (2019b); presented in Appendix A.A simplified map of the investigations undertaken in this phase of work is presented in Figure 4.1.

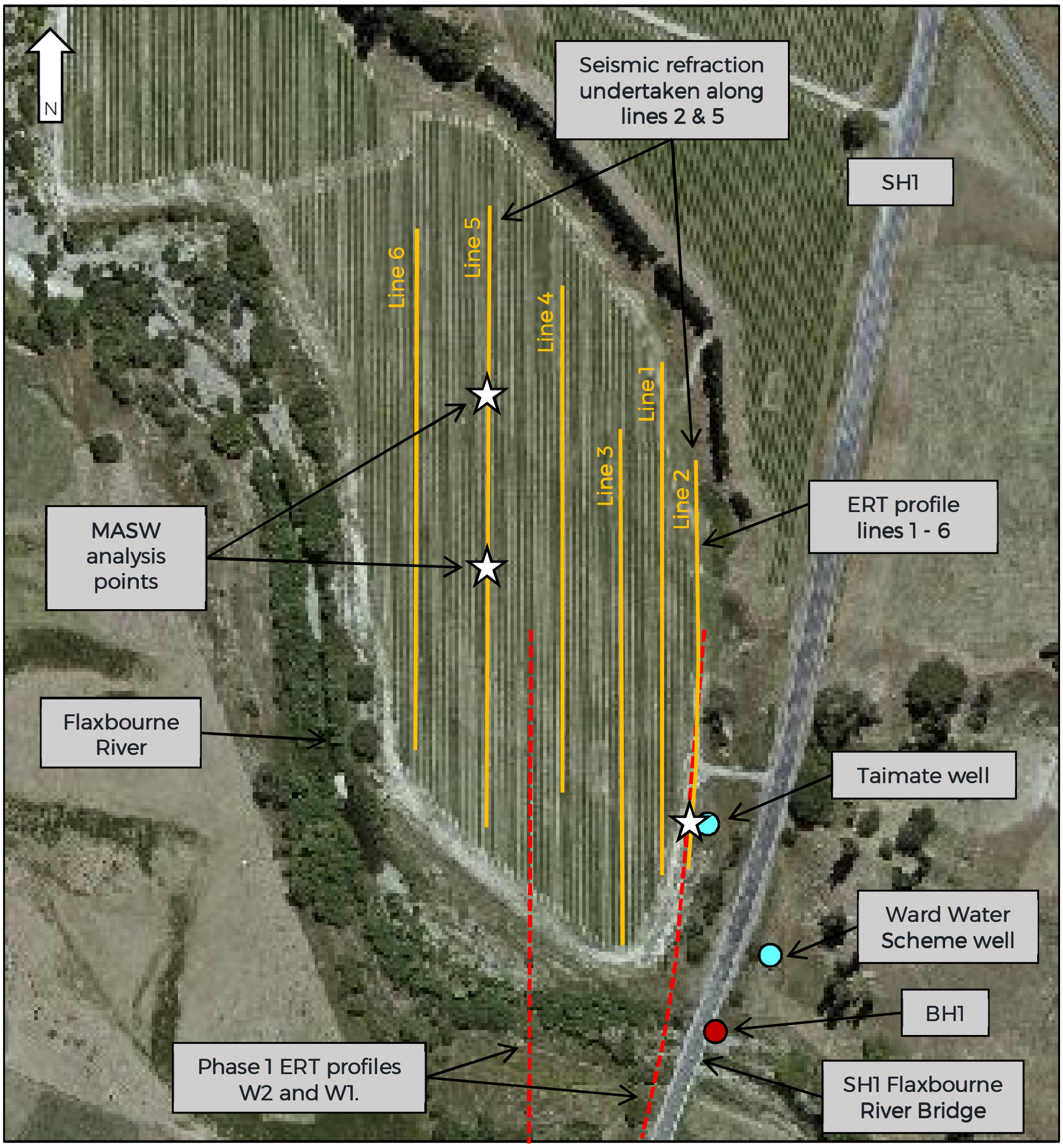


*Figure 4.1: Approximate locations of geophysical investigations along the river terrace north of Flaxbourne River. Further detail is provided in Sutter (2019a & 2019b).*

## 4.1 Results

This investigation was to provide further detail about the hydrogeological nature of the river terrace to the north of the Flaxbourne River (Figure 4.1). The results of these geophysical surveys build on those previously described in Sutter (2019a).

