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The Influence of Extreme Events on Inanga Habitat in the Avon River, Lake Kate Sheppard and Travis Wetlands

GEOG309-16S2 Research Methods in Geography

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The Tides Have Turned: Forecasting the Distribution of Inanga as a Consequence of Extreme Hydrological Events

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1. Executive Summary

1.1 Research Question

How do extreme hydrological events impact the salinity distribution and the possible effects on inanga habitat in the Avon River, Lake Kate Sheppard and Travis Wetlands?

1.2 Research Context

Lake Kate Sheppard is a man-made lake located within the residential red zone of Christchurch. This is an ecological corridor connecting the Avon River and Travis Wetlands.

There is a significant quantity of research regarding inanga (*Galaxias maculatus*) although studies concerning the influence of abiotic gradients such as tidal and rainfall events are limited.

The aim of this project is to determine how the saltwater interface is affected by extreme hydrological events which consequently will impact inanga habitat dynamics.

1.3 Summary of Methodology

Qualitative Methods:

Conclusions in relation to inanga behaviour and their spawning sites in Lake Kate Sheppard are derived from an extensive literature review. Also collected was information regarding the characteristics of a typical inanga habitat, and the potential ramifications this habitat could face in the future, due to both anthropogenic and natural factors.

Quantitative Methods:

An automatic weather station and current meter were utilised to measure the extent of rainfall and tidal events respectively, whilst CTD loggers were positioned in the water providing constant measurements for both events.

1.4 Key Findings

- A clear correlation was found between changes in conductivity and the occurrence of hydrological events.
- Inanga were observed in Travis Wetlands past previous known extents.

1.5 Limitations

- Short research timeframe
- Rainfall forecasts were often unreliable
- Equipment set-up error
- Equipment malfunctions

1.6 Future Research

A longer research timeframe should be considered to observe long term patterns and trends. This can include water quality testing, bathymetry comparisons and the establishment of a biomonitoring programme. Further investigation into inanga spawning should also be undertaken as their distribution has changed temporally at this site.

2. Introduction

Inanga (*Galaxias maculatus*) is one of five diadromous species of Galaxis (whitebait) that inhabit New Zealand Waterways (Walrond, 1999). Inanga spawn predominantly in estuarine environments at the saltwater interface in amongst the riparian vegetation (Richardson & Taylor, 2002). In the Canterbury region, past research has demonstrated that inanga have been observed in eleven waterways, with one of the main spawning sites being located in the Avon River (Taylor, 2002). The Avon River is located in the Anzac Drive Reserve which is connected to Travis Wetlands via Lake Kate Sheppard (Orchard & Avon Ōtākaro Network, 2016). Lake Kate Sheppard is a tidally influenced man-made lake that acts as both an ecological corridor and a sediment trap for silt flowing from Travis Wetlands (Taylor & Blair, 2011). Taylor and Chapman (2007) mapped the location of inanga eggs and found they were predominantly located south of the jetty in Lake Kate Sheppard. However, in 2011 after the Earthquake series, no inanga eggs were found in these previously mapped extents and these areas were instead inundated with silt (Taylor & Blair, 2011). Restoration efforts have resulted in a population rebound since 2011 with the distribution of inanga changing. A 2015 study found that spawning sites remain in the previously recorded extent, however the majority of sites are located further north than they were pre-quake (Orchard, 2016).

Since inanga spawning occurs at the saltwater interface, abiotic gradients such as salinity can also influence egg survivorship and spring tidal spawning (Hicks, Barbee, Swearer & Downes, 2010). Hicks et al., (2010) additionally determined that artificial fertilisation was not successful for the higher salinities range. This is of particular importance to inanga since salinity changes can occur in estuarine environments as a consequence of extreme events (Wetz & Yoskowitz, 2013).

The Avon River, Lake Kate Sheppard and Travis Wetlands are located in the Mahinga Kai Exemplar area. The Mahinga Kai Exemplar Area is 16 hectares and has been influenced anthropogenically from land modification (Orchard & Avon Ōtākaro Network, 2016). The Mahinga Kai Exemplar Area is a project managed by the Avon Ōtākaro Network, Ngāi Tūāhuriri Rūnanga and Te Rūnanga o Ngāi Tahu, alongside many other assisting organisations (Orchard & Avon Ōtākaro Network, 2016). The purpose for the Mahinga Kai Exemplar is to restore the Avon River ecosystems and the surrounding residential red zone to promote intergenerational equity (Orchard & Avon Ōtākaro Network, 2016). Our experimental site is located within the Mahinga Kai Exemplar area. Our research question is how do extreme hydrological events impact the salinity distribution and the possible effects on inanga habitat in the Avon River, Lake Kate Sheppard and Travis Wetlands?

The aim of this project was to identify the movement of the saltwater interface and to ascertain which extreme hydrological events caused this. This aims to contribute towards future restoration and management of the biodiversity within the Mahinga Kai Exemplar area. To clarify, the definition of 'extreme events' in the context of our research refers to any rainfall or any substantial tidal variations that occurred within the timeframe and scope of our experiment.

Quantitative data was collected from our experimental site concerning extreme events. Qualitative data was gathered from literature reviews to draw conclusions in relation to inanga. Limitations additionally occurred such as unreliable rainfall forecasts, equipment malfunctions and set-up error. Future research is important for this ecosystem to effectively establish a holistic management plan for inanga and inanga habitats.

3. Literature Review/ Theoretical Framework

The literature review was an important part of the research process as it provided the theoretical framework for our experimental design. This helped to distinguish the main research categories that needed to be focused on including the saltwater interface in relation to hydrological events and inanga spawning habitats. From our findings explanations regarding possible inanga behaviour will be drawn from this literature.

Lake Kate Sheppard is a freshwater environment that is influenced by intruding saline water from the Avon River (Orchard & Avon Ōtākaro Network, 2016). This results in a saltwater interface where the two water densities converge and is also the location of inanga spawning (Richardson & Taylor, 2002). Alterations to this interface can modify ecosystem dynamics (Barendregt & Swarth, 2013) and this influences connected water bodies such as Travis Wetlands (Taylor & Blair, 2011). Saline water has a higher concentration of ions than freshwater which increases conductivity levels (Livelybrooks, 2008). Measuring conductivity is important to determine the interface in Lake Kate Sheppard as it contributes to our project aims.

Extreme hydrological events in Lake Kate Sheppard can change water characteristics such as conductivity and temperature. The extent of change they induce on the system and the timeframe of the event, impacts the ecological environment (Wetz & Yoskowitz, 2013). These events can influence the flow rate, habitat dynamics and water chemistry of the area (Wetz & Yoskowitz, 2013). The extent of these events can be monitored for this project with equipment such as an automatic weather station and a flow meter.

