How can we tell if too much surface water is being taken from Banks Peninsula streams?

Key aim: To determine whether it is a fair assumption that stock and household surface water takes from Banks Peninsula streams are insignificant.

Lyttelton Harbour views (Source: ChristchurchNZ)

Group Members: James Manning, Louisa Prattley
Izaura Oliveira Sarmento, Joe Cummins-Marshall,

Community Partner: Banks Peninsula Water Zone Committee

Table of Contents

Executive Summary **3**

1.0 Introduction **4**

2.0 Literature review **4**

2.1 Policy: 4

2.2 The Impacts of Climate Change on Current and Future Water Use: 5

2.3 Methods of Water Management and Estimating Water with Limited Resources: 5

3.0 Methods **5**

3.1 Study Site: 5

3.2 Selecting Catchments: 6

3.3 Data Acquisition: 7

3.4 Permitted Household and Stock Water Extraction Calculations: 7

3.5 Stock Water and Household Calculations: 8

4.0 Results **9**

4.1 Overview of Catchments: 9

4.2 Extraction Of Water During a Mean Flow Scenario: 10

4.3 Extraction Of Water During a 7DMALF Scenario: 10

4.4 Extraction Rates Compared To Mean Flow and 7DMALF: 11

4.5 Precipitation: 11

5.0 Discussion **13**

5.1 Significance of Permitted Water Takes: 13

5.2 Impacts of Reduced Flow: 13

5.2.2 Ecological Impacts of Permitted Water Takes: 14

5.2.3 Mauri and Mahinga Kai: 14

5.2.4 Climate Change: 14

5.3 Limitations and Uncertainties: 14

5.4 Recommendations: 15

6. Conclusion **16**

7. Acknowledgements **17**

8. References **18**

Executive Summary

Banks Peninsula streams, located in the South Island of New Zealand are subject to water extraction for various uses. Concerns have been raised on whether permitted water extraction for stock and household purposes have the potential to negatively affect the health of nearby streams.

This has led to the Banks Peninsula Water Zone Committee contacting the University of Canterbury Geography Department, in order to develop a methodology to estimate stock and household water takes in Banks Peninsula. The aim of this project is to ascertain if it is a fair assumption that stock and household water takes on Banks Peninsula are insignificant.

Okains Bay and Purau catchments were used as case studies for this project due to limitations in time. Google Earth was used alongside property data and flow rates for streams in each catchment to estimate potential permitted water takes. These potential permitted water takes were then compared to the mean flow and the seven day mean annual low flow (7DMALF).

It was found that there is the potential for permitted water takes in Banks Peninsula to have adverse effects on local waterways, especially during the summer months when stream flow rates are lower and water demand is higher. These key findings suggest the current policy should be re-evaluated in order to effectively manage these waterways.

This research experienced many limitations, with the predominant limitations being a lack of time and available data. The lack of available data resulted in assumptions being made on stock ratios, water takes and population counts being relied on.

Further research on this topic could involve investigating other catchments around Banks Peninsula to provide a pan-peninsula overview. Determining specific stocking rates for each catchment and gauging the amount of water extracted for each property will also be beneficial paths for future research.

1.0 Introduction

Extensive land-use changes have been ongoing for centuries in Banks Peninsula, with a major shift from native forests to agricultural and household land (Wood & Pawson, 2008). This change in land-use has led to an increased demand for water (Christchurch City Council, 2009). The majority of water for consumption in Banks Peninsula is extracted from surface water (Christchurch City Council, 2009). Surface water in Banks Peninsula is particularly vulnerable during the summer months as flows are lower and water demand is higher (Christchurch City Council, 2009). Whilst groundwater is a key component of hydrology within the peninsula, this report focuses on surface water, as this is the area where there are many uncertainties.

Concerns have been raised by locals on whether extractions have the potential to negatively affect the health of the surface water which they take water from. Many locals have attributed the very low flows and subsequent disappearance of native species in Purau during the summer of 2015/2016 to over extraction (Smith & Grimwood, 2018). The ongoing implications on ecosystems make it critical to determine whether the current policy is adequate for sustaining environmental health. As freshwater is a finite resource, the importance of adequate water management is exacerbated by the ability for those at the bottom of the catchment to miss out, if too much is taken in the higher elevations (Smith, 2020). This report seeks to clarify if the current policy which allows the extraction of 2 cubic meters of water per property per day at a rate of less than 0.5 litres per second for stock and household water has the potential for adverse effects on streams in Banks Peninsula (Environment Canterbury, 2016).

This report begins with a literature review, progressing through to a methods section followed by the results and a discussion of its implications.

2.0 Literature review

Existing literature has been foundational at providing direction for this research. In order to get a wider scope on sub-themes regarding the Banks Peninsula surface water topic, each group member was allocated a topic. These topics incorporated; policy, the impacts of climate change on current and future water use, methods of water management, and methods of estimating water when there are limited resources.

2.1 Policy:

Through analysis of these topics, it became sufficiently clear that policy is the underlying aspect controlling sustainability and implications (Jenkins, 2018). Policy dictates how much can be taken, subsequently leading to potential over-extraction within the peninsula. Thus leading to adverse effects, as stated by the Resource Management Act (The New Zealand Government, 1991). Due to the strong relevance of policy within water management, this topic extensively influenced the methodology as calculations employed the permitted take values to provide an outcome of the quantity of water that can be taken from streams. From this, recommendations regarding policy are able to be made, further influencing the major role that policy had on this research. This topic was also of interest to the Banks Peninsula Water Zone Committee, who established this project due to the uncertainty regarding the adequacy of the current policy.

2.2 The Impacts of Climate Change on Current and Future Water Use:

Global surface temperature is predicted to rise by over 1.5 degrees celsius by the end of the 21st Century (Kundzewicz, 2014). Climate change is projected to have many implications for Banks Peninsula, such as increased evaporation, water temperature, drought and decreased precipitation (Christchurch City Council, 2009). Thus significantly impacting water quality and quantity. For these reasons it is important that the surface water issues facing Banks Peninsula are addressed now, as reduced flows, with the same rate of extraction, could potentially have adverse effects on the environment.

