Hydrological Characteristics of Lake Kate Sheppard

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1. Executive Summary

The aim of this project was to analyse several different hydrological characteristics of Lake Kate Sheppard, a man-made urban lake in Christchurch's Residential Red Zone. Lake Kate Sheppard was originally designed as a floodwater holding system, allowing excess flood water from the Avon River to transit into Travis Wetland. Following the Canterbury earthquakes in 2010 and 2011, many aspects of the lake have been significantly altered. This project was inspired by the Avon-Ōtākaro Network, a group interested in investigating the suitability of Lake Kate Sheppard as an exemplar for mahingā kai, and in particular whitebait.

With support from the Avon-Ōtākaro Network, the following physical properties were surveyed: tidal processes, lake bathymetry, and various aspects of water quality.

Findings reveal significant oscillations in the lake water level due to tidal influences. These substantial fluctuations were mirrored by water quality changes, in particular salinity. Temperature, conductivity, dissolved oxygen, pH, nitrate and oxidation redox potential levels showed various spatial distribution patterns, affected by changes in bathymetry. A bathymetric map was produced of Lake Kate Sheppard using a sonar instrument attached to a jet boat. The map revealed a deeper southern basin that contained a tidal island that gradually became shallower moving northward into a channel. The volume of Lake Kate Sheppard during a high-tide is 31,102 m^3. Lake Kate Sheppard is linked to a larger waterway network; there are culvert connections to the Avon River, Travis Wetland, and Anzac Drive Reserve.

These findings are base-line representations of the hydrological characteristics in Lake Kate Sheppard. This will supply the Avon Ōtākaro Network with initial hydrological measurements relevant to mahingā kai. These results are only indicative, further research is required to ensure Lake Kate Sheppard's success as a mahingā kai exemplar.

2. Introduction

The physical geography of Lake Kate Sheppard (LKS) is of particular interest to the Avon-Ōtākaro Network (AvON). Founded in 2011 following the Canterbury earthquake sequence, AvON is a network of individuals and organisations with a vision of creating a natural reserve from the Residential Red-Zone around the Avon River. AvON aims to restore and re-develop mahingā kai in greater Christchurch, recognising the importance of mahingā kai for cultural and heritage values (Avon-Ōtākaro Network, 2013). LKS influences the wider Canterbury hydrological system; information regarding its hydrological dynamics will assist in developing greater understanding of the wider Residential Red-Zone catchment. The information below influenced this project's collection and processing of data concerning LKS.

LKS is an urban man-made lake in Anzac Drive Reserve, located in the eastern suburbs of Christchurch. During the earthquake sequence of 2010 and 2011, LKS was significantly altered by liquefaction and lateral spreading (Zhang & Carrick, 2014). Many private properties surrounding the lake are 'red-zoned', unfit for residential use. Originally, LKS was designed as a floodwater holding system, allowing excess flood water from the Avon River to transit into Travis Wetland (Zhang & Carrick, 2014). This system had the capacity to hold large volumes of flood water before slowly releasing it back into the Avon River *(Appendix 3)* (Zhang & Carrick, 2014). Preceding the earthquakes, LKS was known as a successful īnanga (whitebait) spawning ground.

The aim of this project is to provide AvON with initial hydrological measurements, encouraging further investigation of LKS' potential to successfully host īnanga and other mahingā kai resources. The three properties investigated by this project are tidal processes, lake bathymetry and water quality. These three characteristics were chosen as they are significant to the establishment of a successful mahingā kai site. Quantitative, experimental data was collected using a variety of instruments. This project's focus was to investigate the current hydrological characteristics of LKS; there is no emphasis on comparing pre and post-earthquake data.

This report is structured using the three hydrological properties under investigation: tidal processes, lake bathymetry, and water quality. Tidal processes were observed by measuring conductivity and water height fluxes. A bathymetric map of LKS was produced by recording lake soundings and utilising computer software. The water quality properties examined were temperature, conductivity, dissolved oxygen (DO), pH, nitrate, and oxidation redox potential (ORP - the measure of water's disinfection efficiency defined by World Health Organization, 2006).

This project was supported by Bryan Jenkins, representing the Avon-Ōtākaro Network, and technicians from the University of Canterbury Geography Department, specifically Justin Harrison.

3. Theoretical framework and literature review

Literature reviews were focused on investigating hydrological dynamics of water bodies in similar situations to LKS. The AvON does not have any current LKS hydrology information, therefore it was important to find literature of all aspects related to LKS. However, lake research for this project was primarily experimental and finding literature to support the process was challenging. The majority of literature used for this project is referenced during results analysis.

Barendregt & Swarth (2013) produced a report on the dynamics of tidal freshwater wetland systems. LKS is affected by tidal input from the Avon River, the information about water quality changes from saline intrusion was relevant. Barendregt & Swarth (2013) discuss the significance of biotic diversity for trapping sediment and nutrients in tidal wetlands. Waltham and Connolly (2013) found that producing lake systems instead of canal systems will increase opportunities for aquatic fauna success. This information can be utilised for future projects investigating the effects of riparian planting on water quality levels.

Moses et al. (2011) suggests that higher pollution is associated with smaller lakes, as contaminants are diluted with larger volumes. Conversely, an increase in volume may decrease water pollutants. Furthermore, sediment runoff from flooding events can cause pollution (Moses et al. 2011).

Manga and Wang (2007) focus on hydrogeologic lake changes caused by earthquakes. They outline a wide variety of hydrogeologic responses to seismicity, and provide a schematic illustration to model these responses. This provides a basis for assessing LKS in a post-earthquake environment.

4. Methodology

Both spot and continuous testing techniques were utilized during data collection. For data analysis ArcGIS and Excel were used. ArcGIS was particularly useful when modelling the data, and Excel proved essential when tabulating or graphing the findings. Due to the large datasets, many of the values were averaged in order to identify trends and anomalies.

4.1 Tidal Processes

Change in water height was recorded using an in-situ instrument (CT2X) located alongside the dock in the lower lake basin. Continuous data for water pressure, conductivity and temperature was logged every 10 minutes. The instrument logged from the 1st of August to the 24th of September 2014 and was attached to a metal pole pushed into the lake floor, ensuring stability *(Appendix 4)*. The measurements were corrected for atmospheric pressure using measurements from a separate in-situ air pressure instrument. The data was tabulated, averaged hourly and graphed for interpretation.