Part of the biodiversity that resides in Lake Kate Sheppard is inanga which spawn at the saltwater interface (Richardson & Taylor, 2002). Inanga spawn on the incoming high tides in the riparian vegetation and often use the same spawning sites from which they originated (Richardson & Taylor, 2002). A thriving inanga habitat requires high water quality conditions such as a low suspended sediment load and optimum temperature (Richardson & Taylor, 2002). The health of the inanga in Lake Kate Sheppard has been compromised as a result of the Christchurch earthquakes. Liquefaction and the lowering of ground levels has altered the riparian vegetation and salinity levels within the lake (Orchard and Avon Ōtākaro Network, 2016). Consequently, there is a need for more research to be conducted in this area in order to appropriately monitor the biodiversity within the Mahinga Kai Exemplar (Orchard & Avon Ōtākaro Network, 2016).

4. Methodology

Data collection was conducted using a variety of equipment from different specialities across several locations within our experimental site (appendix 1). Data was continuously collected over the month of August. Interpretation of this data required statistical analysis using programs such as Excel which condensed and collated the data. Graphs were produced to demonstrate temporal and spatial variations.

4.1 Equipment Positioning

In order to compare and validate our results, the GPS positioning of our surveying equipment was required. A LINZ geodetic survey mark was used to achieve this. The positioning of gear was found using Trimble R8 survey grade GNSS, set over the survey mark, refer to appendix 2. The system used real time kinematic surveying which allowed centimetre accuracy to be logged.

4.2 Current Meter

Flow from the Avon River enters Lake Kate Sheppard through the culvert south of the lake. The extent of this flow is dependent on tides and hydrological processes. A Valeport 106 Current Meter was used to measure this in ten second intervals, refer to appendix 3. The velocity of water through the culvert and the direction of flow were identified, allowing high and low tides to be determined. The current meter was hung from a steel pole that stretched across the intake using a chain of an appropriate length so it was submerged during both high and low tides for consistent readings. To balance the current meter, a weight was attached below to keep it level to provide accurate readings.

4.3 Automatic Weather Station

An Onset Hobo H-21-001 portable automatic weather station was set up at our experimental site in close proximity to Lake Kate Sheppard (appendix 4). This was setup to gather evidence on the possible rainfall that could occur at Lake Kate Sheppard. Rainfall is a vital factor in our investigation as it can impact conductivity. Other meteorological aspects that were measured include: wind speed, wind direction, pressure, temperature and relative humidity. These were not analysed as they did not influence the relevant lake characteristics related to our experimental design.

4.4 CTD Logger

Conductivity, temperature and depth was measured in the Avon River, Lake Kate Sheppard and Travis Wetlands using a Solinst level logger model 3001 (appendix 5). These devices simultaneously collected data in ten minute intervals. The position of each of these loggers is displayed in appendix 1. The loggers were subtly placed in close proximity to the bank to mitigate tampering from the public. The loggers were additionally placed in a position that was assumed to be deep enough for the logger to remain below water even in low tide events.

4.5 Barometer

Air pressure was measured on the bank of Lake Kate Sheppard using a Solinst Barologger model 3001 (appendix 1). This device measures atmospheric pressure fluctuations determining the amount of air pressure that is above the lake water level. The barometer was attached to the side of a tree hidden in the riparian vegetation to mitigate public disturbance (appendix 6). The specific barometer data is not included in our results as it was used to correct the CTD loggers.

5. Results

The quantitative data collected at our experimental site demonstrated a range of hydrological processes that interact under particular environmental conditions. The analysed results show patterns reflecting the impacts of extreme hydrological events.

5.1 Equipment Positioning

Site	Northing	Easting	Top of mount elevation (m.s.l.)	Distance from sensor to top of mount (m)	Elevation of sensor
Avon River	5183515	1575948	-0.086	0.24	-0.326
LKS	5183889	1575910	-0.209	0.188	-0.397
Travis Wetlands	5184440	1575859	0.078	0.235	-0.157
Base	5184216	1576058	0.658	1.016	-0.358

Figure 1: Measurements demonstrating the elevation of the CTD loggers using a Trimble Survey Grade GNSS. Note: LKS is an abbreviation for Lake Kate Sheppard.

GNSS results can be seen in figure 1. These findings represent the elevation of the CTD logger in each location in relation to sea level. These results are used to anticipate the possible effects of predicted sea level rise in this area.

5.2 Tidal Chart

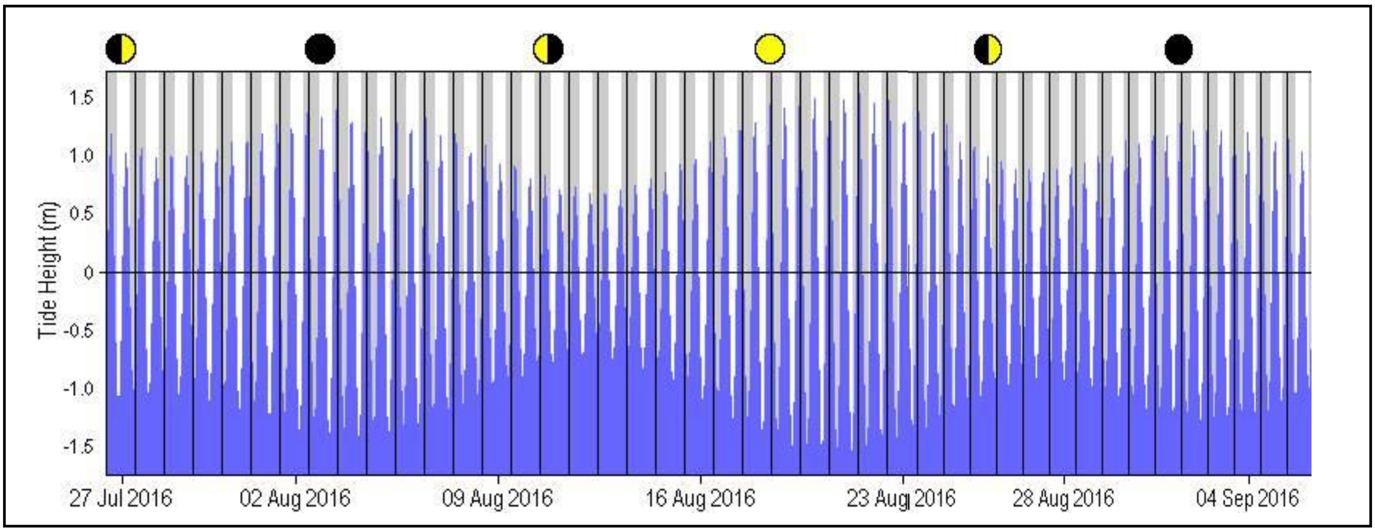

Figure 2: Lyttelton tide forecasts from the 27/07/2016 to 06/08/2016. Copyright 2016 by NIWA.