The results of the electrical resistivity tomography (ERT), seismic refraction (SR) and multi-channel analysis of surface waves (MASW) indicate that:

- There are four sub-surface layers, as defined by their resistivity (Figure 4.2);
  - Unit A (yellow) – Most resistive unit (100 - >120Ωm), comprised of floodplain gravel with sand and silt.
  - Unit B (blue) – Lower resistivity values (40 - 80Ωm). Predominantly comprised of silt with sand.
  - Unit C (green) – Second highest resistivity values (80 – 100Ωm). Likely to comprise gravel and sand with lesser deposits of silt.
  - Unit D (purple) – Lowest resistivity values (20 - 40Ωm). Interpreted to mark the transition from clay to siltstone.
- The general stratigraphic profile comprises floodplain gravels (A) overlying variable deposits of gravel, sand and silt (B & C). These layers are underlain at depth by low resistivity bedrock and clay (D).
- Units A and C (floodplain gravels with minor fine sediment) are considered as potential water-bearing units. Unit B (silt and sand) may contain water but is likely to have a lower hydraulic conductivity or transmissivity because of a higher percentage of fine sediment.
- The profiles along the western side of the river terrace (Lines 4 – 6) indicate homogenous stratigraphic layers, where the resistivity generally increases with depth (Figure 4.2). While there are zones of more resistive deposits at depth (units A & C), these are isolated and well-defined.
- The profiles along the eastern side of the river terrace (Lines 1 – 3) indicate more variability in both the surficial floodplain gravels and the underlying gravel, sand and silt deposits (Figure 4.2). These profiles indicate lenses of higher resistivity material which appear discontinuous.
- An example of this is along the eastern edge of the terrace (Line 2), where a feature is present between 80–130m, at 10–30m depth (Figure 4.2). While there is a similar zone along the adjacent Line 1, the features do not match along the profile, indicating the zone along Line 2 is isolated.
- There are differences between profiles undertaken during each of the two surveys. Areas where profiles overlap (or are situated very close) between the two surveys (i.e. W1 & Line 2 and W2 & Line 4) indicate different resistivities and features. This may be because the profiles have been acquired at slightly different angles, or as a result of greater water saturation during winter. This is indicated by the generally lower resistivities measured during the second phase of investigations, which were undertaken during spring.