4.2 Lake Bathymetry

Lake bathymetry was recorded using two instruments: the PA 500 Tri-Tex, an echo sounding sonar; and the Trimble R8 GNSS, a surveying system. Attached to a remote controlled jet boat, these instruments recorded geo-referenced depth soundings of the entire lake bottom. Data collection was completed one hour either side of high tide, minimising tidal influence during measurements.

Bathymetry data analysis was completed in ArcGIS (v.10.2). The data points were used to interpolate a raster surface between the nearest points. Point anomalies in the raw data were removed pre-analysis, any remaining spikes in the bathymetry may be attributed to sticks or weed in the lake. The shoreline was defined by the edge of the point data. The raster surface was then draped over an aerial image of LKS and transferred to ArcScene (v.10.2) for three dimensional analysis. Due to the small variation in depth, a vertical exaggeration was applied to illustrate the bathymetry more clearly. Since the depth below surface values were positive, the values were inverted to get a bathymetric 'bathtub' model. Finally, basic volumetric analysis was completed to calculate the area and volume of the lake model.

4.3 Water Quality

Two methods were employed to test water quality in the lake. The first method utilised the CT2X, positioned beside the dock on the eastern side of the lower lake body *(Appendix 4)*. The second method utilised the Eureka MANTA2, a multi-parameter device recording temperature, conductivity, dissolved Oxygen, pH, nitrate and ORP. The MANTA2 was used for spot testing 10 significant areas in and around the lake, and continuous data logged within LKS. The continuous measurement was achieved by attaching the device onto a kayak and paddling around the lake (*Appendix 2)*, each variable was logged every 60 seconds.

To evaluate the measured variables from the CT2X, each dataset was averaged hourly and daily, then graphed to allow interpretation of significant fluctuations within variables. The MANTA2 spot data was analysed by comparing the different levels across the study area, and the continuous datasets were presented using ArcGIS. This presented the spatial distribution of water quality variables in LKS.

5. Results

5.1 Tidal Processes

Figure 1 shows the tidal influence seen within LKS for August, maximum height was 900mm, on August 15th, and minimum was 29.4mm, on August 26th.
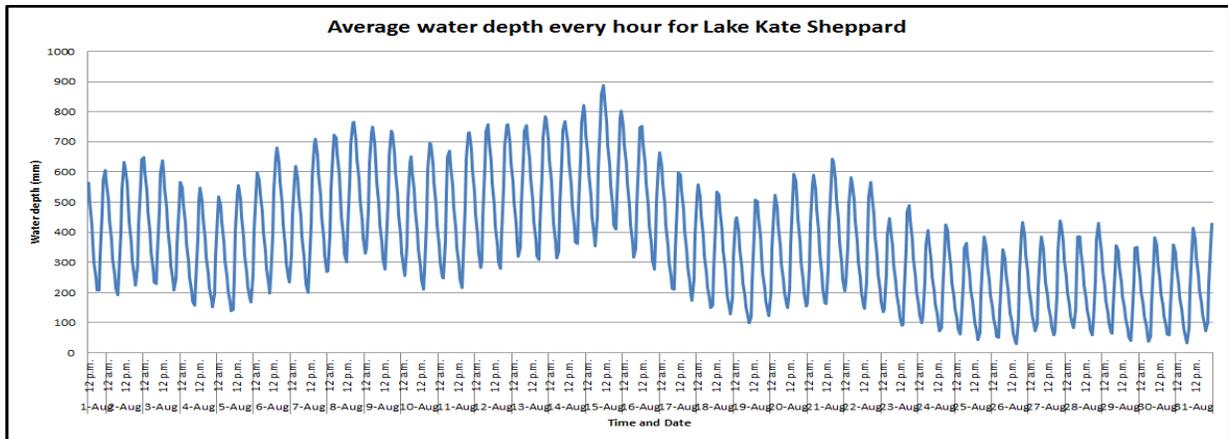
*Figure 1.*CT2X water height measurements over the month of August.

Figure 2 shows LKS water height changes from 1st to 24th September, with a minimum of 72mm and a maximum of 832mm.
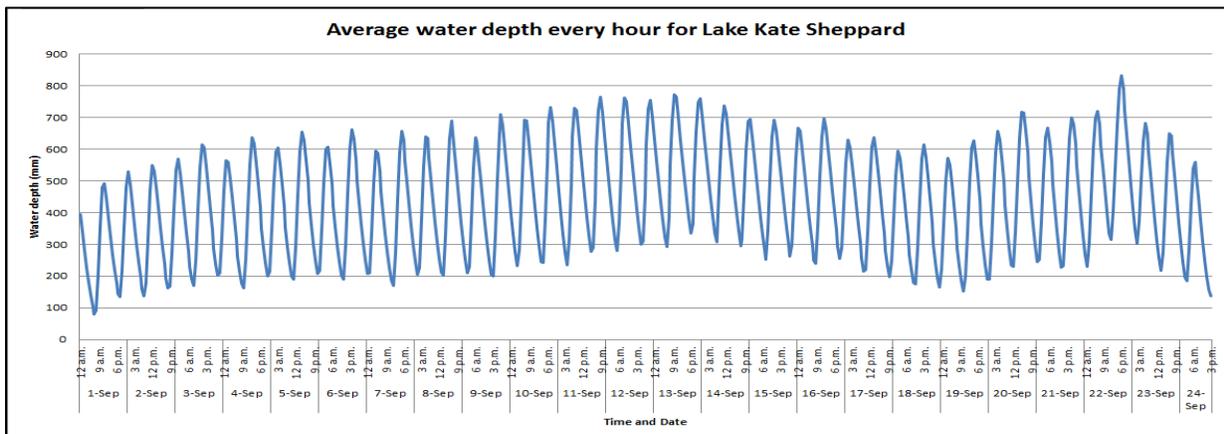
Figure 2. CT2X water height measurements during September.