The tidal chart provided by the National Institute of Weather and Atmospheric Research (NIWA) displays tidal fluctuations in Lyttelton over the duration of our data collection. This is the closest tidal predictor to our experimental site which resulted in a lag time. To mitigate this we utilised depth measurements and flow velocity to determine the occurrence of high or low tide.

5.3 Current Meter

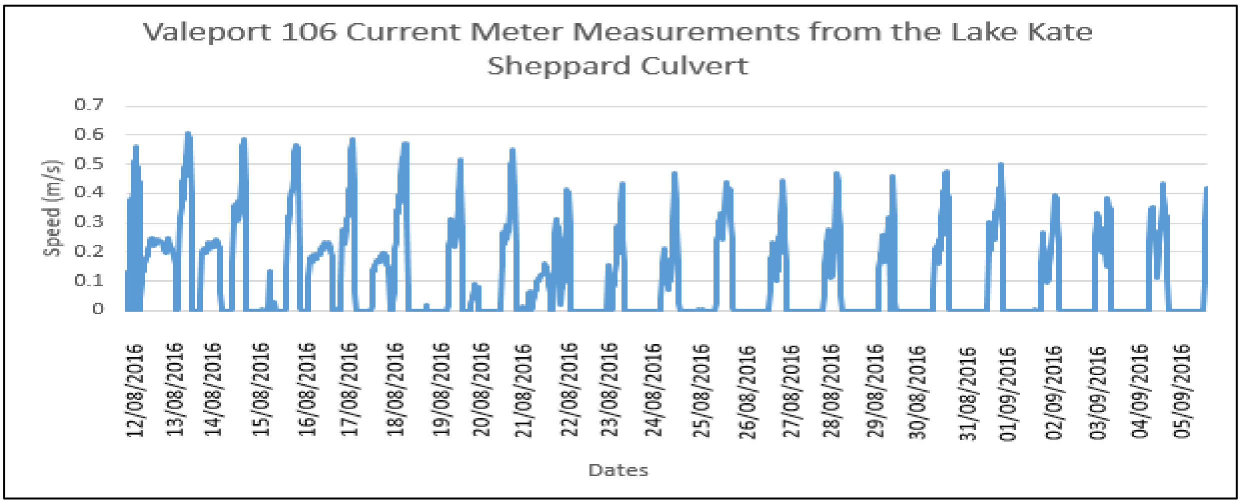

Figure 3: Flow velocity measurements in the Lake Kate Sheppard culvert were recorded by a Valeport 106 Current Meter.

Figure 3 demonstrates the average daily flow measurements recorded at the Lake Kate Sheppard culvert from the 12/08/2016 to the 5/09/2016. This demonstrates the velocity at which water was flowing into the lake from the Avon River due to tidal influences.

5.4 Automatic Weather Station

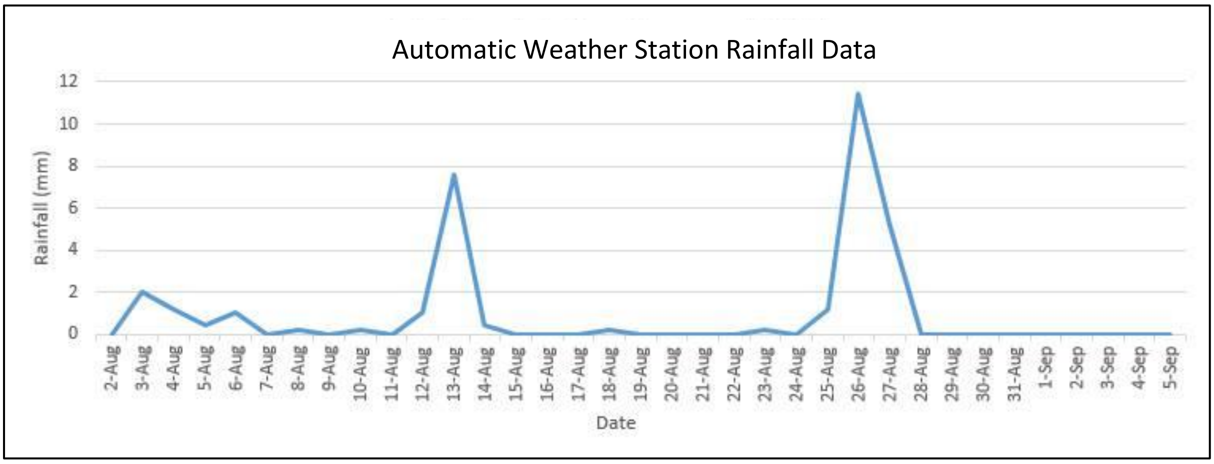

Figure 4: Rainfall was recorded at Lake Kate Sheppard with a portable Automatic Weather Station model Onset Hobo H-21-001.

Figure 4 displays the amount of rainfall that occurred at Lake Kate Sheppard between the 2/08/2016 to the 5/09/2016. Two significant rainfall events occurred during this time, on the 13/08/2016 and the 26/08/2016. Each of these events impacted other hydrological aspects in our experimental site.

5.5 Conductivity

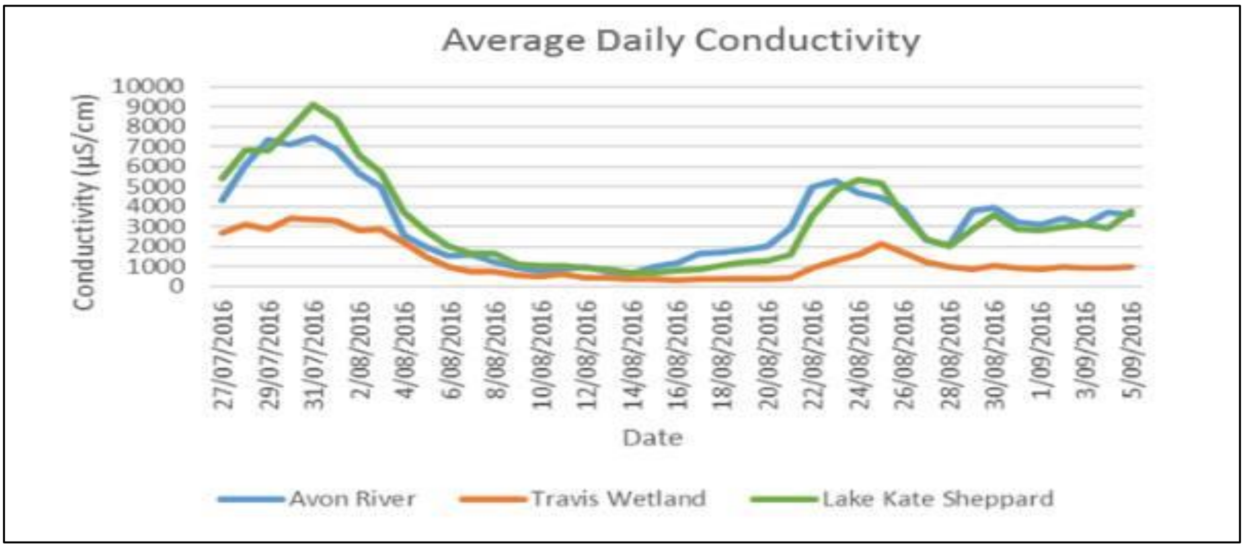

Figure 5: Average daily conductivity measured with three Solinst level loggers model 3001 positioned at the Avon River, Travis Wetlands and Lake Kate Sheppard.