2.3 Methods of Water Management and Estimating Water with Limited Resources:

The review of literature surrounding methods of water management have identified the use of water meters and the implementation of geographical information systems (GIS), as effective ways to manage water. GIS was shown to be a powerful tool when used alongside other environmental secondary data such as precipitation and water flow data. Water meters are not installed in many parts of Banks Peninsula; however, governmental organisations such as Land Information New Zealand (LINZ) have GIS data, in the form of layers, for Banks Peninsula which could be used with stream flow data provided by Environment Canterbury. It was additionally found that GIS is also a useful tool when there are limited resources, as it enables secondary data to be built upon, often producing significant results and statistics.

Primary data collection such as surveying was highlighted as a potential method to estimate water use when there are limited resources. However, this approach was decided against under the advice of the Banks Peninsula Water Zone Committee, due to strong perspectives held by local residents on the subject of water use and also the uncertainty surrounding the ability to travel created by Covid-19. These findings prompted the use of GIS with respect to secondary data as the core of this research project's methodology.

3.0 Methods

3.1 Study Site:

Due to the short timeframe of this research process, the entirety of Banks Peninsula could not be analysed. Subsequently, two key catchments; Okains Bay and Purau were selected. Dr. Sam Hampton (2020), recommended Okains Bay as a case study as it is vulnerable to low flows, holds ecological value and the underlying geology of the catchment makes it more comparable to other catchments than any other on the outer flanks of Banks Peninsula. The Purau catchment was identified for investigation on the recommendation from the Banks Peninsula Water Zone Committee, as it has been reported to have experienced very low flows leading to the disappearance of its long-finned eel population (Smith & Grimwood, 2018).

3.2 Selecting Catchments:

Google Earth Pro has been an instrumental tool throughout the entirety of this research. Initially it was employed to illustrate the location of perched springs, provided by Dr. Hampton (2013) in regard to catchment boundaries and river locations provided by LINZ (https://data.linz.govt.nz/data/category/property-ownership-boundaries/) and the Ministry for the Environment (MFE) (https://data.mfe.govt.nz/data/). This process was foundational in providing context to the research and is displayed by Figure 1.

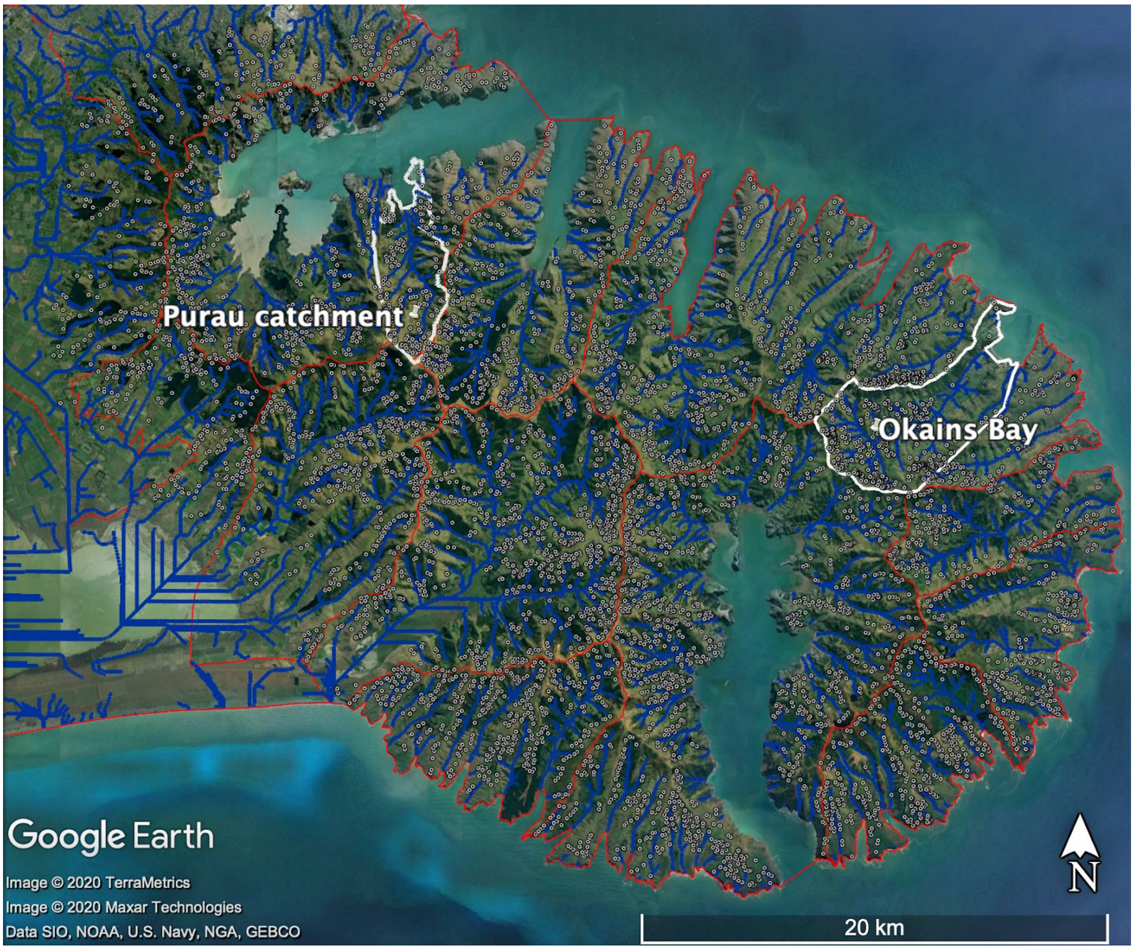

Figure 1: Google Earth imagery portraying location of the approximate 8100 perched springs in Banks Peninsula (Hampton, 2013). The Okains Bay and Purau catchments are outlined in white for location reference, while the red outlines illustrate the other major catchment boundaries. River lines were provided by the Ministry for the Environment and are shown in blue.

Google Earth was also used to generate polygons around the entire Okains Bay and Purau catchments. These catchments were then further divided into smaller polygons to perform a property count with respect to property boundary data provided by LINZ, displayed in Figure 2. This allowed for property counts to occur and generated the area of land that could potentially be subject to agriculture. Property count and land size are illustrated in Table 1.

