WATER RACES LAND USE

Review of Longwood and Moroa Water Races

Prepared by South Wairarapa District Council

Version 1.0
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Contents

1 SURVEY SUMMARY

A survey of the Longwood and Moroa Water Races was conducted during March and April of 2016. The objective of the survey was to:

- Report on the current state of the Races on different farms.
- Evaluate both the farmlands' impact and reliance on the Races.
- Evaluate the effectiveness of the water races
- Allow the ratepayers to express their views about the race.

To maximise the response, multiple options for completing the survey were provided. A letter containing the survey and the Code of Practice was sent to each ratepayer on the 15th of May. The letter also contained an email address to contact, if the respondent wanted to complete the survey electronically.

A consultant also visited each property and every farm that could be visited (i.e. had a house). This allowed the survey to be filled out in person, along with any questions to be answered. If the survey could not be filled out during the consultant's visit, the consultant would leave a copy of the survey at the farm (along with a contact number), allowing the respondents to either complete the survey by themselves, or arrange another visit with the consultant.

Approximately a third of the farms were surveyed either by the consultant or the respondent. While GIS was used to survey the rest, this was limited to determining the length of the race on the farm, verifying the area that the race could service, and determining if the farm had a bore as an alternative source of water.

2 INTRODUCTION

2.1 Summary of Water Races

Water races are an historical feature in the Wairarapa, diverting water from the Tauherenikau and Waiohine Rivers to provide valuable water for stock. The Races are gravity fed, with both falling approximately 80-85 m in height along their length.

The Longwood Water Race was constructed in the 1920's and diverts water from the Tauherenikau River to 1,500 ha of farmland around Featherston. Longwood has 17 distinct branches (four main) that discharge either back into the Tauherenikau River or into the Otauira Stream. While common estimates state the Race is 31 km in length, analysis using the South Wairarapa District Council's Geographical Information system (GIS) estimates its length at 40 km.

The Moroa Water Race was constructed in the 1890's and diverts water from the Waiohine River to 8,500 ha of farmland on the Moroa Plains. The Race consists of 51 distinct branches (13 main) that discharge into a number of creeks/streams that subsequently flow into the Tauherenikau and Waiohine Rivers. The Race is commonly stated as 240 km long, which is confirmed by analysis with GIS.

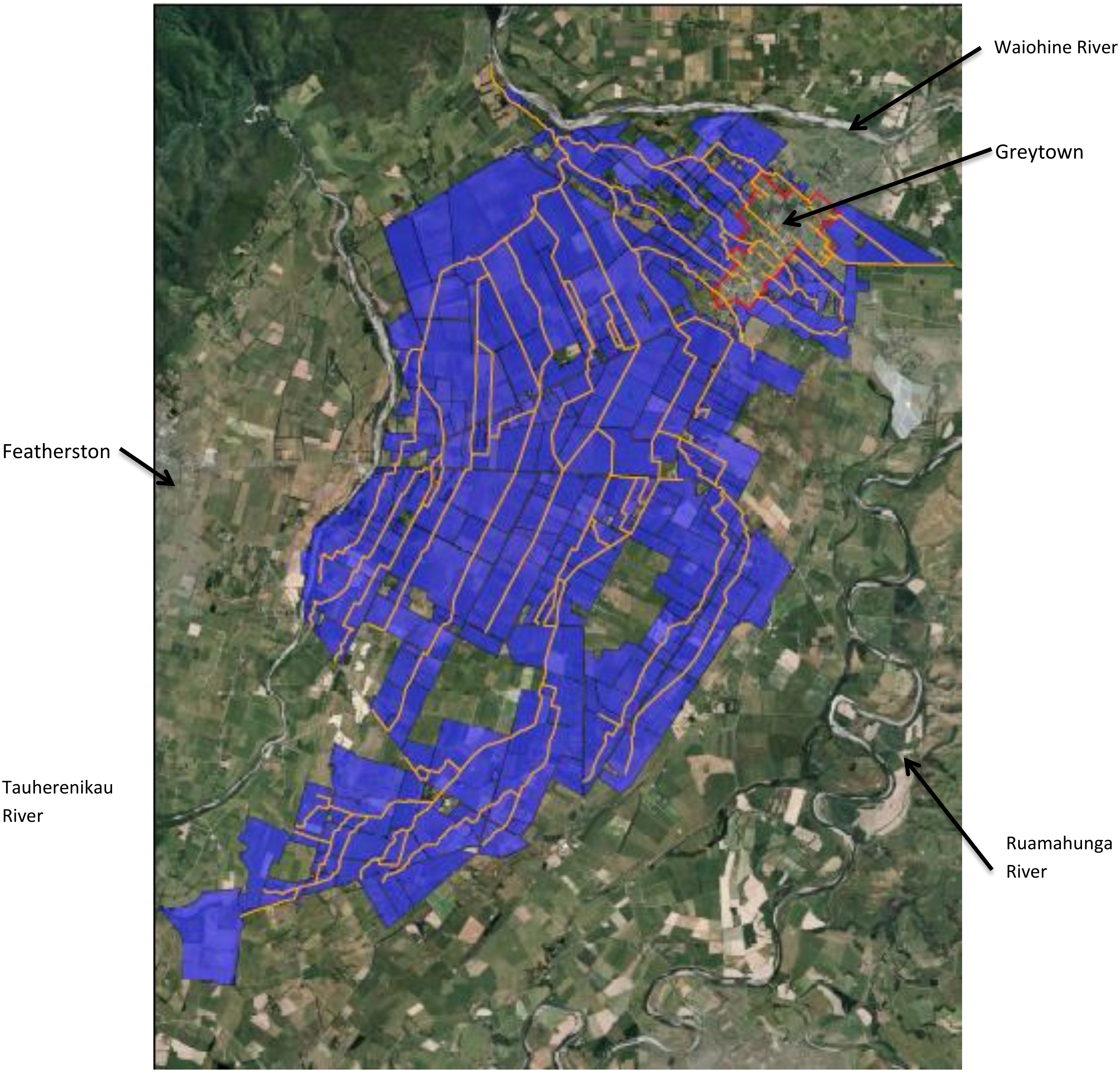
Both Races are managed by the South Wairarapa District Council: Moroa under the Moroa Water Race Bylaw 2007; and Longwood under the Longwood Water Race Bylaw 1936.