Figure 5 shows a comparison of the average daily conductivity between the Avon River, Lake Kate Sheppard and Travis Wetlands between 27/07/2016 and 5/09/2016. The largest decline in conductivity was between 02/08/2016 and 20/08/2016.This conductivity can be correlated to the extreme events that occurred.

5.6 Temperature

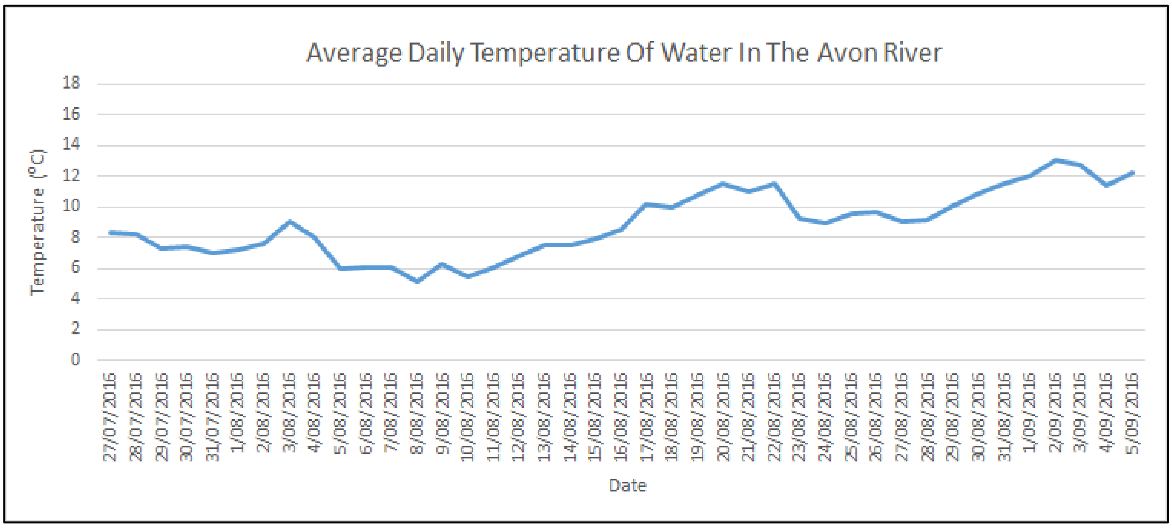

Figure 6: Average daily water temperature recorded from the Avon River with a Solinst level logger 3001.

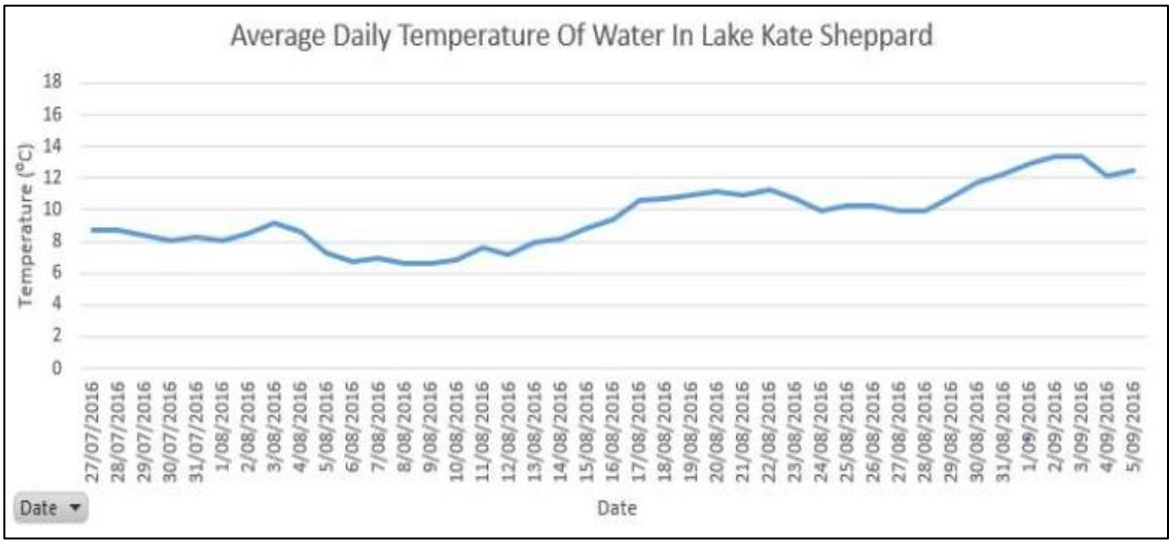

Figure 7: Average daily water temperature recorded from Lake Kate Sheppard with a Solinst level logger 3001.

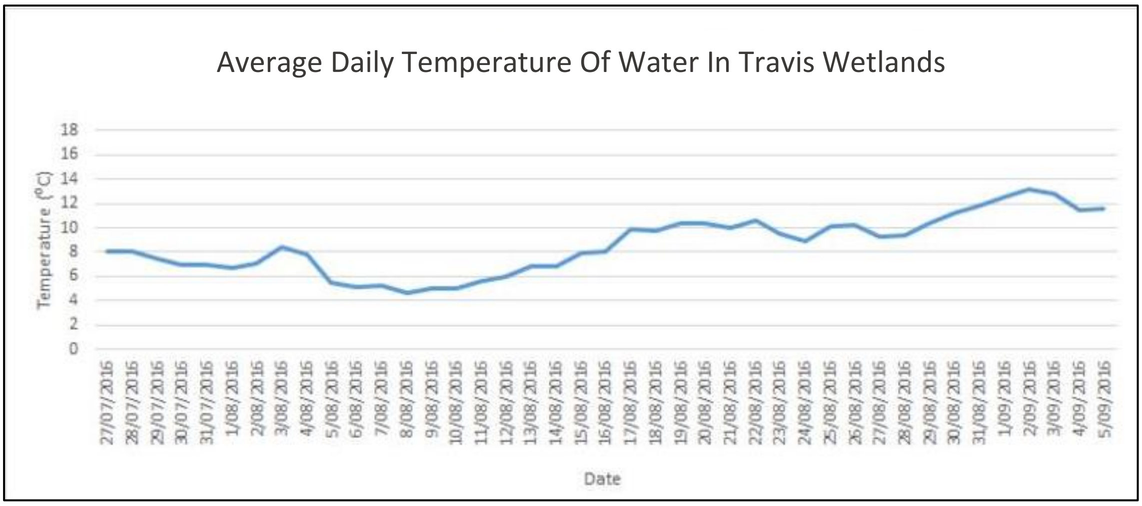

Figure 8: Average daily water temperature recorded from the Travis Wetlands with a Solinst level logger 3001.