Figure 3 shows conductivity and water depth measurements for LKS during a period in August, the largest flux in conductivity is during the 15th to 16th of August.
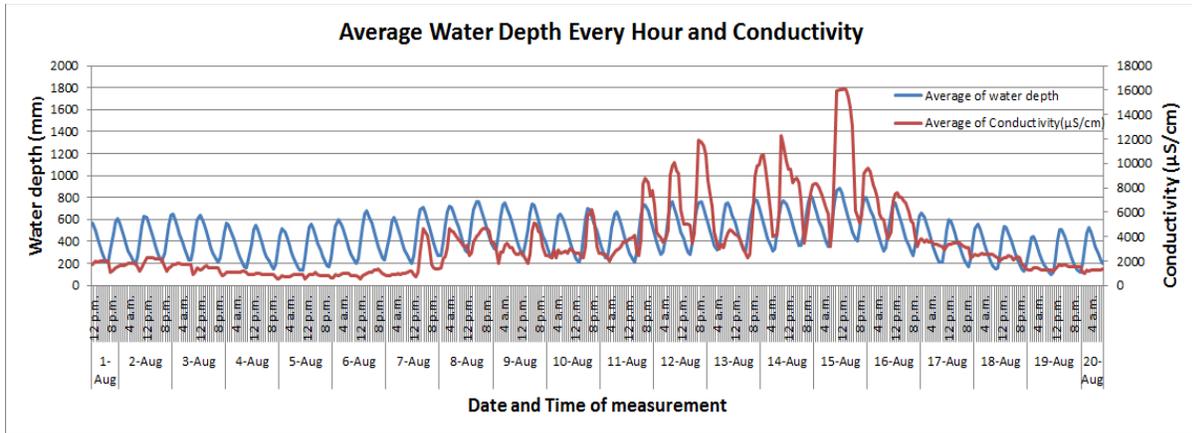
Figure 3. Average water depth and conductivity levels from 1st to 20th August for LKS.

Figure 4 shows LKS salinity levels and water depths from 1st to 20th August. The largest flux is during the 15th and 16th of August.
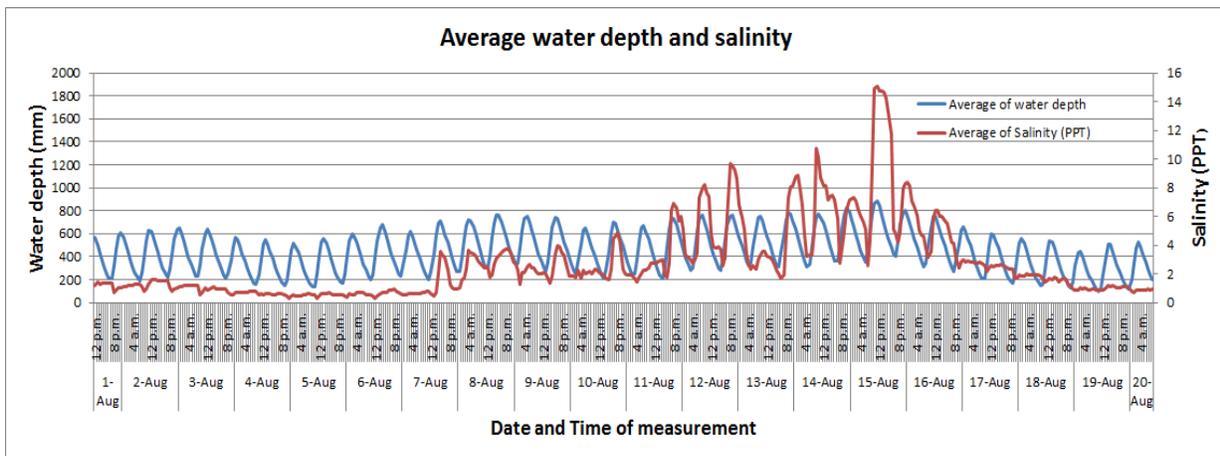
Figure 4. Water depth graphed against salinity levels.

5.2 Lake Bathymetry

The deepest point in the lake is 3.08 meters, located in a basin at the southern end of the lake, near the Avon River culvert connection (*Figure 6)*. The basin gradually becomes shallower towards the narrow northern channel connecting Travis Wetland to LKS. The average depth is 0.9 meters; *Figure 5* shows the bathymetric sounding of LKS. The white colour represents the deepest sections, while green illustrates the shallowest.

The   effects   of   the   tidal   impacts   are   expected   to   be   ±   5cm.

Figure 5. A 3-D side view of LKS bathymetry, illustrating the deeper southern basin and the shallow northern reaches, captured using a jet boat containing a 500 Tri-Tex echo sounding radar and Trimble R8 GNSS surveying system.

Figure 6. Plan view of raster surface draped over aerial image. Green indicates ground covered in interpolation; yellow, pink, to white indicate lake bathymetry.

Table 1 shows the results of the volumetric analysis. The surface area of LKS was calculated to be 42, 210.8 m2, and the water volume was calculated to be 31,102.8 m3. This volume represents the specific tidal period during data collection.

Table 1. Volumetric analysis results from LKS. Note, this includes the area covering land (refer to Figure 6 for coverage extent).

Plane Height	Reference	Z-Factor	Area 2D	Area 3D	Volume
0.1m	ABOVE	1	42, 125m^2	42, 210m^2	31, 102m^3