Table 1: Water Race summary

Water Race	Source	Overall Distance (km)	Number of branches	Points of Discharge
Longwood	Tauherenikau River	40	17 Distinct Branches 4 Major Branches 10 Points of Discharge	Tauherenikau River Otauita Stream
Moroa	Waiohine River	255	51 Distinct Branches 16 Major Branches 26 Points of Discharge	Tauherenikau River Stonestead (Dock) Creek Otukura Stream Papawai Stream Muhunoa Stream Waohine River

Figure 1 Map of Longwood Water Race

Figure 2 Map of Moroa Water Race



3 CURRENT STATE OF THE WATER RACE

3.1 Improvements for the Management of Water Races

Under the Code of Practice – Moroa and Longwood Water Races the management of water Races needs to maintain a certain standard in order to minimise the wastage of water, contamination of water, and other negative environmental impacts on the race.

Wastage of water can be a problem if it leaves sections of a water race with little water for stock. The Code of Practice notes that at the maximum allowable level of allowable water take (240 L/s for Longwood and 500 L/s for Moroa) flows at the ends of the Races were minimal. This was further observed during the survey and it was also noted that some of the middle sections also had minimal flow and were, in some cases, dry.

To limit the wastage, the Code of Practice recommends:

- *Keeping the water race narrow and freeboard high.* During the survey both were found to vary considerable; but, on average, the races had an average width of 1.23 m and an average freeboard of .5 m.
- *Keeping the permeability of the water race low.* Due to the amount of silt along the bottom of most of the surveyed sections, no observation was done on the current permeability of two races in question.
- *Using water only for stock watering.* For both races, this appeared to be the case, with alternative use being rare and, even in those cases minimal and limited in minor irrigation (such as domestic garden use).

The Code of Practice recommends the following to limit contamination of the water race:

- Preventing stock from wandering in the Race; either by fencing the race off and pumping the water, placing an electric wire down the centre of the race, stocking the paddocks with stock that do not stand in the race.
- Preventing drainage from entering the Race.
- Ensure vehicles cross over Races, rather than through.
- Limit herbicide use during Race cleaning.
- Keep fertilizer away from the Race.

Stock wandering in the race appeared to be common along both Races with 57% of properties surveyed having at least some wandering. During the survey, problems were noted with the implementation of the aforementioned recommendations, including:

- The cost of fencing many kilometres of race. In a few cases, respondents saw cutting the water race off as the more viable option.
- An inability to pump the race water due to the area of farmland having no available electricity; this land often also lacked the slope to gravity feed
- Cattle pushing electric fences aside with ease.

- The water race being the only source of stock water on the farm, meaning that cattle did, at some point, have to be placed in paddocks that the race passed through in order to drink.
- Stock providing a cheap and easy way to keep the race banks clear of weeds.

Only four of the 102 farms surveyed had drainage ditches or stock races feeding into the Races, showing that most farmers took steps to prevent contamination through drainage. On many properties, the land sloped gently down into the water race, meaning that general land drainage was likely to occur. On other farms however, as a side effect of cleaning out the race, high banks had been developed on either side, that would limit general land drainage.

Most of the farms surveyed had either a culvert or bridge to prevent vehicles or stock crossing through the race with the majority of others only using the non-bridged crossing on rare occasions. During the survey, there appeared to be a strong understanding of the need for culverts.

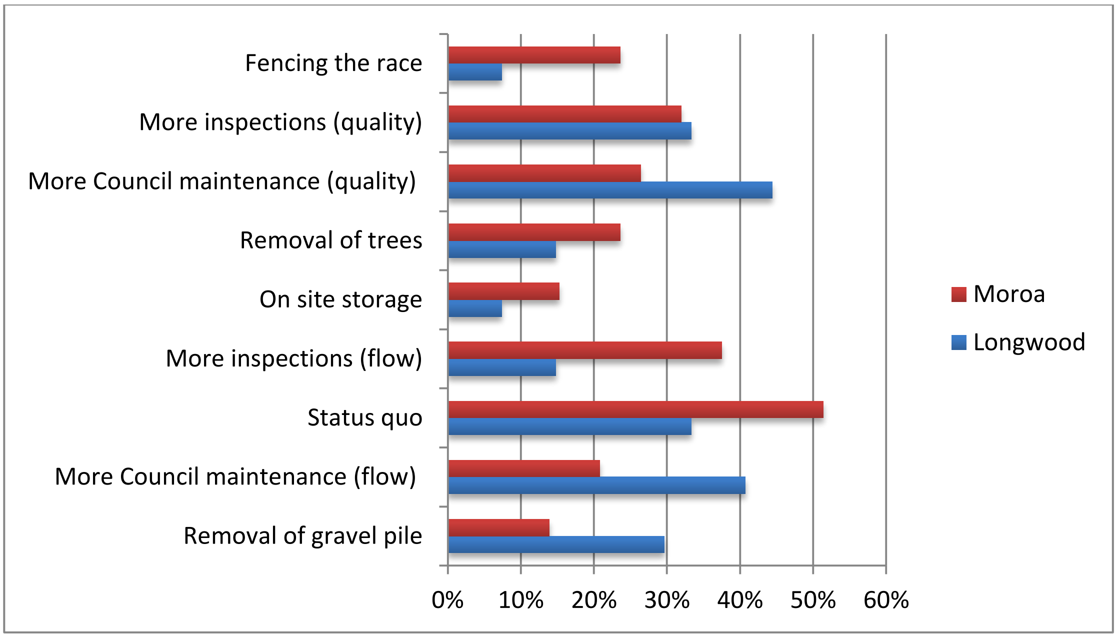
Very few farms used herbicide in cleaning, with most cleaning the race manually, allowing stock to graze the sides, using a digger, or employing a contractor. Of those that did use herbicide, most used a form of glyphosate (Round-Up). Only a few farms (27%) applied fertilizer. Of these, 40% ensured that the fertilizer was applied away from the race to limit contamination.