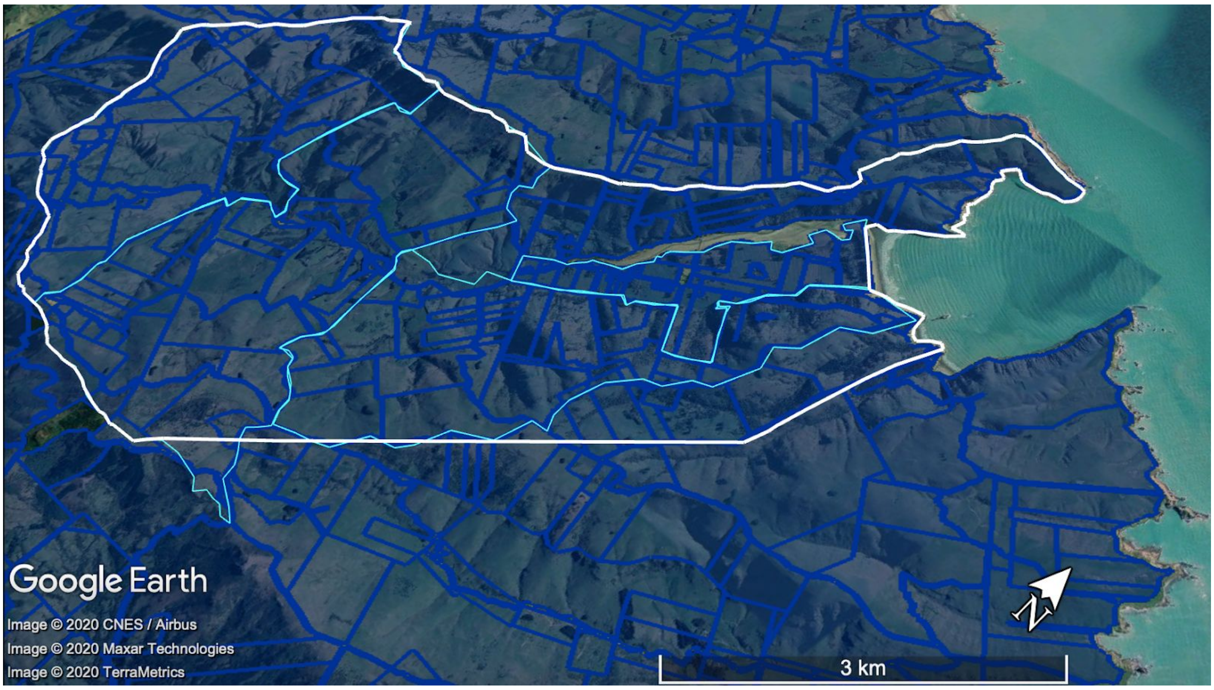

Figure 2: Annotated Google Earth Imagery of Okains Bay with respect to LINZ property boundary data shown in dark blue (2020). Okains Bay boundary lines are represented in white, with sub-catchments in light blue.

Table 1: Property count and land size of the two selected catchments.

	Okains Bay	Purau
Number of Properties	188	117
Hectares	2980	1359

3.3 Data Acquisition:

Annual rainfall data was obtained from the National Institute of Water and Atmospheric Research (NIWA) climate database (https://cliflo.niwa.co.nz). Average water use per person in Christchurch and the population of Okains bay and Purau was obtained from the Greater Christchurch Partnership website and the Christchurch City Council Community mapping report (Greater Christchurch Partnership, 2020) & (Smith & Grimwood, 2018).

Stocking rates and water flow data was obtained from Environment Canterbury (Environment Canterbury, 2016) & (Millar, 2020). Stock water consumption values were obtained from the Horizons Regional Council Reasonable Stock Water Requirements technical report (Stewart & Rout, 2007).

3.4 Permitted Household and Stock Water Extraction Calculations:

According to Environment Canterbury (2016), water extraction for stock and household water use in Okains Bay and Purau is a permitted activity providing that no more than 2 cubic meters is extracted per day and that the rate of extraction is less than 0.5 litres per second.

These extraction limits were used with respect to property count per catchment to determine the maximum daily takes and maximum permitted take at any given time. Next, these takes were compared to the total daily mean flow and the total daily seven day mean annual flow (7DMALF) of the rivers and streams for each catchment. The process of calculating maximum permitted takes and comparing them to the flow of nearby streams is represented in Figure 3.

The mean flow is the average flow a river or stream has and the 7DMALF is calculated by recording the lowest 7 consecutive day flows of the year which is averaged out over the entire record (Environment Canterbury, 2016).

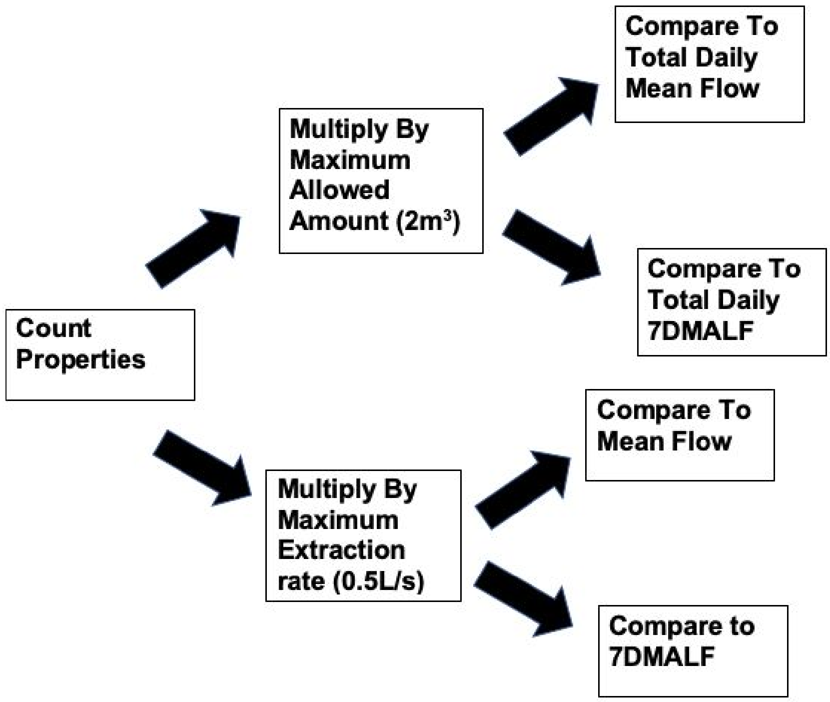

Figure 3: Flow diagram of permitted extraction calculations which were compared to the flows of nearby streams under different flow scenarios.