5.3 Water Quality

5.3a. CT2X continuous measurement

The CT2X measured water temperature every 10 minutes from the 1st of August to the 24th of September 2014. *Figure 7* indicates LKS' water temperature during August, averaged over the hour.
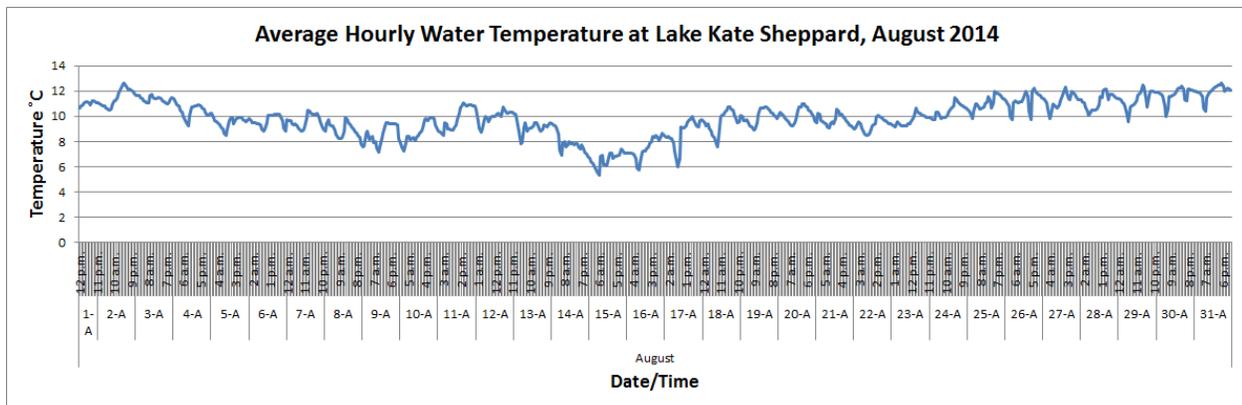
Figure 7. The average hourly water temperature of Lake Kate Sheppard during August, recorded using CT2X.

Figure 8 shows average hourly water temperature for LKS from the 1st-24th of September.
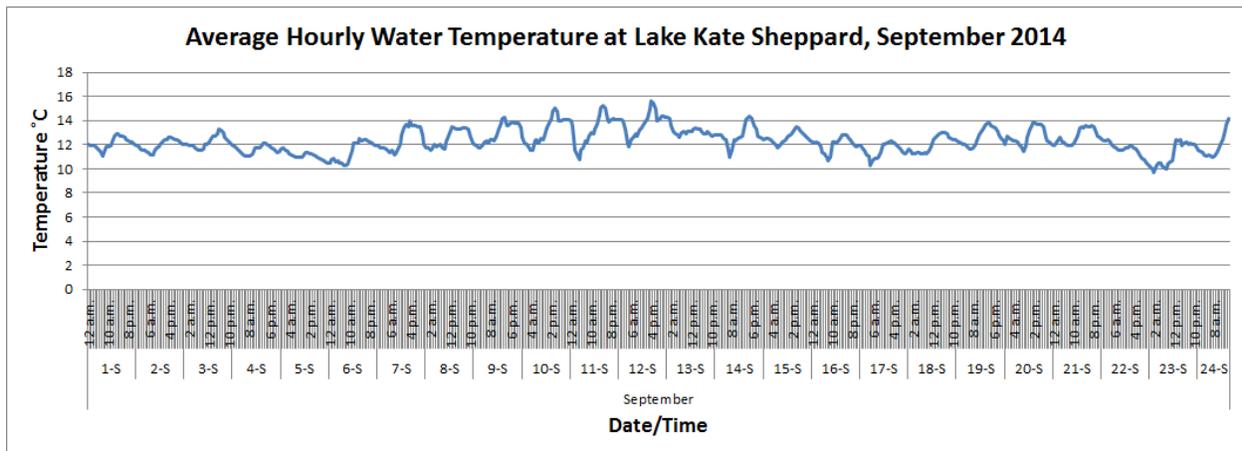
Figure 8. The average hourly water temperature of Lake Kate Sheppard from the 1st to the 24th of September, recorded using CT2X.

Figure 9 shows average daily water temperature for the entire study period 1st August through to 24th September.
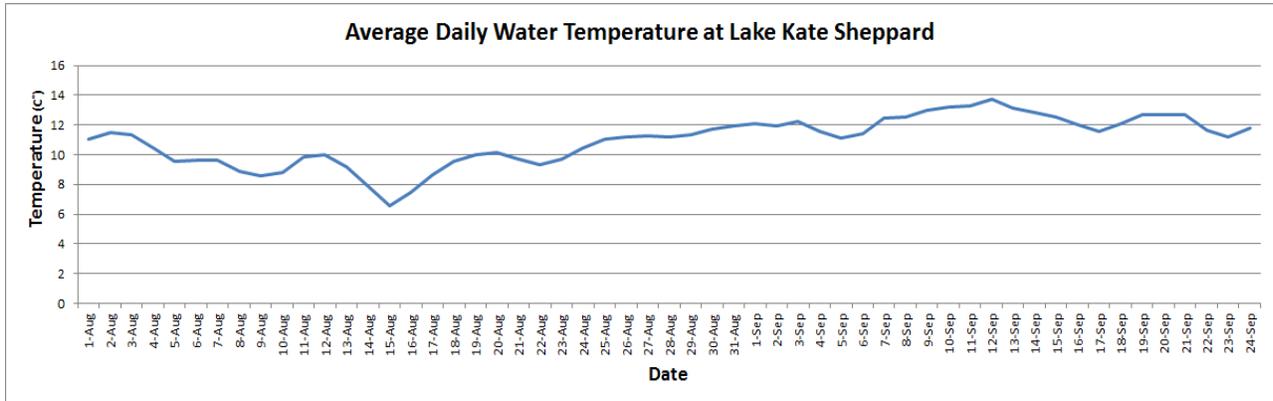
Figure 9. The average daily water temperature of LKS during the entire study period from the 1st of August to the 24th of September, recorded using CT2X.

In August the average water temperature was 9.89˚C. In September the average water temperature increased to 12.31˚C. The total temperature range 10.05˚C: the lowest temperature was recorded on August 15th at 7 a.m. at 5.25˚C, and the highest temperature was 15.3˚C, recorded on September 11th at 4.30 p.m.