Replacing the water race with a piped network could prevent the majority of stock water contamination. During the survey, the landowners were polled for their opinion on the viability of a piped network. Of those that gave an answer, only 19% agreed that piping the scheme would be viable (8% in Longwood and 24% in Moroa). A similar percentage was in favour of investigating such a scheme in 2003 (Clark, 2003)

Due to age (both being over 90 years old) the Races have become important parts of the natural ecosystem and serve as a home to eels and fish. To minimise the environmental impacts, the Code of Practice recommends that eels and fish be returned downstream of the cleaning activity. While there was little indication that this occurred, the majority of respondents kept the race clean via methods that did not require the removal of eels and fish in the first place (such as weeding, racking or allowing stock to graze.)

The respondents were offered the opportunity to express how they believe the water flow and quality should be improved (respondents were allowed to select more than one). The response from each Race was very different (Figure 3), with only the proportion wanting more inspections of quality showing a close similarity. A far larger proportion of Moroa respondents supported fencing the race, while Longwood respondents tended to favour the council doing more maintenance. Over 50% of Moroa respondents supported the status quo, although some of them also support other suggestions.

Figure 3: Response to possible suggestions on improving the water race's flow/quality



In addition to the above, some respondents gave additional suggestion, such as:

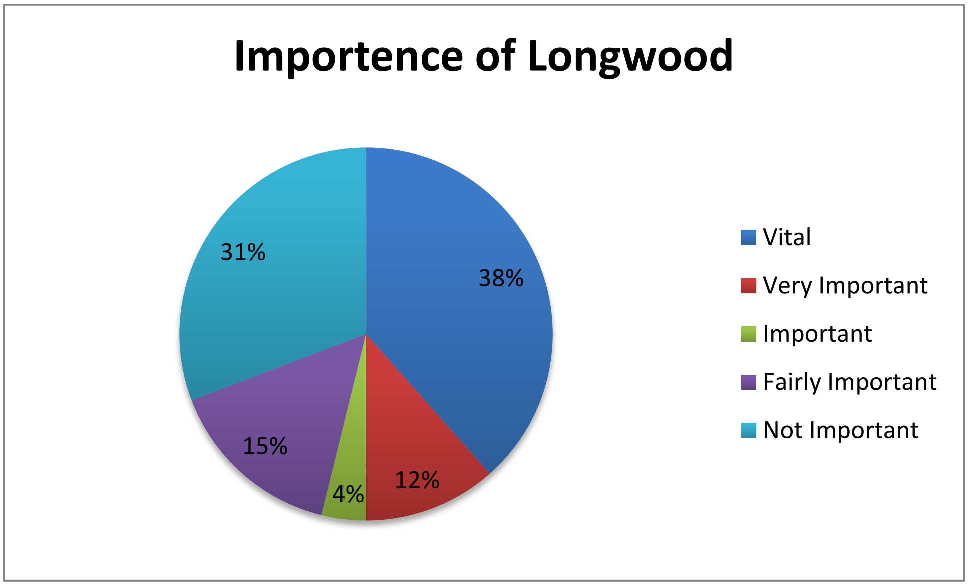
- Planting trees along the side of the race to keep back weeds.
- Better education on race use and care.
- Ensure those managing the race understood the race system and were proactive about its care.
- Have the council work with landowners to identify key improvements on each property.

3.2 Importance of the Longwood Water Race

3.2.1 Overview

Fifty percent of respondents considered the Longwood Race as either very important or vital; with a further 19% holding the race at some level of importance (Figure 4). A relatively low proportion of owners considered the race to be just 'important', with the majority of owners either considering the race to be of high or low importance.

Figure 4: The distribution of water race importance to Longwood property owners



3.2.2 Redundent Branches

The lack of respondents to the Survey made identifying unimportant/redundant branches difficult. However, the majority of the branches pass through at least one property where they are considered vital. The only major branch that does not, the branch that travels under Camp road and State Highway 53, is still consider fairly important by one respondent.