Figure 6, 7 and 8 demonstrate the trends of the average daily water temperatures within the Avon River, Lake Kate Sheppard and Travis Wetlands. All of the data was collected in ten minute intervals and has been averaged for each day at the three CTD logger sites. The three different sites follow the same patterns of water temperature, though the Avon River has the most prominent change day to day.

5.7 Small Timescale Graph Examinations

Decreasing the time scale of the graphs to an eight day period allows them to be analysed in more detail, rather than a diurnal average. Using the eight day period chosen meant that the impact of rainfall on the area can be examined in detail and that the variable of rainfall could be removed. Therefore easier examination of events such as king tides could be undertaken.

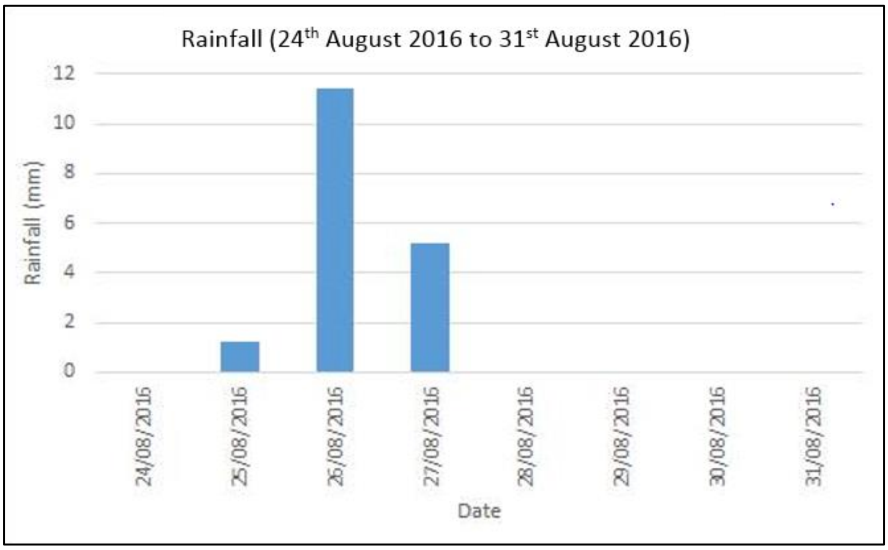

Figure 9: The total amount of rainfall recorded over an eight day period. This displays data collected during a significant rainfall event at the experimental site between the 24/08/206 and 31/08/2016.

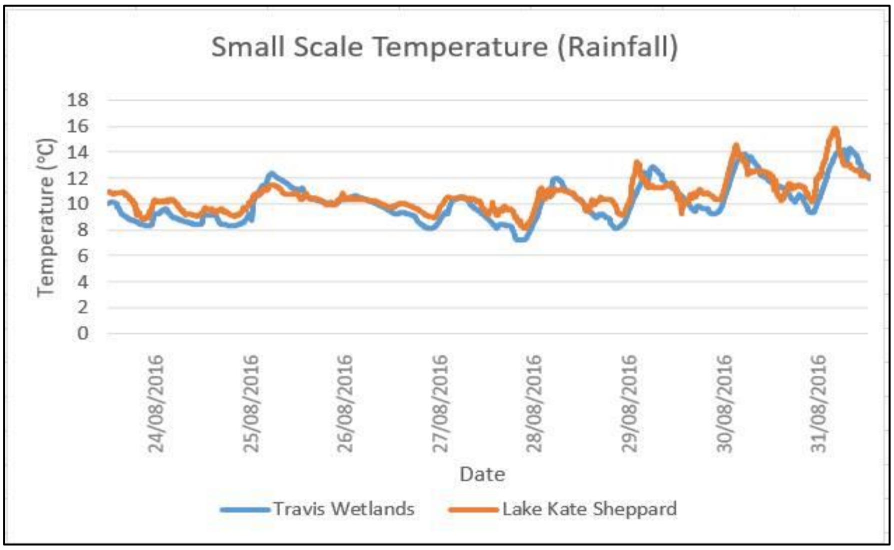

Figure 10: Detailed graph displaying daily water temperature in Lake Kate Sheppard and Travis Wetlands during a significant rainfall event over an eight day period, from the 24/08/2016 to the 31/08/2016. The prominent peaks and troughs correspond to diurnal cycles without rainfall while the section of graph with less variance occurred during rainfall.

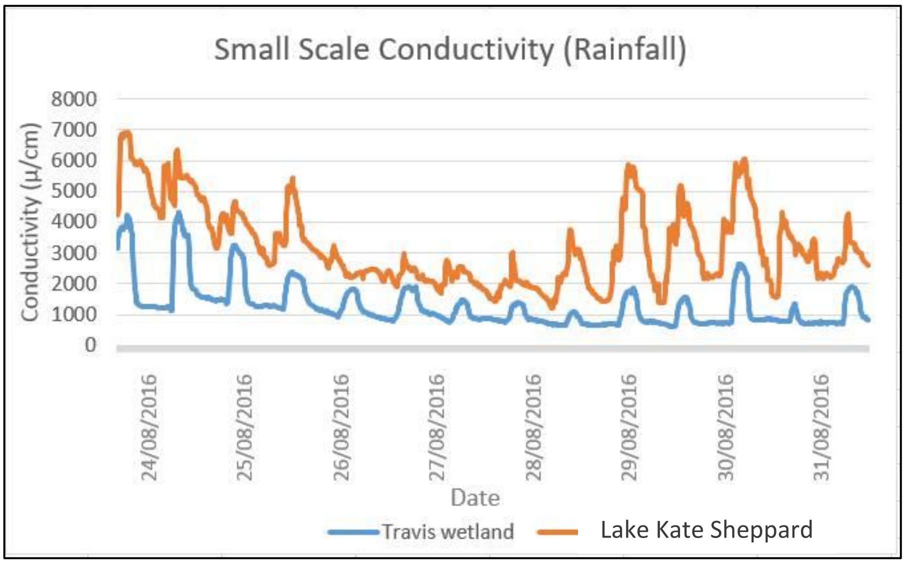

Figure 11: Level of conductivity in Lake Kate Sheppard and Travis Wetlands during a significant rainfall event occurring on the 25th, 26th and 27th of August during an eight day period, from the 24/08/2016 to the 31/08/2016.

Figure 9, 10 and 11 display the impacts that a significant rainfall event has on the water temperature and the conductivity in Lake Kate Sheppard and Travis Wetlands. By examining this data over an eight day period, changes to the hydrology during rainfall events can be inspected in depth.