5.3b. Spot-testing MANTA2

Water quality spot-testing was completed on the afternoon of August the 1st, during a high-tide. Testing occurred at 10 locations in and around LKS; Three in the lake, two in Avon River, one in Travis Wetland and one in the swamp area west of Anzac Drive. These locations are shown below in *Figure 10.*
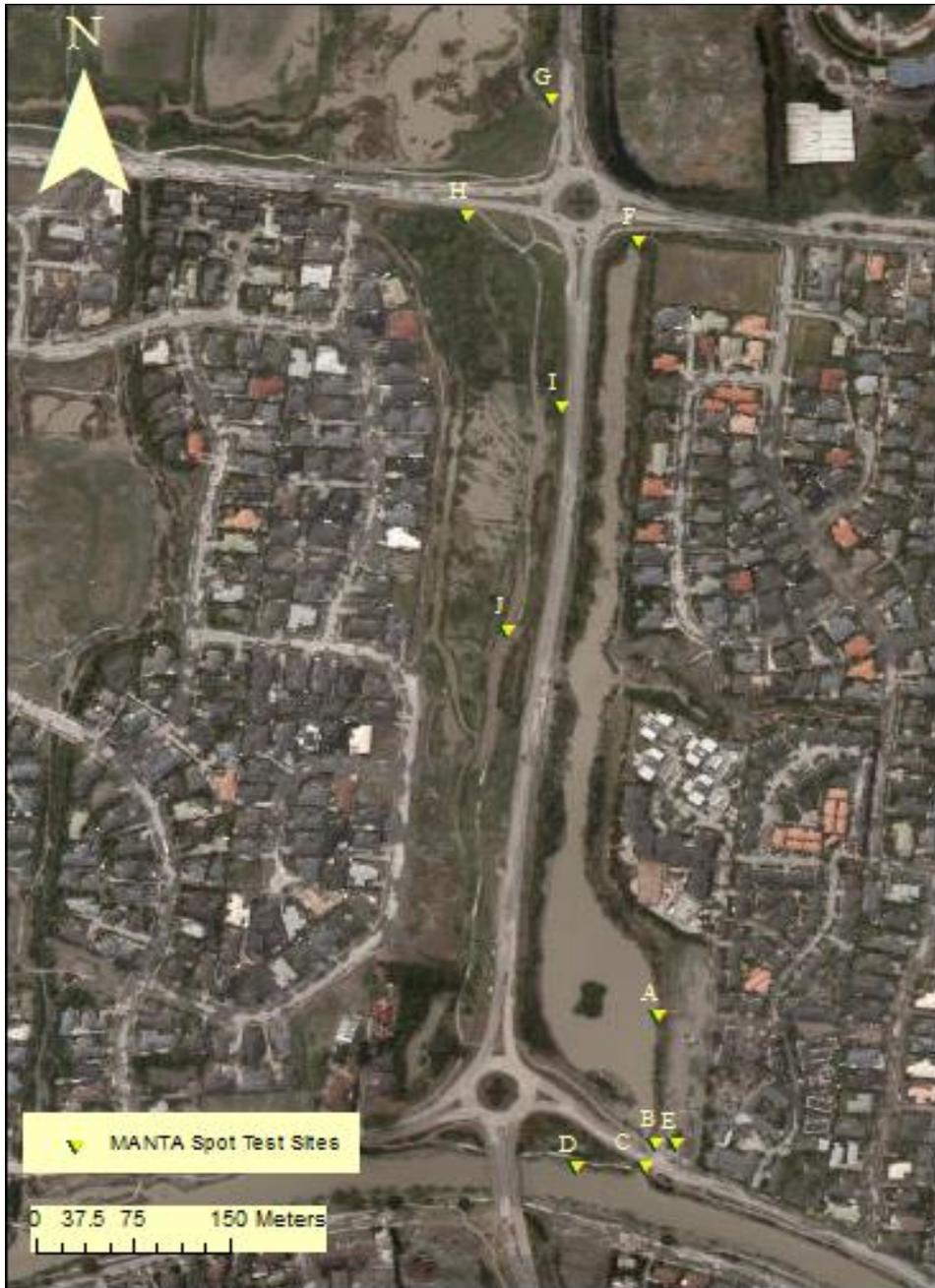
Figure 10. Values A-J representing the MANTA2 spot-testing locations.

Where MANTA2 spot-testing occurred, temperature, conductivity, dissolved oxygen, pH, nitrate, and oxidation redox potential levels were measured. This data is presented in *Table 2.*

*Table 2.*The measured variables from the spot-testing locations in and around LKS using the MANTA2 device.

Value	Location	Temp (C°)	Cond. (µS/cm)	DO (mg/L)	pH	NO3(mg/L)	ORP (mV)
A	Dock	9.47	1460	12.33	7.75	3.5	187
B	Avon Culvert	9.51	1549	10.45	7.65	3.7	130
C	Avon River	9.48	1532	10.6	7.65	3.7	104
D	Avon River Up	10.35	665.1	11.28	7.69	3.1	112
E	Little Stream	13.15	151.6	5.05	7.66	0.2	63
F	Top of LKS	9.66	436.8	12.33	7.45	3.5	184
G	Travis Wetland	9.31	523.9	11.1	7.55	1.4	64
H	Top Swamp	10.47	1121	6.7	7.07	1.4	85.1
I	1st Culvert	10.93	3153	14.23	7.8	4.6	19
J	2nd Culvert	10.84	523.9	12.72	7.55	1.4	64

The highest temperature, lowest dissolved oxygen, and lowest nitrate levels were recorded in the stream adjacent to LKS, and the coldest temperature was found in Travis Wetland. pH remained relatively consistent throughout the locations. ORP and conductivity levels vary significantly throughout the test sites.

5.3c. Continuous-testing MANTA2

On September 18th during a high-tide, MANTA2 was attached to a kayak, taking measurements every 60 seconds (*Appendix 2)*. Temperature, conductivity, dissolved oxygen, pH, nitrate and ORP variables were measured, and are shown below. The colour schemes are explained for each variable below.