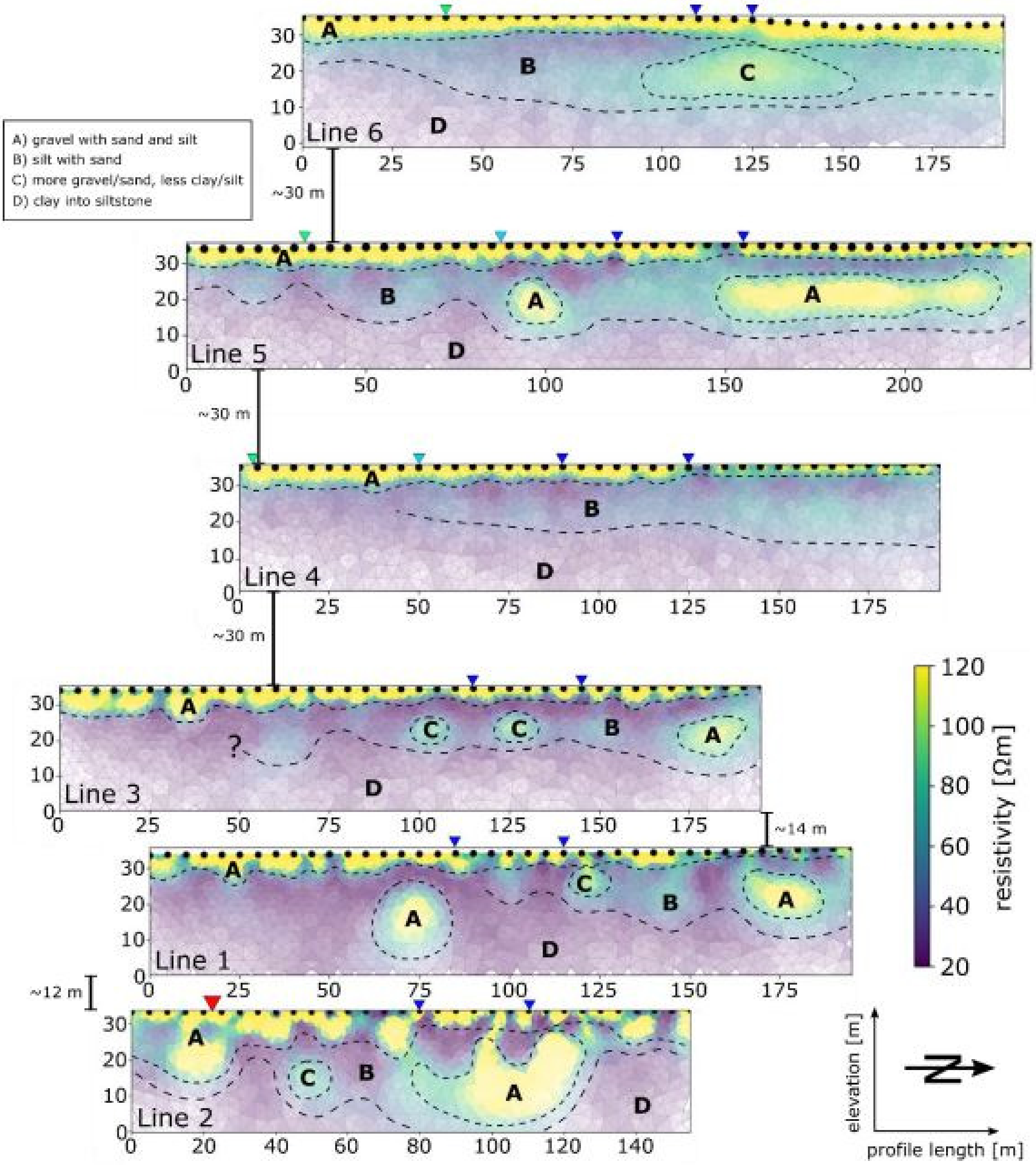


*Figure 4.2: 2D ERT profiles with interpreted units. The Taimate well is marked by the red arrow and approximate locations of paleochannels (observed in surface topography) are marked by the blue and green arrows (Sutter, 2019b).*

- MASW data was collected at three points along Lines 2 and 5 (Figure 4.1). As shear waves are not directly influenced by water, this data provides information on changes in the saturated sediments. MASW data provides information between depths of 1.5–12m.
- The general profile from the MASW relates well to that from the ERT profiles. A generally higher shear wave velocity was observed at depths to ~3 – 4m, which matches the surficial floodplain gravel unit (A). The velocity then decreases where the ERT surveys indicate sand and silt deposits, before increasing again in higher resistivity deposits (Figure 4.3).