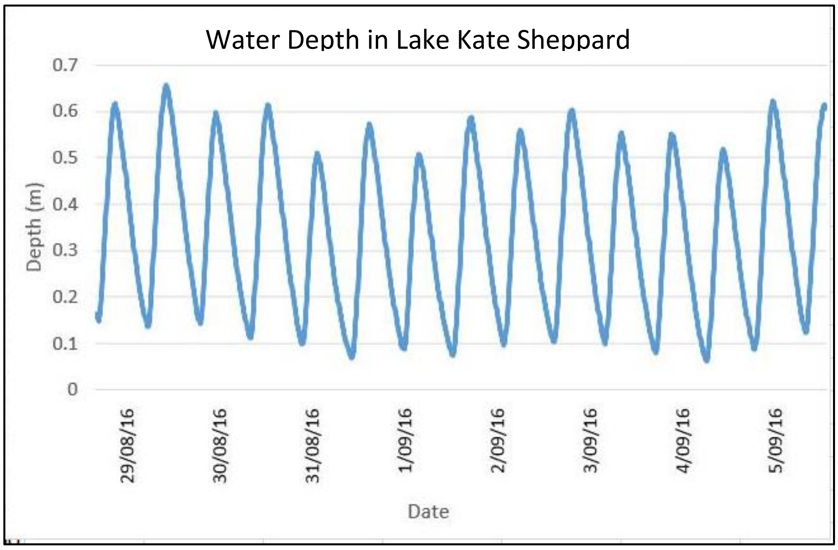

Figure 12: The depth was recorded by a Solinst level logger model 3001 at Lake Kate Sheppard between 29/08/2016 and 5/09/2016, during this period no rainfall occurred. The extent of the peaks and troughs can be attributed to high and low tides at the experimental site.

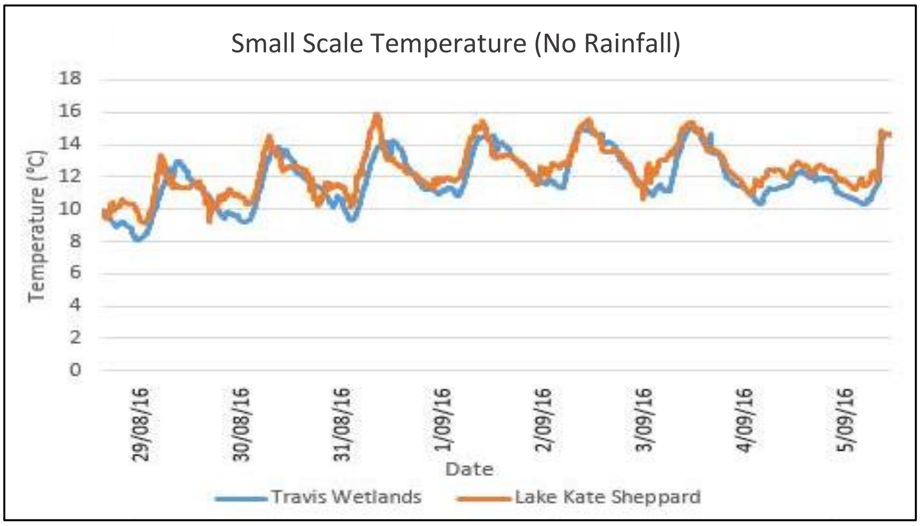

Figure 13: Daily water temperature was recorded between the 29/08/2016 and 5/09/2016 when no rainfall occurred. This demonstrates the impacts of both tidal and diurnal cycles.

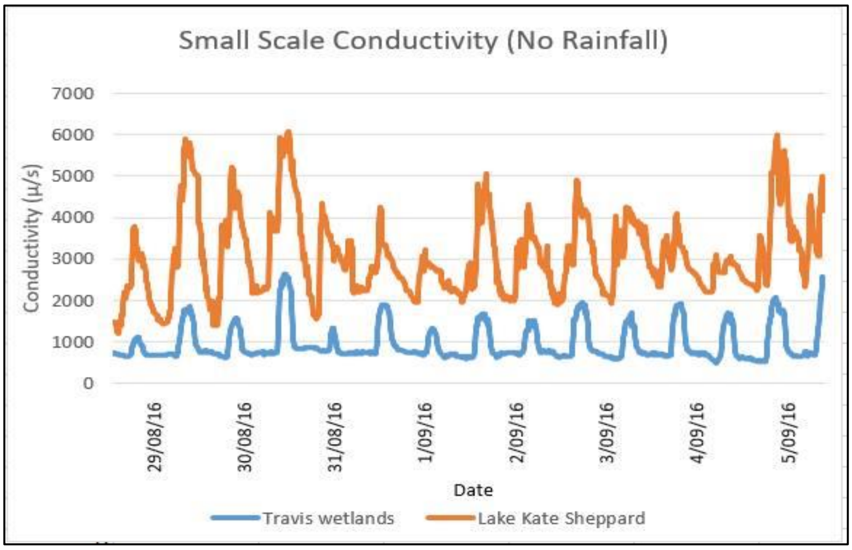

Figure 14: Conductivity measurements recorded between the 29/08/2016 and 5/09/2016 showing tidal influences at the experimental site.

Figure 12, 13 and 14 shows the impact that tides have on the experimental site. The variable of rainfall has been removed from this data set as it did not take place over this time period. Figure 12 demonstrates how the height of the water level changes with the volume of water brought into the lake by the tide. The largest peak in depth was on the 29/08/2016 at a depth of 0.66 metres. A small timescale depth graph allows for more accurate investigations of variations in depth. Figure 14 shows that the amount of conductivity in both areas declined during this period and a lag is present between the two CTD loggers. The Avon River CTD was not included due to a systematic error occurring which is discussed further in limitations.

6. Discussion

6.1 Rainfall

The conductivity observed at each of the localities was significantly influenced by the rainfall that occurred. During rainfall events a substantial decline in conductivity was observed at all three CTD sites as displayed in figure 5. Through in depth analysis of figure 11 and figure 14, we were able to delineate that when rainfall did not occur conductivity fluctuated consistently with the tides. However, during rainfall events the conductivity was supressed despite normal tidal fluctuation.

During our investigation two differing types of rainfall occurred; prolonged rainfall and shorter more intense rainfall. Prolonged rainfall occurred from the 02/08/2016 to 14/08/2016 as depicted in figure 4. Demonstrated in figure 5 the conductivity is supressed for several days after rainfall ceases. In contrast the shorter high rainfall event which occurred on the 26/08/2016 demonstrated a dramatic decline in conductivity. This is additionally influenced by Horton's overland flow which occurs once infiltration capacity in the soil has been exceeded (Smith & Goodrich, 2006). This results in an increase in horizontal runoff as percolation can no longer occur since pore spaces are fully saturated. However, over a prolonged time frame with occasional rain events, run-off would have less effect on the water bodies as there would be more time for the water to percolate through the soil. This is particularly relevant as larger but less frequent rainfall events are predicted to occur in the future as a result of global warming causing an amplification of the hydrological cycle (Knap et al., 2008).