Temperature: Figure 11 shows the temperatures recorded during testing. Red represents warmer temperatures, while blue represents cooler temperatures. The maximum temperature recorded was 15.1°C and the minimum was 12.6°C.
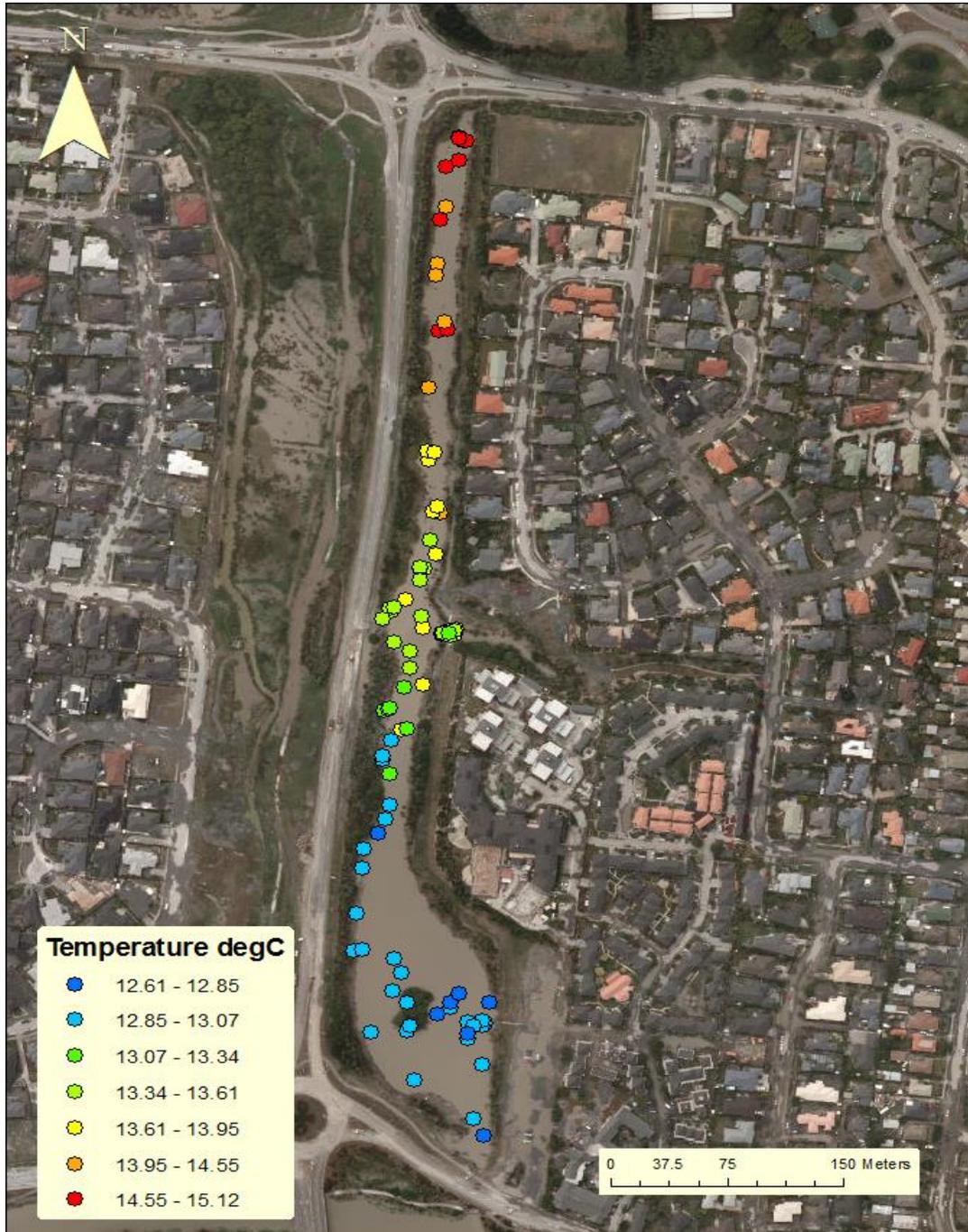
Figure 11. Distribution of temperature in LKS.

Conductivity: Figure 12 shows conductivity in LKS. Red represents the higher, while blue represents lower conductivity. The maximum was 4403 µS/cm and the minimum conductivity was 1680 µS/cm.

Figure 12. Distribution of conductivity in LKS.

Dissolved Oxygen: Figure 13 shows DO levels of LKS. Darker blue represents the higher levels, while light blue represents the lower. The maximum DO was 10.3 mg/L and the minimum was 15.6 mg/L.

Figure 13. Distribution of dissolved oxygen in LKS.

pH: *Figure 14* shows the pH levels of LKS. Darker blue represent higher values or more alkaline water, while green represents the more neutral water. The maximum pH was 7.8 and the minimum was 8.4.

Figure 14. Distribution of pH values in LKS.

Nitrate: Figure 15 shows the nitrate levels in LKS. Dark blue represents lower nitrate, while lighter yellow and green represents the higher nitrate levels. The maximum nitrate recorded was 7.8mg/L, and the minimum nitrate level was 2.8 mg/L.
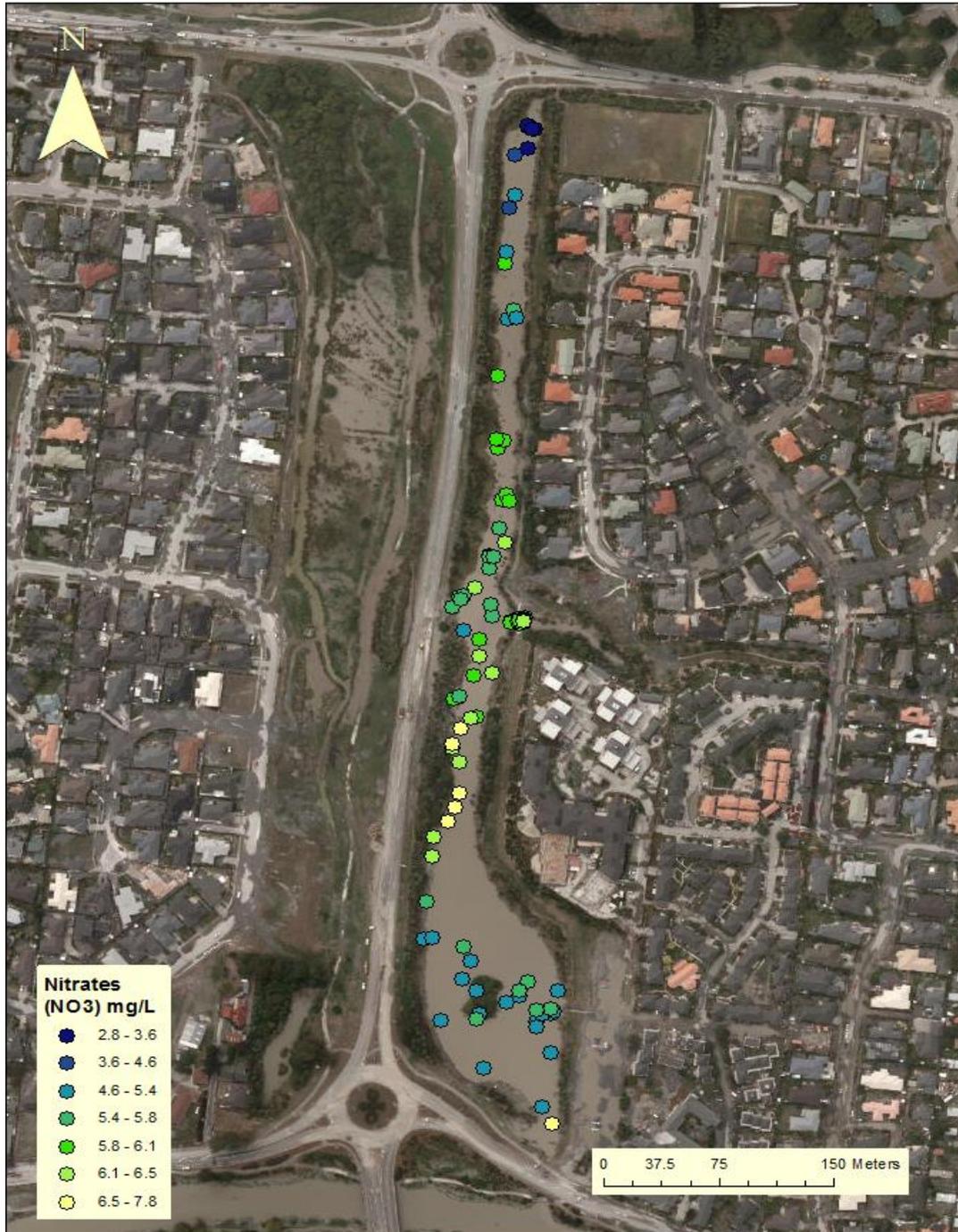
Figure 15. Distribution of nitrate levels in LKS.