3.5 Stock Water and Household Calculations:

In Banks Peninsula stocking rates run between 5-7 stock units per hectare, comprising three quarters sheep and one quarter beef cattle (Millar, 2020). One mixed age ewe is equivalent to 1 stock unit and one mixed age cow is equivalent of 6 stock units. In order to calculate potential water consumption from stock, the total amount of land used for farming was multiplied by a maximum and minimum consumption scenario.

A maximum consumption scenario assumes that there are 7 stock units per hectare and that livestock are consuming at Peak Day Demand (PDD) rates. The PDD of water for a ewe is 3 litres per day and the PDD for a mature beef cattle is 30 litres per day (Stewart & Rout, 2007).

A minimum consumption scenario assumes that there are 5 stock units per hectare and that livestock are consuming at Average Day Demand rates (ADD). The ADD of water for a ewe is 4.5 litres and 55 litres for a mature beef cattle per day.

Required water for residents in each catchment was estimated by multiplying the number of residents in each catchment by 359 litres. This was the average amount of water used by Christchurch residents in 2018 (Greater Christchurch Partnership, 2020).

Once potential water requirements for stock and residents were calculated they were combined and compared to the total daily mean flow and the total daily 7DMALF of the streams for each catchment. Figure 4 illustrates how stock water and human water requirements were estimated, through a flow diagram.

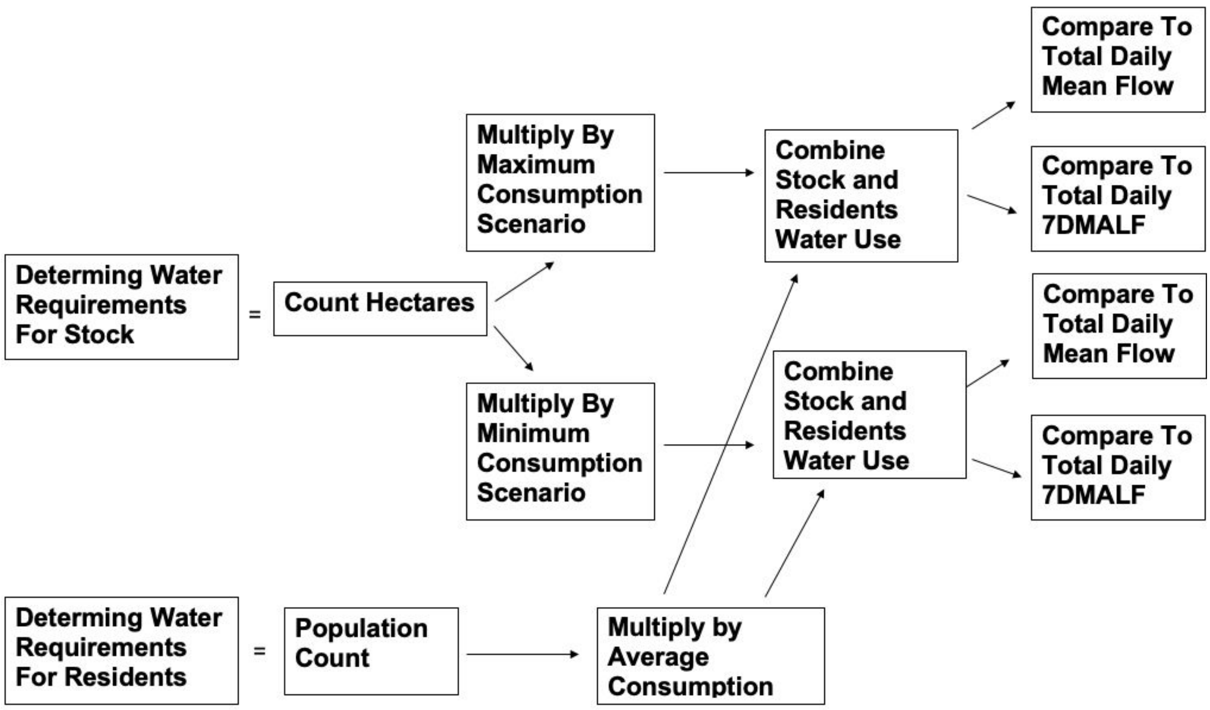

Figure 4: Flow diagram of the calculation process used to estimate the amount of water required for residents and stock in each catchment which were then compared to the flows of nearby streams under different flow scenarios.

4.0 Results

4.1 Overview of Catchments:

Okains Bay was found to be the larger catchment being approximately 2980 hectares in size with 188 properties. Purau is approximately 1359 hectares in size with 117 properties. Both catchments had similar mean flows, 230 litres per second in Purau and 249 litres per second in Okains Bay. Okains Bay had a larger 7DMALF of 45 litres per second while Purau's 7DMALF was 14 litres per second.

4.2 Extraction Of Water During a Mean Flow Scenario:

Under a mean flow scenario, 1.8% of the daily water flow in Okains Bay is allowed to be extracted and 1% of the daily water flow in Purau is allowed to be extracted. Estimated required water for stock and residents will account for 1.2% of the mean flow in Okains Bay and 0.3% of the mean flow in Purau. This is represented in Figure 5.