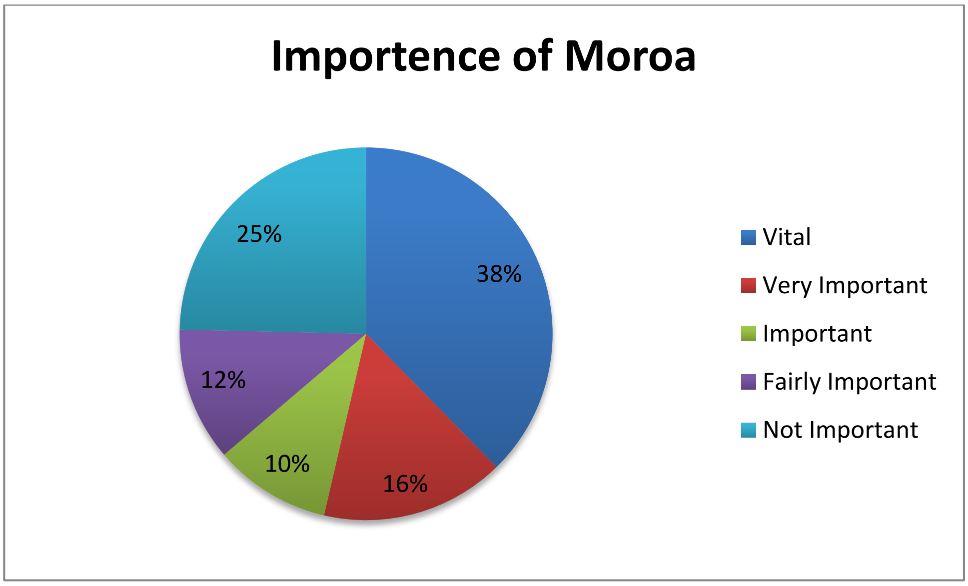
There are four minor branches that no respondent considers important; the two to the west of Greens Road, the branch running along State Highway 2, and the branch south of State Highway 2. However, this finding is due to there being no respondents from these branches and it is likely that, given the views of surrounding farms, that the branches are important to landowners some extent.

3.3 Importence of the Moroa Water Race

3.3.1 Overview

Variation in the importance of the Moroa Race is similar to that of Longwood. 54% of respondents considered the Race as either very important or vital; with a further 22% holding the Race at some level of importance (Figure 5). Unlike the Longwood respondents, only 25% of Moroa respondents considered the Race 'not important'. Additionally, the relative proportions of respondents considering the Race 'Important' or 'very important' are also higher.

Figure 5: The distribution of water race importance to Moroa property owners



3.3.2 Redundent Branches

As with Longwood, there were not enough responses to identify redundant branches. However, it was noted that respondents at the end of the North Street and Papawai Road branches all consider the Race to be not important. It is possible that each of these branches is being used upstream (the North Street Race is considered vital by at least one respondent) however the properties are small with limited stock and alternative water supplies could be available.

All respondents on the Branch between Ward's Line and Bidwills-Cutting road considered the Race 'not important'. However it is likely, given the number of properties the Branch passes through, that the branch is actually more important than responses suggest.

4 FIELD SURVEY

4.1 Response

The Longwood Race services approximately 65 properties, of which 27 (42%) were surveyed (Table 2). The Moroa Water Race services approximately 267 properties, of which 75 (28%) gave been surveyed. The number of properties was estimated by taking the list of serviced lots and ignoring the times when a ratepayer paid rates for a different lot on the same road; this was done as such lots were normally part of the same property (based on information from owners). However, this estimate ignores recent subdivision and possible occurrences where the race is not on the property.

Table 2: Number of respondents and number of properties

	Total respondents	Part 1 Only	Part 2 Only	Number of properties 2003	Number of properties 2015
Total	102	7	2	236	332
Longwood	27	1	1	51	65
Moroa	75	6	1	185	267

The majority of respondents responded to both parts of the survey, however a small number only responded to one part. As respondents to part 2 were asked to provide a contact number, the majority of the 'part 2 only' respondents were later contacted, with part 1 being completed over the phone.

The number of properties in 2015 was compared with the number of properties in 2003 and there has been a substantial increase, 44% in the case of Moroa, probably due to subdivision. While the effects of this, beyond decreasing the land area that may use the race, are still unknown it is expected that these smaller properties will:

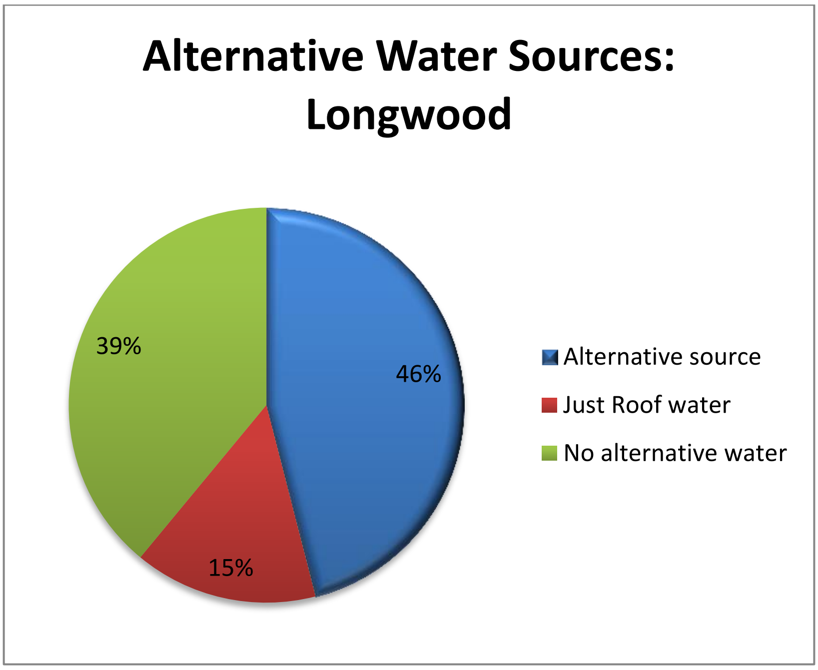
- Have owners that are often absent, meaning intermittent maintenance of the water race.
- Tend to hire a contractor to keep the race clean.
- Be less likely to have a reliable alternative source of water and thus be more reliable on the race for stock water.
- Be likely to run less stock.