Oxidation Redox Potential: Figure 16 shows the oxidation reduction potential (ORP) levels recorded in LKS. Red represents the lower (and negative) values, while yellow represents the higher (and positive) values. The maximum recorded value was 149 mV, and the minimum ORP value was -57 mV.
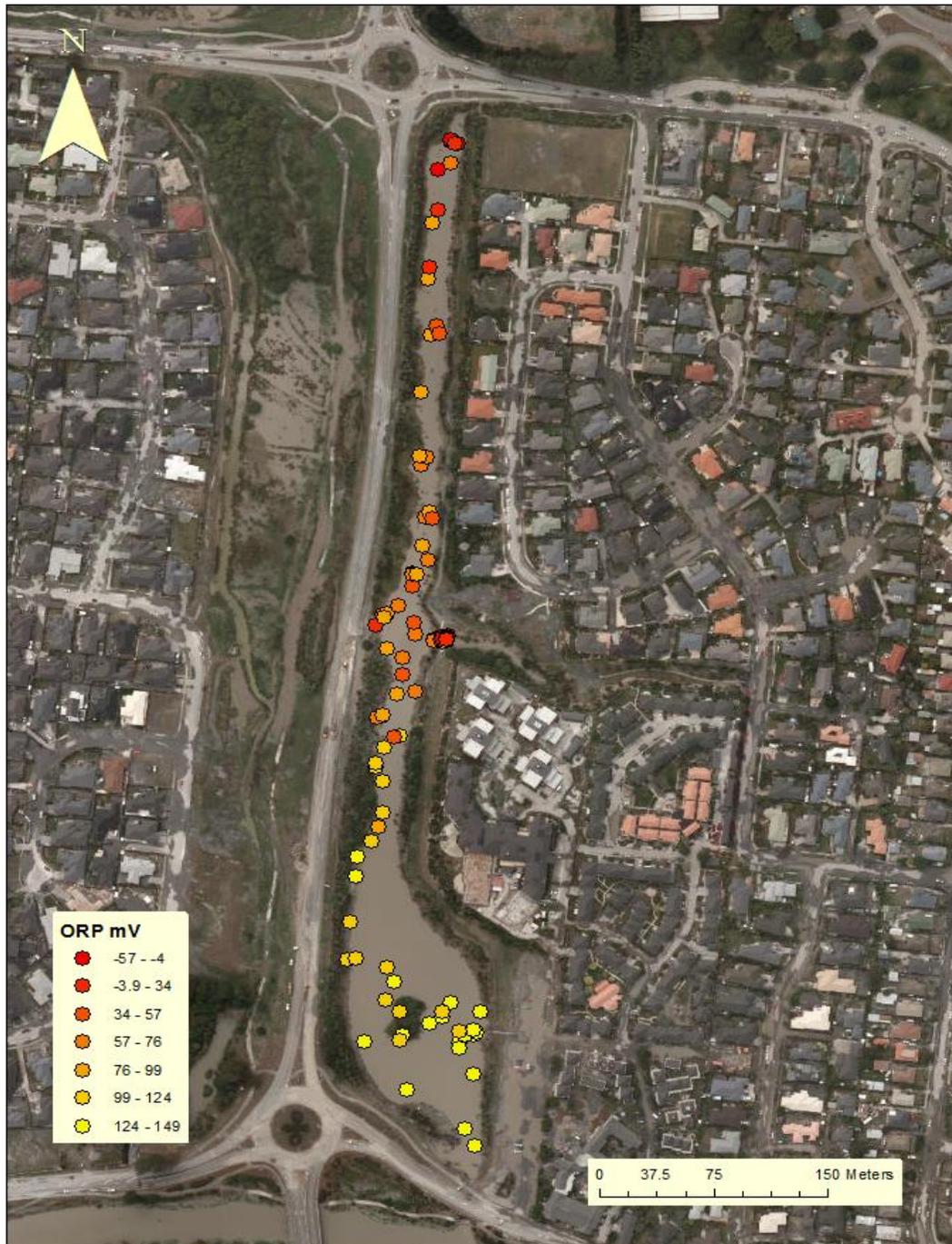
Figure 16. Distribution of ORP levels in LKS.