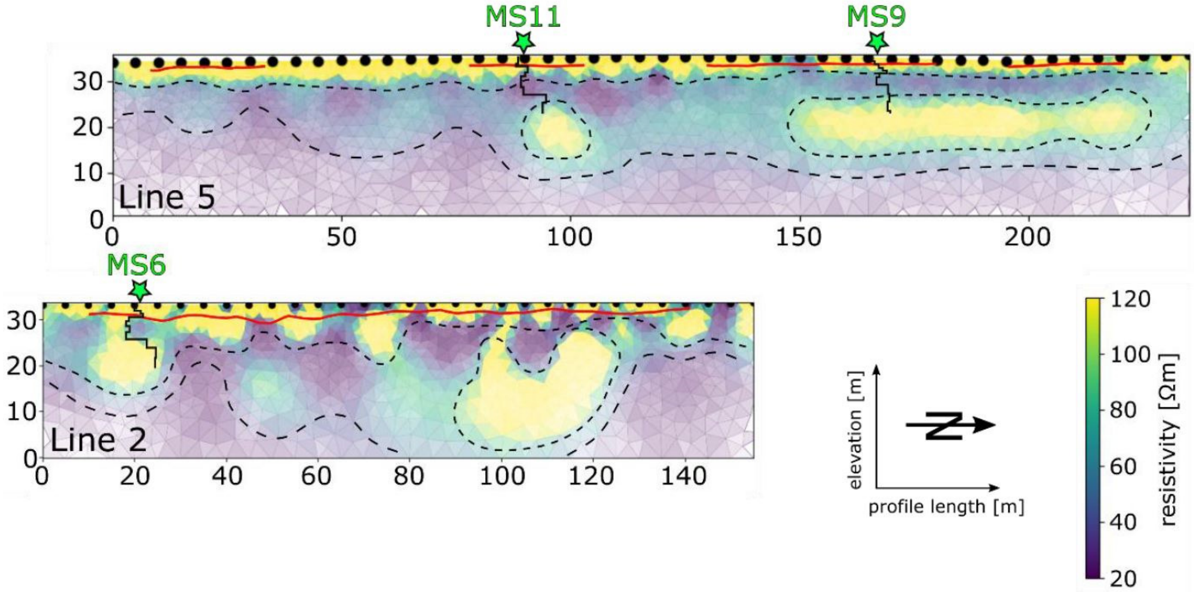


*Figure 4.3: ERT profiles of Lines 2 and 5 with MASW results and interpreted groundwater level from SR results overlain (Sutter, 2019b).*

- Seismic refraction results indicate a distinct change in P-wave velocity between two layers. The top layer has a velocity of 200–500m/s and overlies a layer which has velocities of 1100–1600m/s.
- In sediments such as gravel and sand, a P-wave velocity of ~1500m/s indicates the groundwater table. Therefore, the interface provides an indication of the groundwater level (or the full saturation of sediment) across the river terrace.
- Along the eastern side of the river terrace (along Line 2), the interface is generally at a depth of less than 2m depth at the northern end of the line and increases to 3–4m at the southern end, closer to the Flaxbourne River.
- Along the western side of the terrace (along Line 5) the interface is approximately 1–2m deep and consistent along the length of the terrace.
- These profiles indicate that groundwater is shallower in the north-west of the terrace than at the eastern edge near the Taimate well. The interpreted groundwater levels are consistent with topography. This suggests that water is flowing from the north-west to the south-east, which aligns with the flow of the Flaxbourne River, as expected.

## 4.2 Water resource implications

The results from both phases of the geophysical investigation have the following implications for water resources in this area:

- Alluvial gravel deposits are the only potential source of groundwater in the vicinity of the SH1 Bridge. These deposits are constrained to the contemporary floodplain of the Flaxbourne River. This limited extent suggests a limited storage capacity, and a reliance on ongoing recharge from the Flaxbourne River to support the groundwater system.
- Seismic refraction data suggests that groundwater is present across the river terrace. The depth to groundwater is generally <2m from the ground surface along the western side of the

terrace, and slightly deeper along the eastern side i.e. 2–4m. This is consistent with the topography.

- The resistivity of the stratigraphic layers underlying the alluvial gravel can be variable, but resistivity generally decreases with depth. This is likely to be associated with the silt and clay deposits identified in BH1, as well as the siltstone bedrock. Neither of these layers is likely to provide a viable groundwater resource.

- Although the surficial gravel is the most resistive layers encountered, its resistivity is considered lower than normal for gravel. This may be because of the sand and silt within the gravel matrix and the presence of groundwater. The gravel units with the lowest proportion of fine-grained material, and highest resistivities (80 – 120Ωm), are expected to have the greatest potential to support a water resource.

- The sub-surface profiles tend to be more homogenous at the western side of the terrace. However, the majority of profiles indicate localised zones of more resistive material. These zones are more likely to have higher conductivity and transmissivity and either represent paleochannels or localised, discontinuous water-bearing lenses.

- The nature of these zones can vary between seasons. Generally, lower resistivities were measured in the second phase of investigations, following winter when ground conditions were wetter. Therefore, any further investigation should target large zones of higher resistivity during drier months.

# 5 Recommendation

The potential of these zones, and the associated deposits to provide a more resilient water supply should be further investigated. This should comprise exploratory drilling and, if results are favourable, pump testing of the aquifer. From the results of the investigations to date (Sutter, 2019b), the following locations appear promising to support a water resource (Figure 5.1):

- Line 2, between 100 – 120m, to a depth of up to 25m; and

- Line 5, between 160 – 200m, to a depth of up to 25m.

These locations should be accurately positioned prior to drilling, through the use of the data captured during the previous geophysical investigations.