4.2 Alternative Water Sources

4.2.1 Longwood

Of the surveyed properties, 38% had no alternative water source (such as a bore or town supply), meaning they were reliant solely on the Race. A further 15% had roof water as the only alternative, a source that can be unreliable (Figure 6). A more complete view of the situation was found by using Greater Wellington Regional Council and South Wairarapa District Council's GIS, to check what non-surveyed properties had a bore available and storage tanks on-site. The result showed that only 38% of properties had a reliable alternative source of water. This difference between this and the 46% found in the survey is likely due to most surveyed properties having a house, and thus the need for an alternative source of water.

Figure 6: Alternative water sources on Longwood properties

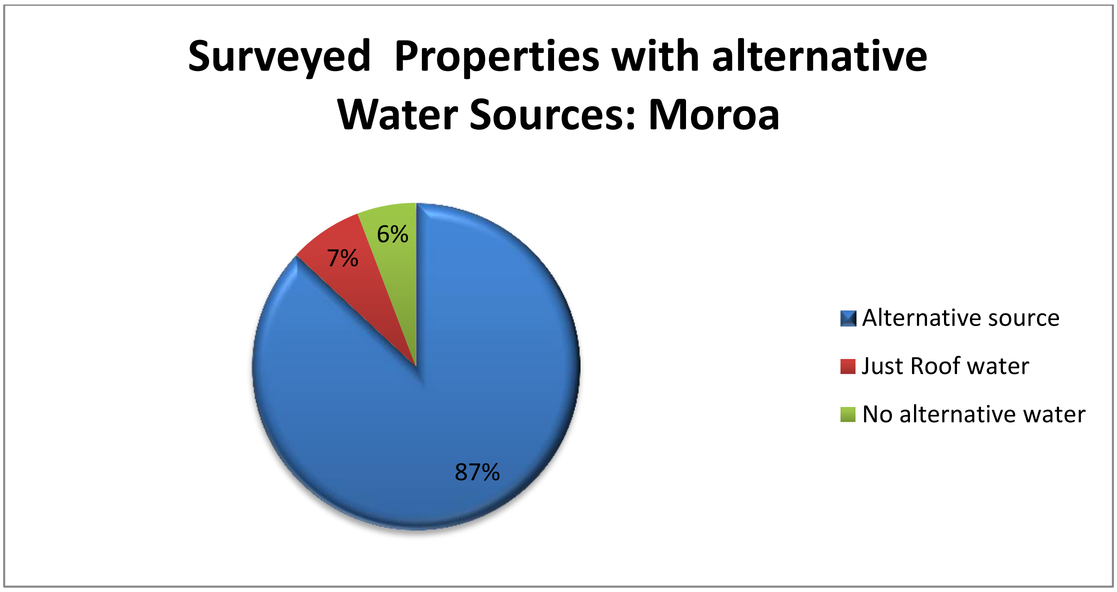


4.2.2 Moroa

Unlike Longwood, the majority of surveyed properties (87%) had an alternative water source, with a further 7% having access to just roof water (Figure 7). However, further analysis using GIS showed that the proportion of properties with a reliable alternative source of water was 58.5%. This is, again, likely due to the surveyed properties having a house while properties that were not surveyed tending to be just farmland.

According to both the survey and GIS results, the proportion of Moroa properties with an alternative water source was much higher than that of Longwood.

Figure 7: Alternative water sources on surveyed Moroa properties



4.3 Water Race Water Usage

4.3.1 Race Water Use and Wastage

As it is the only permitted use, it was assumed that the only usage of race water by farmers was for stock. Although non-stock use does occur, there is no way to quantify the amount being used for other purposes. Additionally, non-stock use noted during the survey was minimal.

Of the respondents 93 (26 from Longwood and 67 from Moroa) provided details on the stock types and numbers on their properties (Table 3). No respondent had deer or alpaca on their property, although they were included as options in the survey. GIS was used to find the total area used by the 93 respondents (952 ha for Longwood, 2127 ha for Moroa), allowing an estimate of the stock loading to be found for the land around both Races. GIS was further used to find the total land area (see below) that could use each Race. This allowed for an estimate of the total number of stock that could potentially use the race.

Table 3: Summary of stock numbers

	Dairy Cattle	Dry Cattle	Horses	Sheep	Total
Longwood					
Surveyed	1050	1361	28	1203	3642
Units/ha	1.10	1.43	0.03	1.26	3.83
Expected total	2060	2670	55	2360	7145
Moroa					
Moroa	2810	1332	38	822	5002
Units/ha	1.32	0.63	0.02	0.39	2.35
Expected total	10263	4865	139	3002	18270

Reasonable stock water requirements (Stewart & Rout, 2007) gave a high and low estimate of the stock demand for each stock types stock (Table 4). According to these estimates, the total expected stock uses, for each Race, were 182-456 m^3/day and 713-1197 m^3/day for Longwood and Moroa respectively. For Longwood, this was 1.5% of the maximum intake, while for Moroa it was 2.2% (previous estimates have put the water use at 5% or less).

Table 4: Reasonable stock demands

	Low Demand (liters/head/day)	High Demand (liters/head/day)
Dairy Cows	45	70
Dry Cows	30	55
Horses	35	70
Sheep	3	4.5
Deer	6	12

Estimating the water loss through seepage and evaporation required an estimate of the water surface area. An estimate was made using the average water width surveyed and the length of the water races (Table 5). Due to the estimate being based off sample, a 95% confidence interval was included.