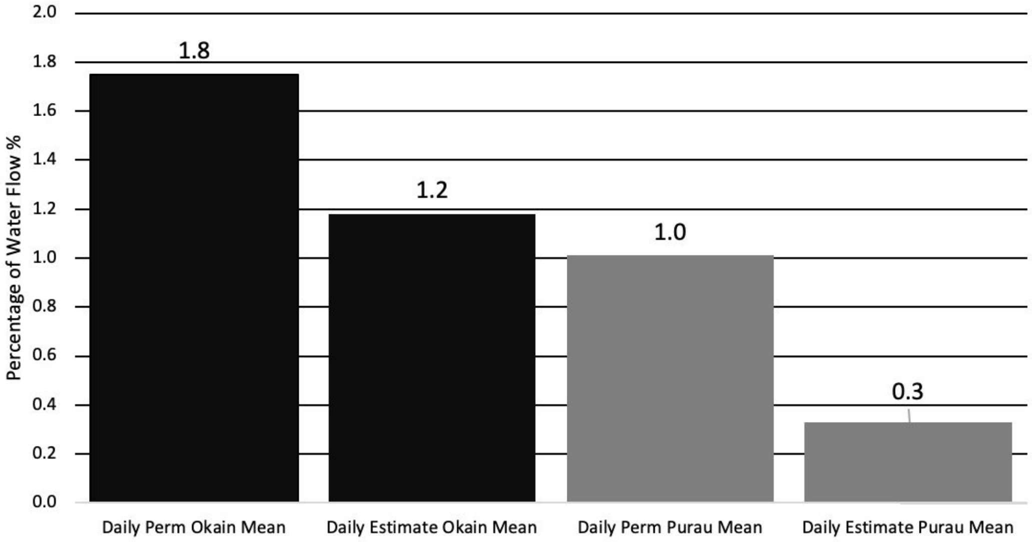

Figure 5: Permitted and estimated takes at Okains Bay and Purau with respect to daily mean flow.

4.3 Extraction Of Water During a 7DMALF Scenario:

Under a 7DMALF scenario, permitted daily water extraction has the potential to take 9.7% of the daily water flow in Okains Bay and 19.6% of the daily water flow in Purau. In a 7DMALF scenario, estimated required water will account for 7.3% of daily water flow in Okains Bay and 7.9% of the daily water flow in Purau for residents and stock in a high consumption scenario. This is shown in Figure 6.

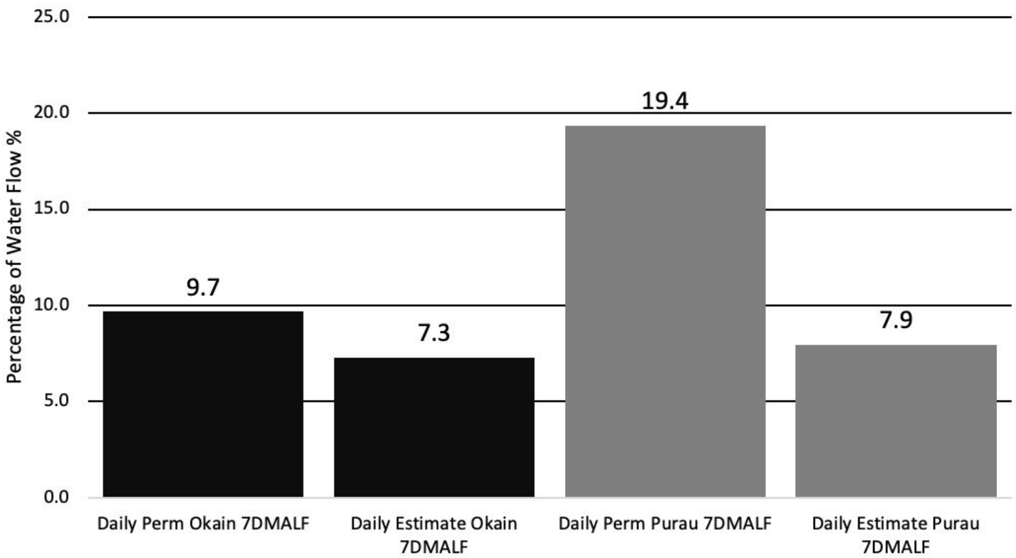

Figure 6: Permitted and estimated takes at Okains Bay and Purau with respect to 7 day mean annual low flows.

4.4 Extraction Rates Compared To Mean Flow and 7DMALF:

If all properties extracted water at the maximum rate simultaneously, permitted take could potentially equal to 37.8% of the flow in Okains bay and 25.4% of the flow in Purau in a mean flow scenario. However in a 7DMALF, permitted take could potentially equal to 208.9% of the flow in Okains Bay and 417.9% of the flow in Purau. This is shown in Figure 7.

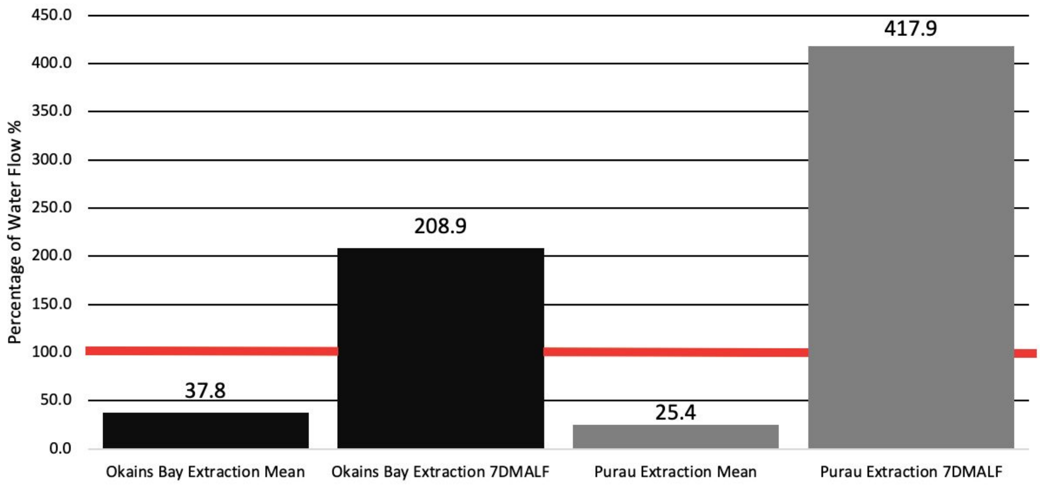

Figure 7: Permitted extraction rates at Okains Bay and Purau with respect to mean flow and 7 day mean annual low flow.

4.5 Precipitation:

Through analysis of available weather station data on Banks Peninsula, the trend remains the same. This shows September through to March receiving low precipitation rates. Thus, additional inputs of water for nearby streams during these months is limited. These trends are displayed on Figure 8. The locations of weather stations used for precipitation data are displayed in Figure 9. Diamond Harbour is next to Purau and Le Bons Bay is next to Okains Bay. This is useful as it provides an approximate understanding of climatology in these locations.