Sutter (2019b) also suggests an exploratory bore along Line 4, at ~150m, to a depth of ~10m. While this location is likely to provide information on the hydraulic properties of material with resistivities in the range of 40 - 100Ωm, it considered less likely that this material will host a high-yielding water resource than other zones. It is not recommended that this area be investigated further at this time.

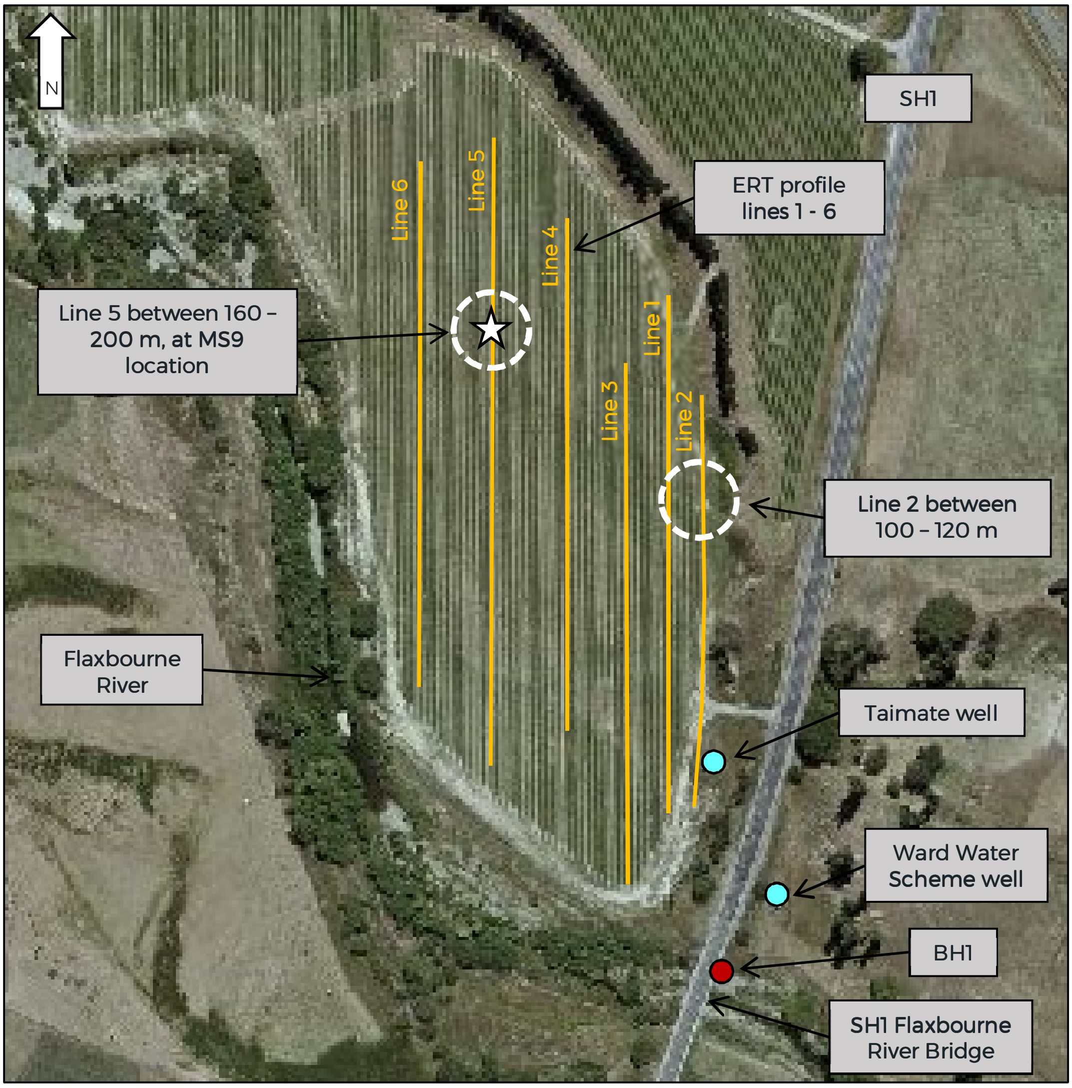


*Figure 5.1: Approximate locations for further investigations.*

# 6 References

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# Appendix A

## Geophysical Assessment Report - Flaxbourne Groundwater Resources Investigation

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