Table 5: Estimated water surface area

	Total water surface (Hectares)	95% Confidence Interval
Longwood	4.8	0.9
Moroa	30.0	2.9

The topsoil from which the water races were constructed is a loamy-silt (Soils Of NZ: By New Zealand Classification) and has an approximate infiltration rate of 10-20 mm/day (Brouwer). Assuming an equal water surface area and seepage area, and using an average infiltration rate of 15 mm, the expected seepage in the Longwood race was calculated at 715 m^3/day (about 3.5% of the intake). For the Moroa water race, the calculated expected seepage was 4522 m^3/day (about 10.5% of the intake). However, given the possible variation in both the surface area and infiltration rate, this could potentially be 70% greater.

The percentage of water loss through seepage is very high for Moroa. The reason for this was that despite the Moroa intake rate only being twice that of Longwood, the surface area of Moroa race network was 6.3 times greater. While 10% is a high value, it is the best-case scenario as it assumed that the base is not, at some locations, cracked or gravel. The actual seepage is likely much higher and it is recommended that more detailed inspections be done to determine how much is being lost, and what branches of the race systems are most effected.

The evaporation from the water race was calculated using the Penman-Monteith evapotranspiration (Allen, Pereira, Raes, & Smith, 1998).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

The calculations were conducted using the historical metrological data for Martinborough (see appendix 2), with the evaporation rate varying from 3.0 mm/day in January to 0.6 mm/day in July. Under these rates Longwood would loss approximately 85 m^3/day (0.41% of the intake), while Moroa would lose approximately 540 m^3/day (1.25% of the intake)

4.3.2 Longwood Race Water and Land Use

Any future work on the race requires an understanding of the amount of land area currently being serviced and the land area that can be serviced are both important. The land area that can be serviced is the total area that the ratepayers can use the race water for. The land area being serviced is the land area that is currently relying on the race for stock water and ignores land that is not in use or relying on alternative water sources,

GIS was used to calculate the total area that can be serviced by totalling the area of land for which rates were paid. While not all the areas were available, the sum of those that were was 1705 ha; this is interesting as the previous stated value was 1500 ha. Based on an average value, the total area that can be serviced by the race is 1868 ha, with a 95% confidence interval of 82 ha.

An attempt to gauge the total area being serviced was done via the survey, with respondents being asked for the area of their land that was being serviced. Twenty respondents gave a value with the total being 809 ha. Attempts to use the results to predict the total land being serviced where made, however due to that large variation and small sample size, this could not be done to any level of accuracy.

The vast majority of farms surveyed have some form of live-stock (Table 5). Based on the above stock numbers (Table 3), the land use appears vary between dairy, beef and sheep, with the surveyed over totals of each type being over 1000 animals. A high proportion of farms have sheep and/or beef (Table 6), with the majority of these having 100 animals or less (of either sheep or beef). It should be noted that one farm had the majority of sheep. The same occurs for beef. Comparably, only three farms have dairy cows, however the number of dairy cows was never less than 250.

Table 6: Percentage of surveyed farms with stock type

	Dairy Cattle	Dry Cattle	Horses	Sheep	Total
Longwood	11.5%	50.0%	30.8%	38.5%	88.5%
Moroa	11.9%	31.3%	13.4%	34.3%	68.7%

4.3.3 Moroa Race Water and Land Use

The land area that can be serviced by the Moroa Race is commonly stated as 8,500 ha; however, like Longwood, this is unlikely the actual value. The GIS results returned a known area of 7,000 ha, with an estimated total area of 7,850 ha. Although the area of 27 properties is not accounted for, a 95% confidence interval put the total service area at less than 8,000 ha, showing the previous value could be an overestimate. However, it is more likely that the area has decreased due to subdivision.

Sixty respondents gave a value for the area of land being serviced by the water race, with the total being 1,299 ha. As with Longwood, attempts to estimate the total area being serviced were made, due to the larger sample size, these were considered reliable. Based on the average value of 22 ha/farm, an estimate of 7,109 ha was obtained.

Opposed to Longwood, Moroa's land and water use appeared to have a stronger dairy focus, with the total number of dairy cows across the surveyed farms being 3,280, over twice that of dry cattle. However, like Longwood, the number of farms with dairy cows was only 12%. Although the majority of farms run some form of stock, the proportion is less than Longwood.

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6 Appendix 1: Plan to Close a Water Race Branch

Council has received a few requests for closure of individual water races where they are no longer required.

The following steps are proposed, for example the Moroa water race branch on North Street.:

The initiator of the closure request should contact Council and ask for Operations Engineer, to discuss whether proposed race is appropriate for closure.

The initiator of the closure request is required to co-ordinate with all affected land owners to provide the following documents to Council:

a. Agreement to close water race form signed by all affected property owners -
b. A map showing the extent of the requested closure – a blank map will be provided by the Operations Engineer.

Water race closure requests will be publicly advertised.

Should interested parties wish to present their views there will be an opportunity at the Water Race Users group meeting – To be decided.

Applications for closure will be discussed and if appropriate, approved by the Water Race Users Group. The group are planning meet every quarter at the above frequency. The council's contractor who has a long relationship with the water races shall form part of the group.

Details of the decision will be posted on the Council website and affected land owners will be informed.

If appropriate fish salvage will be undertaken prior to race closure.

Physical water race closure will be undertaken in conjunction with the Council's Contractor.

Benefiting land owners will be liable for their share of the cost of closing the water race.