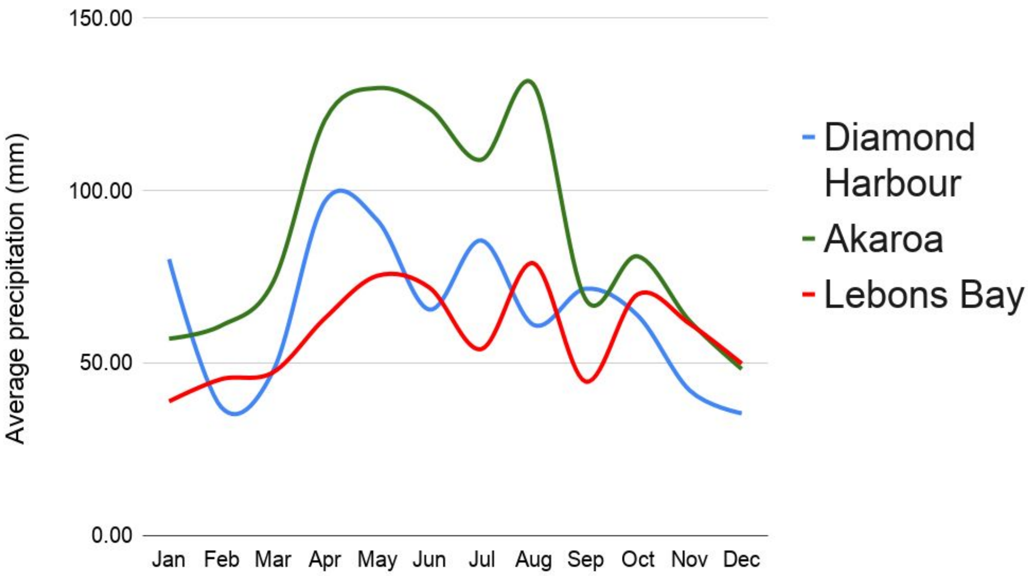

Figure 8: Average monthly precipitation in Banks Peninsula Catchments.

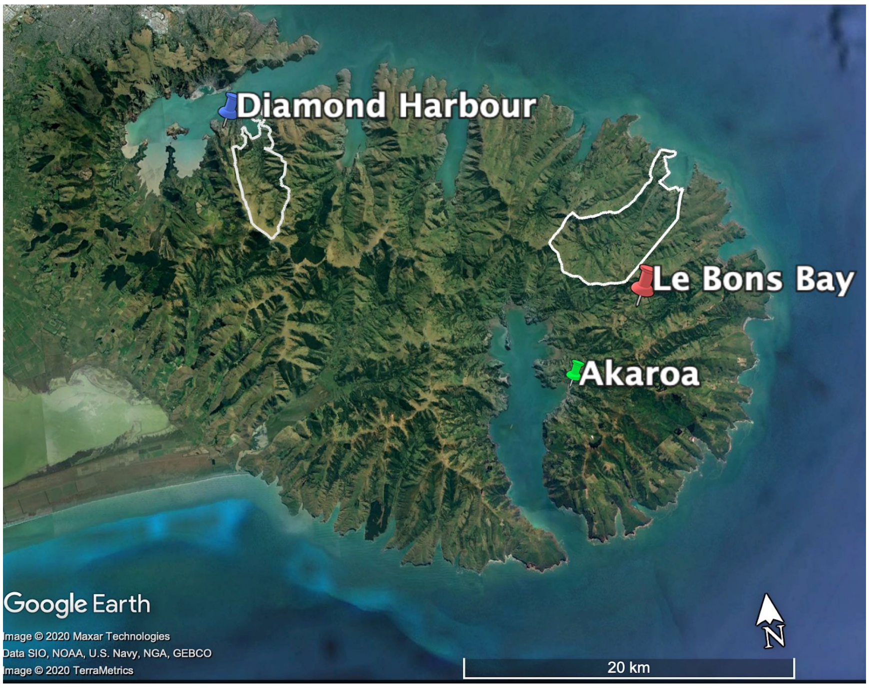

Figure 9: Weather station locations alongside outlined catchments.

5.0 Discussion

5.1 Significance of Permitted Water Takes:
In order to mitigate adverse effects, rivers with a mean flow rate of less than 5 cubic meters per second should have a minimum flow of 90% of the MALF (Ministry for the Environment, 2008) & (Bradford & Heinonen, 2008). The majority of streams in Banks Peninsula fall within this category, therefore, no more than 10% of the MALF should be extracted in these locations.

Figure 6 showed 9.7% and 19.4% of the flow is allowed to be extracted from Okains Bay and Purau respectively. As the total extractions from Okains Bay are situated directly on the border of the safe rate of extraction, any changes to extractions or river attributes has the potential to greatly impact river quality and quantity. Thus, making Okains Bay extremely vulnerable to climate related changes. Meanwhile, Purau has the ability to have almost double the safe amount, extracted from its streams. Therefore, permitted water takes in both of the studied catchments have the potential to have adverse effects under a 7DMALF scenario.

5.2 Impacts of Reduced Flow:
As shown previously in Figure 8, precipitation in Banks Peninsula is limited from September through to March. Consequently, permitted water takes from these streams during these months could potentially lead to issues relating to low flows. Reduced flows can have many negative impacts on the water quality, ecology, mauri and mahinga kai values of streams.

5.2.1 Water Quality:
Shallow water heats up faster than deep water as a larger portion is exposed to the atmosphere, thus receiving more energy (Moore & Miner, 1997) Therefore, the lower flow rates have the potential to contribute to a rise in temperature within the streams in Banks Peninsula. Subsequently, habitats of aquatic species are jeopardized, as some species cannot adapt to the increased temperatures (Taranaki Regional Council, 2018) & (Richardson, Boubée & West, 1994). Warmer temperatures also reduce the amount of dissolved oxygen in the waterway, putting further pressure on the ecosystems within the streams (Rajwa-Kuligiewicz, Bialik & Rowiński, 2015).

The reduction in flow can also lead to an increase in the concentration of nutrients and other pollutants within streams (Ansari, Gill, Lanza, & Rast, 2011). Increased concentrations of nutrients such as nitrogen and phosphorus can lead to toxic algal blooms (Burrell, 2011). Algal blooms cover the top layer of the waterway while also producing toxic compounds, making the water unfit for human use and having detrimental effects on aquatic ecosystems (Burrell, 2011). Furthermore, high concentrations of nitrogen can be toxic to some species and make water unsafe to drink (Ministry for the Environment & Stats NZ, 2020). These aspects exacerbate the importance of considering water quality, whilst determining safe water extraction rates, as many parts of Banks Peninsula rely on surface water as the primary water supply (Christchurch City Council, 2009).