After a significant rainfall event occurred there was a large lag time demonstrated between the three CTD loggers, refer to figure 9 and figure 5. This lag time occurred as a result of the interaction between the two predominant drivers of an estuary; the freshwater and saltwater flux (Savenije, 2012). This resulted in the Avon River followed by Lake Kate Sheppard and then Travis Wetlands in returning to usual conductivity levels.

The temperature as depicted in figures 6, 7 and 8 exhibited a general increase until data collection ended. Small scale investigations showed that the temperature varied at all three CTD's as a result of diurnal and tidal events (figure 13). Rainfall acts as a third temperature variable that minimised the peaks and troughs as freshwater enters the system (figure 10). Richardson and Taylor (2004) concluded that inanga prefer temperatures generally less than 20 degrees. Because none of our results exceeded this figure, temperature changes did not require further investigation in order to understand the distribution of inanga spawning sites.

Since the estuary is a balance between two opposing driving forces; the freshwater flux and the tidal flux, when rainfall occurs there is an increase in freshwater added to the system (Savenije, 2012). This causes an imbalance between these two fluxes resulting in the freshwater flushing the saltwater out of the system. This effects the conductivity in Lake Kate Sheppard and the surrounding area.

6.2 Tidal Processes

Through literature reviews it has become apparent that Lake Kate Sheppard is likely to undergo a sea level rise of 0.31 to 0.49 metres (Bell, Hume & Hicks, 2001). This prediction has the potential to influence the distribution of the saltwater interface and have subsequent effects on inanga spawning. This mechanism can be examined throughout our results. Comparison between the depth (figure 12) and the conductivity (figure 14) over a period of no rainfall demonstrated that the higher tides correlated to a significant increase in conductivity in Lake Kate Sheppard. The depth peaked at 0.66 metres whilst the conductivity increased to 6000 µS/cm as a consequence of the saltwater intrusion. Information such as this allows for credible predictions regarding sea level rise and the extent of saltwater intrusion into Lake Kate Sheppard and Travis Wetlands to be formed.

No rainfall was recorded over the period shown in figures 12 and 14 resulting in any variations in the depth and conductivity of the Lake Kate Sheppard CTD to be attributed to the tidal regime. The peaks displayed on figure 12 show the occurrence of the maximum tidal influence. This is reinforced by figure 3 which exhibits fluctuations in the inflow and outflow between the Avon River and Lake Kate Sheppard. Although the peaks labelled in figure 12 only represent small variations in maximum tide height, corresponding peaks in conductivity can be seen in figure 14. This link between the extent of saltwater intrusion into the system and the tide height demonstrates how a small amount of sea level rise will have a marked effect on the distribution of the saltwater interface.

Analysis of figure 1 displaying the GNSS positioning of the CTD's alluded to why slightly higher tides had a relatively large effect on raising conductivity levels throughout the Avon River, Lake Kate Sheppard and Travis Wetlands. The placement of all three CTD's were found to be below mean sea level by 0.326, 0.397, and 0.157 respectively. The close proximity to the mean sea level adheres to why small variations in tides have been found to have large effect on conductivity and hence salinity.

The research undertaken has allowed connections to be made between the height of the tide and the extent of the saltwater intrusion. Through the resulting graphs provided in figure 2 and figure 5 we can conclude that even slightly higher tides <5cm, push the saltwater interface a considerable distance further back into the water bodies. With evidence of saltwater intrusion already displayed in Travis Wetlands it is likely that we will see the saltwater interface redistributing well into the brackish swamp affecting the equilibrium of the area.

Several impacts can be expected in the experimental site due to an increased extent of saltwater intrusion. Some of these effects were visible on site visits. Salt intrusion into typically freshwater such as Travis Wetlands will have adverse effects on plant growth and seed germination (Kim, Rayburn, Voigt, Parrish, Lee, 2012). Jiang, Donald, DeAngelis, Anderson and Smith (2014) describe the movement of the ecotone separating freshwater and saltwater environments as sea level rises causing the landward migration of estuarine plant species. Within the surveyed area this may result in oioi (*Apodasmia similis*), a halophytic plant that was abundant in Lake Kate Sheppard replacing areas of raupo (*Typha orientalis*), a glycophytic species abundant in the Travis Wetland. Evidence of this biota shift was clear on the banks of Lake Kate Sheppard with many cabbage trees (*Cordyline australis*), which is a glycophytic species, observed to be struggling to tolerate the environmental conditions.

The re-distribution of the ecotone between fresh and saltwater plants may benefit inanga spawning sites. Firstly, raupo displays a tendency to clog low level swamps, this clogging effect does not benefit inanga which require open water for hunting (Richardson and Taylor, 2004). Richardson and Taylor (2004) also include several photos of idealistic spawning habitats many of which contain oioi or similar species.

A negative impact of salt intrusion into freshwater swamps is the lowering of biomass and production. Craft et al., (2009) found that the freshwater and brackish conditions had 40-70% more biomass than the higher salinity areas. By losing biomass in Travis Wetlands as saltwater intrudes, the overall production of the area will possibly decrease which may restrict nutrients that are required by inanga. Further studies on the habitat and food source of inanga within the area would be required to prove or disprove this hypothesis.

Changes in salinity may not affect inanga and their habitat dramatically until there is substantial and continual change in salinity levels. According to Urbina and Glover (2015), inanga successfully acclimatised to an increase in salinity levels however Hicks et al., (2010) determined that artificial fertilisation was not successful for eggs in the higher salinity range. Consequently, inanga may be found further upstream in order for inanga spawning and egg survivorship to be successful. The spawning sites of inanga could subsequently be affected as sea level rise occurs and rainfall intensity increases (Knap et al., 2008)

7. Limitations

- With Christchurch receiving only a small amount of rainfall per year, an extreme event was unlikely to occur during the six weeks of data collection.
- Metservice data was unreliable and continuously changing.
- The Avon River CTD logger was positioned incorrectly therefore it was unable to collect data at low tide due to being positioned above the water level.
- The current meter malfunctioned during data retrieval.
- The research time frame would not allow long term trends and patterns to be identified within the research site.
- Due to the time constraints of data collection and analysis, conclusions of inanga spawning sites is based off relevant literature and previous research of Lake Kate Sheppard.

In regards to the limitations listed above, the research was completed to the highest possible standard within the allocated time frame. Conclusions from this project can therefore be used for future research.

8. Future Research

Further research into Lake Kate Sheppard would be beneficial for the future use of the area. This would provide a greater understanding of different hydrological aspects and could improve managerial practices to appropriately restore this area.