7 Appendix 2: Calculation of Evapotranspiration

The evapotranspiration from the water surface was calculated using the Penman-Monteith equation.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \text{ (Equation 1)}$$

Where

$ET_o = Reference\ evapotraspiration\ \left[\frac{mm}{day}\right]$

$R_N = Net\ Radiation\ at\ the\ water\ surface\ \left[\frac{MJ}{m^2 day}\right]$

$G = Soil\ Heat\ flux\ density\ \left[\frac{MJ}{m^2 day}\right]$

$T = mean\ daily\ air\ temperature\ at\ 2m\ [°C]$

$u_2 = wind\ speed\ at\ 2m\ height\ \left[\frac{m}{s}\right]$

$e_s = saturation\ vapour\ pressure\ [kPa]$

$e_a = actual\ vapour\ pressure\ [kPa]$

$\Delta = slope\ vapour\ pressure\ curve\ \left[\frac{kPa}{°C}\right]$

$\gamma = psychrometic\ constant\ \left[\frac{kPa}{°C}\right]$

The saturation vapour pressure is related to the air temperature via Equation 2

$$e^{\circ}(T) = 0.6108e^{\frac{17.27T}{T+238.3}} \text{ (Equation 2)}$$

As Equation 2 is non-linear, the average daily saturation vapour pressure is taken as the average of the saturation vapour pressures day's high and low temperatures, rather than the saturation vapour pressure at the day's average temperature. For Martinborough, the average daily high in January was 23.6 degrees Celsius and the average low was 12.2 (Cliflo: Station 2651)

$$0.6108e^{\frac{17.27*23.6}{23.6+238.3}} = 2.91\ kPa$$

$$0.6108e^{\frac{17.27*12.2}{12.2+238.3}} = 1.42\ kPa$$

$$e_s = \frac{2.91 + 1.42}{2} = 2.16\ kPa$$

The actual vapour pressure is related to the saturated vapour pressure using Equation 3

$e_a = \frac{RH_{Mean}}{100} e_s$ (Equation 3)

Where RH_{Mean} is the mean relative humidity; for Martinborough in January, this was 71.3%.

$$e_a = \frac{71.3}{100} * 2.16 = 1.54\ kPa$$

The slope of saturation vapour pressure is also related to the temperature.

$\Delta = \frac{4096 e_s}{(T+237.3)^2}$ (Equation 4)

Given the average January temperature of 17.9 and the saturation vapour pressure as 2.16, the slope was found to be

$$\Delta = \frac{4096 * 2.16}{(17.9 + 237.3)^2} = 0.0832\ \frac{kPa}{°C}$$

The psychometric constant for less location less than 100 m above sea level is 0.67 $\frac{kPa}{°C}$.

The magnitude of the soil heat flux for a day is relatively small and can thus be considered zero for the calculations. The 2 m wind speed can be related to the measured wind speed via Equation 5

$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)}$ (Equation 5)

Where

$u_z = The\ measured\ wind\ speed\ \left[\frac{m}{s}\right]$

$Z =\ height\ of\ measurement\ \left[\frac{m}{s}\right]$

Cliflo gives an average wind speed near Martinborough of 3.5 m/s; assuming that the data was taken at the same height as most meteorological data (10 m) Equation 5 gives:

$$u_2 = 3.5 * \frac{4.87}{\ln(67.8 * 10 - 5.42)} = 2.6\ \frac{m}{s}$$

The net radiation on the surface is related to the net shortwave radiation and the net longwave radiation (Equation 6).

$R_n = R_{ns} - R_{nl}$ (Equation 6)

$R_{nl} = \sigma \left[\frac{T_{maxK}^4 - T_{MinK}^4}{2}\right] \left(0.34 - 0.14\sqrt{e_a}\right) \left(1.35 \frac{R_s}{R_{so}} - 0.35\right) \left[\frac{MJ}{m^2 day}\right]$ (Equation 7)

$R_{ns} = (1-\propto) R_s \quad \left[\frac{MJ}{m^2 day}\right]$ (Equation 8)

Where

$\sigma = Stefan - Boltzmann\ constant = 4.90 * 10^{-9}\ \frac{MJ}{m^2 day}$

$T_{maxK} = Maximum\ absolute\ remperature\ during\ the\ 24\ hour\ period\ [K]$

$T_{maxK} = Minimum\ absolute\ remperature\ during\ the\ 24\ hour\ period\ [K]$

$R_s = Calcuated\ solar\ radiation\ [\frac{MJ}{m^2 day}]$

$R_{so} = Calcuated\ clear\ sky\ radiation\ [\frac{MJ}{m^2 day}]$

$\propto = Albedo = 0.23$

The maximum and minimum absolute temperatures are related to the Celsius temperatures by adding 273 (for Martinborough in January this gives 296.6 and 285.2 respectively). The solar radiation and clear sky radiation are both related to the extra-terrestrial radiation via the following Equation 9 and Equation 10.

$R_{so} = (0.75 + 210^{-5} z) R_a$ (Equation 9)

$R_s = (a_s + b_s \frac{n}{N}) R_a$ (Equation 10)

Where

$z = elevation\ above\ sea\ level\ [m]$

$a_s + b_s = fraction\ of\ extraterrestials\ radiation\ reaching\ the\ earth\ on\ clear\ days$

$n = actual\ duration\ of\ sunshine\ [hours]$

$N = maximum\ possible\ duration\ of\ sunshine\ or\ daylight\ hours\ [hours]$

$R_a = Extraterristral\ radiation\ [\frac{MJ}{m^2 day}]$

The values of a_s and b_s were not know; as a result there default values, 0.25 and 0.50 respectively, where used.