5.2.2 Ecological Impacts of Permitted Water Takes:
Banks Peninsula streams accommodate native species such as inanga and long-finned eel, which are vulnerable to a reduction in flow (Environment Canterbury, 2020). Water flows influence many ecological processes such as food delivery, nutrient transport and channel connectivity (Ministry for the Environment & Stats NZ, 2020). Low flows act as a 'habitat bottleneck' as lower flow rates can reduce the size of habitats. Thus, having the potential to reduce the quantity of species (Taranaki Regional Council, 2018).

5.2.3 Mauri and Mahinga Kai:
In te ao Māori (the Māori worldview) water bodies are of major importance as many Māori believe that each water body has its own mauri (Life force) (Environment Foundation, 2020). The reduction in water quantity and quality can diminish the mauri of water bodies, therefore having negative cultural impacts. The ability for Māori to partake in mahinga kai (the act of gathering and preparing food) may also be hampered if native species such as long finned eels and inanga were to disappear due to low flows (Environment Canterbury, 2020).

5.2.4 Climate Change:
It is projected that the Canterbury region will face drier conditions in the future as a result of global climate change (Christchurch City Council, 2009). Increased demand alongside higher evaporation rates will put further stress on surface waters in Banks Peninsula.

5.3 Limitations and Uncertainties:
The results that were produced from this research project are impacted by many limitations and uncertainties. Time restrictions and a lack of water extraction data have led to many assumptions being made in order to produce a suitable outcome.

In many parts of Banks Peninsula the amount of water extracted from surface water is not monitored. In order to navigate through this, calculations were made with an assumption that all properties in the selected area, regardless of size or purpose, extract the maximum allowed amount of water. It is unlikely that all properties will extract the same amount of water as different properties will have different water requirements. This research also creates a scenario where all properties extract water at the same time of day. This is unlikely as different properties have different water storage capacities.

This research additionally assumes that the maximum population is present in each catchment of interest. This data was obtained from Smith & Grimwood (2018) who cites the 2013 Census. The true population may be different as this data was collected seven years ago. Many of the properties in these study areas do not have permanent residents as they are baches, resulting in population fluctuations throughout the year. The limitation regarding population is exacerbated during summer months, as bach goers tend to visit the bays more regularly, and also take friends and whanau with them, who may not be counted within the census data (Smith & Grimwood, 2018).

This project also assumes that stocking rates in the Banks Peninsula area run between 5-7 stock units per hectare, of which three quarters are sheep and one quarter are beef cattle, advised by Environment Canterbury's land management advisor (Millar, 2020). The exact amount and type of stock was unable to be obtained so this assumption had to be made. As hectare values were used to calculate the number of stock in these locations, the results may vary, as not all non-urban land (identified on Google Earth) is viable for farming, as some areas comprise steep topography and dense bush.

Due to time limitations, it was not possible to cover the entire area of Banks Peninsula, so representative catchments were selected. Given the vast differences found between Okains Bay and Purau, it is known that the effects of permitted water takes on streams in every catchment in Banks Peninsula will differ. The differences in microclimates, topography and the amount of residents and stock consuming water differ between catchments, which will impact outcomes.

This research also assumes that all water for consumption is extracted from surface water. This is not accurate as rainwater is collected by some residents in Banks Peninsula and sometimes water is trucked in (Smith, 2020). Groundwater is also a large component of the hydrology within the peninsula; however, given limited time and resources, groundwater extractions could not be taken into account.

5.4 Recommendations:

As stated in section 5.1, there is potential for permitted water extraction to have adverse effects on streams in Banks Peninsula, so a re-evaluation of the current policy is recommended.

Current policy allows the same amount of water to be taken per property, regardless of the size and purpose. Whilst completing this research, this appeared to be unsuitable for Banks Peninsula, as not all properties are inhabited year round and will not require as much water. A review of policy could allow water to be redistributed to areas where it is most needed.

Monitoring water with the use of water meters could help decrease the uncertainties surrounding this topic. Installing water meters where water extraction occurs will allow for the correct quantities of water extraction to be known which will allow for effective management. According to Peter (2010) the implementation of water meters played a crucial role in reducing water consumption in Tauranga, removing the need for water restrictions and saving money as additional water supplies were not needed. Over a thirty year period, approximately 3.4 million dollars per year was saved in Tauranga following the implementation of water meters. This proves that the costs of running a water meter, such as installation and readings are severely outweighed by the benefits (Peter, 2010).

Improving water storage and rain collection facilities around Banks Peninsula could reduce the pressure of permitted water takes on streams as seen in the works of Okoye et al (2015), where water storage tanks have been optimized for household rainwater collection.

Catchments in the area would also benefit from habitat restoration such as riparian planting. O'Briain, Shephard, Matson, Gordon & Kelly (2020) state that riparian planting can be an effective climate change mitigation tool to reduce stream temperatures while also maintaining flows by reducing evaporation. It is also likely that it would positively influence the biodiversity within and surrounding the streams by providing more habitats (Boothryod et al, 2004).

6. Conclusion

This research project has found that permitted surface water takes in Banks Peninsula has the potential to have adverse effects on the environment. The effects from permitted takes will be greatest during the summer months when stream flow is low and water demand is high. Therefore, this report recommends that the current policy regarding permitted water takes in Banks Peninsula should be reviewed. It is important to acknowledge that the results and findings from this report have been built upon many limitations and assumptions, and is the outcome of an undergraduate learning experience. More research and detail will be required to improve the reliability of the results.

7. Acknowledgements

The group would firstly like to acknowledge Gina Waibl and Paula Smith from the Banks Peninsula Water Zone Committee. We would also like to acknowledge Harry Millar, Jen Dodson, Suzanne Gabites & Tim Davie from Environment Canterbury for providing stream flow and stocking rate data. Additionally, we would like to acknowledge Dr. Sam Hampton for his advice on this project and for providing spring location data. Lastly we would like to acknowledge our supervisor Dr. Heather Purdie for her great advice and encouragement throughout this research project.