Additional investigation into the current bathymetry of Lake Kate Sheppard would provide valuable information regarding sediment depositional rates which can be compared to previous data to determine possible sedimentary changes.

Water quality monitoring of Lake Kate Sheppard and Travis Wetlands should be undertaken.

Due to a significant lack of current research, an extensive biodiversity monitoring plan needs to be developed in order to determine the extent of inanga in the Mahinga Kai Exemplar area.

9. Conclusion

Our investigation demonstrated that extreme hydrological events such as rainfall and tides can have a substantial effect on the characteristics of Lake Kate Sheppard, the Avon River and Travis Wetlands. With measurements such as the conductivity, temperature, depth and flow indicating marked changes during these events. Consequently hydrological events can impact ecosystem dynamics and modify the inanga habitats that are present in our study area.

Our results indicate that rainfall causes the salinity to decrease across our experimental site with short intense rainfall events causing a dramatic decrease in conductivity in contrast to prolonged rainfall events. There was additionally a lag time observed between the CTD loggers as a result of this environment being tidally influenced. Tidal processes also impact the location of the saltwater interface due to saltwater intrusion consequently this influences the location of ideal inanga habitat conditions. This could result in inanga spawning occurring in closer proximity to Travis Wetlands in order to adapt to these changing environmental conditions. This prediction is not unrealistic given this study has observed inanga past previous known extents in Travis Wetlands.

Predictions regarding localised changes due to global warming and sea level rise vary. However the amplification of extreme hydrological events could have a pronounced impact on this locality. Therefore considering the limitations of our study, our findings can be utilised as baseline information for future researchers.

Further concise research into the area is necessary to comprehensively examine the dynamic relationships that were established between extreme events, inanga and our experimental site, to the fullest extent.

10. Acknowledgements

The authors of this paper would like to thank Professor Bryan Jenkins, our community partner for supporting the research that was undertaken, which has beneficial information for future researchers. Another thank you to Professor Eric Pawson and Professor Simon Kingham for initiating this research project. Finally, a special thank you to our tutor Justin Harrison who dedicated a large amount of time and effort to this research, without whom the fieldwork component could not have been completed. We appreciate the guidance provided throughout the entirety of the research process.

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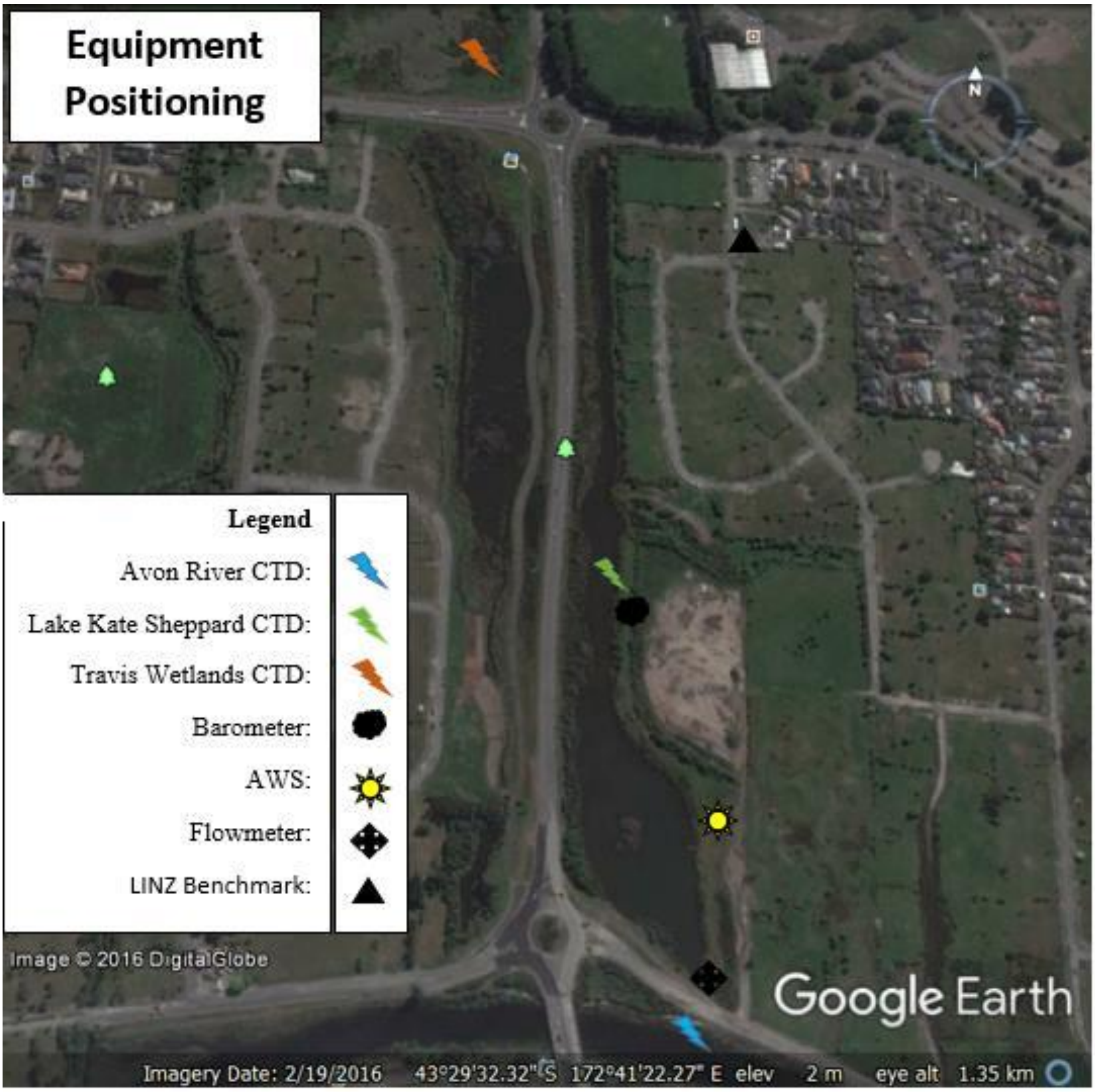
12. Appendicies



Apendix 1. Map of the experimental site including the Avon River, Lake Kate Sheppard and Travis Wetlands. This shows the location of all the equiptment that was used in the field.

Appendix 2. Trimble R8 survey grade GNSS placed over a LINZ geodetic survey mark.

Appendix 3. Valeport 106 current meter was set up at the Lake Kate Sheppard culvert. In ten second intervals, the water velocity (m/s) and direction of water flow was recorded.

Appendix 4. The Onset Hobo H-21-001 portable Automatic Weather Station measured rainfall data.

Appendix 5. The Solinst level logger 3001 used to measure conductivity, temperature and depth at 10 minute intervals.

Appendix 6. The Barometric logger Solinst Barologger model 3001 measured air pressure. This was hidden amongst the riparian vegetation