According to Cliflo, Martinborough receives, on average, 7.7 hours of direct sunlight in January (i.e. when the sun is not blocked by clouds and hills). The maximum possible duration of sunlight, i.e. sun is never blocked by hills/clouds, for a given latitude and day is found with Equation 11

$N = \frac{24}{\pi} \omega_s$ (Equation 11)

Where

$\omega_s = the\ sunset\ hour\ angle\ [radians]$

The sunset hour angle is based on the latitude and the day and is found by Equation 12

$\omega_s = \cos^{-1}(-\tan(\varphi)\tan(\delta))$ (Equation 12)

Where

$\varphi = latitude\ [radians]$

$\delta = solar\ decimation\ [radians]$

The extraterrestrial radiation for a given latitude can be estimated with Equation 13

$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_2)]$ (Equation 13)

Where

$G_{sc} = solar\ constant = 0.0820\ \frac{MJ}{m^2 day}$

$d_r = inverse\ relative\ distence\ Earth - Sun$

The latitude of Greytown is -41.08 degrees or -0.717 radians. d_r and δ are related to the day of the year by Equation 14 and Equation 15

$d_r = 1 + 0.033\cos(\frac{2\pi}{365}J)$ (Equation 14)

$\delta = 0.409\sin(\frac{2\pi}{365}J - 1.39)$ (Equation 15)

Where J is day's number in the year (January 1st being 1 and December 31st being 365). In this case, the average day in January (halfway between 1 and 31) is 16, thus

$$d_r = 1 + 0.033\cos(\frac{2\pi}{365}16) = 1.032$$

$$\delta = 0.409\sin(\frac{2\pi}{365}16 - 1.39) = -0.367\ radians$$

Via Equation 12 the sunset hour angle was calculated for January

$$\omega_s = \cos^{-1}(-\tan(-0.717)\tan(-0.367)) = 1.913\ \ radians$$

This allows the extraterrestrial radiation to be calculated (Equation 13)

$$R_a = \frac{24(60)}{\pi} * 0.082 * 1.032 * [1.913 \sin(-0.717) \sin(-0.367) + \cos(-0.717) \cos(-0.367) \sin(1.913)] = 43.2 \ \frac{MJ}{m^2 day}$$

Using the sunset hour angle the maximum possible duration of sunlight was found for the 15th of January (Equation 11)

$$N = \frac{24}{\pi} 1.913 = 14.6 \ Hours$$

Assuming an elevation of 40 m, Equations 9 and 10 were used to find the clear sky radiation and solar radiation respectively.

$$R_{so} = (0.75 + 210^{-5} * 40) * 43.2 = 32.40 \ \frac{MJ}{m^2 day}$$

$$R_s = \left(0.25 + 0.5 \frac{7.7}{14.6}\right) 43.2 = 22.18 \ MJ \ \frac{MJ}{m^2 day}$$

These, in turn, were used to find to find the net shortwave radiation and the net longwave radiation (Equations 7 and 8)

$$R_{nl} = 4.9 * 10^{-9} \left[\frac{296.6^4 - 285.2^4}{2}\right] \left(0.34 - 0.14\sqrt{1.54}\right) \left(1.35 \frac{22.18}{32.40} - 0.35\right) = 3.33 \ \frac{MJ}{m^2 day}$$

$$R_{ns} = (1 - 0.23) * 22.18 = 17.077 \ \frac{MJ}{m^2 day}$$

As a result, the net radiation was calculated (Equation 6)

$$R_n = 17.077 - 3.33 = 13.68 \ \frac{MJ}{m^2 day}$$

Substituting all values into Equation 1 gives the calculation of the reference evapotranspiration.

$$ET_o = \frac{0.408 * 0.0831(13.68) + 0.67 \frac{900}{17.9 + 273} * 2.58 * (2.16 - 1.54)}{0.0831 + 0.67(1 + 0.34 * 2.58)} = 2.82 \ \frac{mm}{day}$$

The above is, however, a reference evapotranspiration for a reference surface; convert to the actual evapotranspiration involves the following.

$ET = K_w ET_0$ (Equation 15)

Where K_w is the conversation factor to an open water surface and is considered to be 1.05. Therefore, by Equation 15, the evapotranspiration rate of the water race will be approximately;

$$ET = 1.05 * 2.82 = 2.97 \quad \frac{mm}{day}$$

8 Appendix 3: Survey Results

Note, a table is not included here if the result is shown in full in the report.

	Length Surveyed (km)
Total	84.42
Longwood	31.91
Moroa	52.51

	Average Width (m)	Standard deviation (m)	Sample size	95% Confidence Interval (m)
Total	1.23	0.53	99	0.1
Longwood	1.19	0.56	26	0.2
Moroa	1.26	0.52	73	0.1

	Average Freeboard (m)	Standard deviation (m)	Sample size	95% Confidence Interval (m)
Total	0.67	0.46	81	0.1
Longwood	0.83	0.69	19	0.3
Moroa	0.62	0.34	62	0.1

	Total Land area serviced surveyed (ha)
Total	2103
Longwood	809
Moroa	1299

	Average Land area serviced (ha)	Standard deviation (ha)	Sample size	95% Confidence Interval (ha)
Total	27	59.05	81	13
Longwood	39	75.88	21	32
Moroa	22	51.02	60	13

	Respondents (num)	Apply Fertilizer near race (%)	Apply Fertilizer away from race (%)	Don't apply fertilizer (%)
Total	94	15.96	10.64	73.40
Longwood	24	20.83	8.33	70.83
Moroa	70	14.29	11.43	74.29

9 Appendix 4: The Survey