8. References

Ansari, A. A., Gill, S. S., Lanza, G. R., & Rast, W. (2011). *Eutrophication: causes, consequences and control* (1. Aufl. ed.). *Retrieved from:* https://link-springer-com.ezproxy.canterbury.ac.nz/book/10.1007%2F978-90-481-9625-8

Burrell, T. K. (2011). *Trophic State in Canterbury Waterways*, University of Canterbury, Biological Sciences). *Retrieved from:* https://ir.canterbury.ac.nz/bitstream/handle/10092/6236/thesis_fulltext.pdf?sequence=1&isAllowed=y

Boothroyd, I. K. G., Quinn, J. M., (Lisa) Langer, E. R., Costley, K. J., & Steward, G. (2004). Riparian buffers mitigate effects of pine plantation logging on new zealand streams: 1. riparian vegetation structure, stream geomorphology and periphyton. *Forest Ecology and Management, 194*(1), 199-213.

Bradford, M. J., & Heinonen, J. S. (2008). Low flows, instream flow needs and fish ecology in small streams. *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques, 33*(2), 165-180.

Brunner, L., Lorenz, R., Zumwald, M., & Knutti, R. (2019). Quantifying uncertainty in European climate projections using combined performance-independence weighting. *Environmental Research Letters, 14*(12). Retrieved from: https://doi.org/10.1088/1748-9326/ab492f

Christchurch City Council (2009). *Water Supply Strategy 2009-2039*. *Retrieved from:* https://www.greaterchristchurch.org.nz/assets/Documents/The-Council/Plans-Strategies-Policies-Bylaws/Strategies/WaterSupplyStrategy2009Full.pdf

Environment Canterbury (2020). *Banks Peninsula Zone Biodiversity*. *Retrieved from:* ecan.govt.nz/your-region/your-environment/our-natural-environment/nature-in-your-area/banks-peninsula-zone/

Environment Canterbury (2016). *Canterbury Land and Water Regional Plan. 1. Retrieved from:*https://ecan.govt.nz/your-region/plans-strategies-and-bylaws/canterbury-land-and-water-regional-plan/

Environment Canterbury (2020). *Mahinga Kai*. *Retrieved from:* https://ecan.govt.nz/your-region/your-environment/our-natural-environment/mahinga-kai/

Environment Foundation (2020). *Māori and Environment Law. Retrieved from:* *http://www.environmentguide.org.nz/overview/maori-and-environmental-law/*

Greater Christchurch Partnership. (2020). Water use. Retrieved from: https://www.greaterchristchurch.org.nz/indicators/environment/water-use

Hampton, S., McGuire, C., Carrol, B., Armanetti, C., Pontifex, T., Holzer, I., and Bell, D (2013). Hydrogeology, mapping, and management strategies for volcanic derived perched springs of Banks Peninsula. pp1-22

Jenkins, B. R. (2018). Water management in New Zealand's Canterbury region. *A sustainability framework.* Pp21-73

Kundzewicz, Z. W. (2014). Fifth IPCC assessment report now out. Papers on Global Change IGBP, 21(1), 9-27. doi:10.1515/igbp-2015-0001

Ministry for the Environment & Stats NZ (2020). New Zealand's Environmental Reporting Series: Our freshwater 2020. www.mfe.govt.nz

Ministry for the Environment. (2008). Proposed National Environment Standard on Ecological Flows and Water Levels. *Retrieved from:* https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/Proposed%20National%20Environmental%20Standard%20on%20Ecological%20Flows%20and%20Water%20Level%20Discussion%20document.pdf

Moore J.A., Miner J.R., (May, 1997). Stream Temperatures. Some basic considerations. Oregon State University Extension Service. Pp1.

Peter, B. (2010). Review of water metering costs in Tauranga City Council. *Retrieved from:* https://www.smartgrowthbop.org.nz/media/1124/q-review_of_water_metering_costs_in_tauranga_city_council_-_tcc_-_march_2010.pdf

O'Briain, R., Shephard, S., Matson, R., Gordon, P., & Kelly, F. L. (2020). The efficacy of riparian tree cover as a climate change adaptation tool is affected by hydromorphological alterations. Hydrological Processes, 34(11), 2433-2449. doi:10.1002/hyp.13739

Okoye, C. O., Solyalı, O., & Akıntuğ, B. (2015). Optimal sizing of storage tanks in domestic rainwater harvesting systems: A linear programming approach. *Resources, Conservation and Recycling, 104*, 131-140.

Rajwa-Kuligiewicz, A., Bialik, R. J., & Rowiński, P. M. (2015). Dissolved oxygen and water temperature dynamics in lowland rivers over various timescales. *Journal of Hydrology and Hydromechanics, 63*(4), 353-363. doi:10.1515/johh-2015-0041

Richardson, J., Boubée, J. A. T., & West, D. W. (1994). Thermal tolerance and preference of some native new zealand freshwater fish. *New Zealand Journal of Marine and Freshwater Research, 28*(4), 399-407. doi:10.1080/00288330.1994.9516630

Smith, P., & Grimwood, S. (2018). *Banks Peninsula Community Mapping*. *Retrieved from:* https://www.ccc.govt.nz/assets/Documents/The-Council/Community-Boards/Banks-Peninsula-community-board/Banks-Peninsula-Community-Mapping.pdf

Stewart, G., & Rout, R. (2007). *Reasonable Stock Water Requirements Guidelines for Resource Consent Applications*. *Retrieved from:* http://www.horizons.govt.nz/HRC/media/Media/One%20Plan%20Documents/Reasonable-Stock-Water-Requirements-Guidelines-for-Resource-Consent-Applications.pdf?ext=.pdf

Taranaki Regional Council (2018). *Review of Minimum Flows and Water Allocation in Taranaki*. *Retrieved from:* https://www.trc.govt.nz/assets/Documents/Plans-policies/SoilWaterPlanReview/WaterAllocationReport2018.pdf

The New Zealand Government. (1991). Resource Management Act. *Restrictions relating to water.* Pp74. *Retrieved from:* http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html

Wood, V., & Pawson, E. (2008). The banks peninsula forests and akaroa cocksfoot: Explaining a new zealand forest transition. *Environment and History, 14*(4), 449-468. doi:10.3197/096734008X368394