6. Discussion

6.1 Tidal Processes

Tidal fluctuations within LKS were an area of great interest; the extent of tidal flux was previously unknown, and tidal influence has an important role in LKS' potential of hosting mahingā kai.

Figure 1 and 2 reveal the significance of tidal processes acting in LKS. On average, a tidal change of 450mm is seen. However, it should be noted that the tidal signature of LKS is asymmetric; there is four hours on the rising limb and nine hours on the falling limb, as opposed to a conventional tidal variation of six hours. A lag time of approximately 2.5 hours exists between high-tides recorded in Lyttelton Harbour and high-tide in LKS. In conjunction with this, there is also a low-tide lag of approximately 3 hours. This lag is likely to relate to the tidal push travelling up the Avon River and continuing into LKS. This can be attributed to the one way water valve located in the south of LKS *(Appendix 4)* and the distance the water needs to return back into the ocean. As *Figure 1* shows, from approximately the 6th of August through to the 16th, there are larger high tide fluxes. These are approximately 1.5 times higher than earlier in the week, this illustrates the effect of monthly tidal cycle.

When overlapping tidal fluxes and conductivity from August 1st to the 20th *(Figure 3),* it was clear to deduce that conductivity increased during high tidal events. The largest increase was recorded during the highest tidal push on the 15th, with conductivity levels increasing to approximately 16000 microsiemens per centimeter. Conductivity is the amount of dissolved minerals and ions within a water body (*Conductivity, 2010)*. For context, conductivity of high-quality deionized water is approximately 5.5 µS/m, typical drinking water is between 5-50 mS/m, and seawater approximately 5 S/m (i.e. sea water's conductivity is one million times higher than that of deionized water (Lenntech, 2014)).

Conductivity and salinity have a linear relationship *(Figure 4)*. Like conductivity, salinity levels fluctuated with high and low-tides, illustrated in the corresponding spike during the highest high-tide in August 15th. Salinity levels rose to approximately 15 ppt (parts per thousand). For context, freshwater is 0.5 ppt and seawater is 35 ppt (*Conductivity, 2010)*. During the tidal push on the 15th of August *(Figure 4)* LKS recorded water that was approximately 50/50 freshwater seawater.

Rainfall dilution was also analysed, noted during the tidal measurements (Figure 17). The black arrows below depict two rainfall dilution events, on the 13th of August there was 10mm of rain and on the 11th of August there was 3mm. This dilution influence is seen as a decrease in salinity.
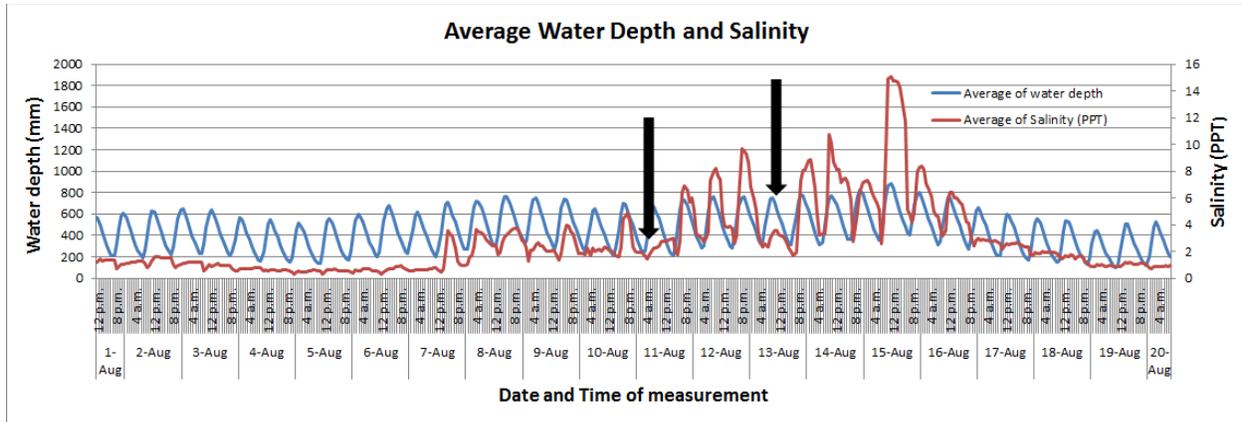
Figure 17. Dilution during rainfall events indicated by black arrows.

6.2 Lake Bathymetry

Variations in lake depth can be attributed to influences from water flow and sediment transport. There are three features of interest that illustrate the aforementioned influences: the northern Travis Wetland culvert, the southern Avon River culvert, and the eastern side stream connection.

As a result of the noticeable tidal influence on LKS from the Avon River culvert, if sediment was being transported from the Avon, it would likely settle out in the southern basin due to a reduction in flow velocity with increased area. The placement of the Avon River culvert may attribute to the uneven depth across the wide section. It appears that more transportation is occurring on the eastern side of the island causing a shallow zone on the west side of the island. The sediment may be transported northwards to the shallower reaches, however it appears the flow continues to transport the sediment around the top of the island to the western side, possibly adding to the shallower region.

The Travis Wetland culvert has visually limited flow; most sediment transported from Travis Wetland is likely to be trapped by the dense aquatic vegetation at that end, attributing to the shallow depth at the northern end. The deeper section halfway along the narrow reaches coincides with the eastern side stream connection. Although flow through the stream is now minimal, pre-earthquake flow may have been greater and transported sediment from the stream into the lake.

6.3 Water Quality

CT2X continuous measurement:

During the research period there was an increase in water temperature (*Figure 9*). This can be attributed to Canterbury progressing into spring, as water temperature is directly

related to warming air temperature (Stenseth et al., 2002). *Figures 7* and *8* show how average water temperatures oscillate over a 24-hour period, warming throughout the day.

The coldest temperature was 5.25˚C and recorded the morning after a passing southerly. The warmest temperature was 15.3˚C during a warm day reaching 20˚C (TuTiempo, 2014). In February, the maximum air temperature can exceed 30˚C in Canterbury (TuTiempo, 2014). It can be inferred that the water temperature of LKS will continue to increase during summer. The maximum range in water temperature was 10.05˚C. The sensor remained completely below the waterline during testing; the lowest tide recorded 10 mm over the sensor plate, however the shallow water height would have absorbed and emitted more radiation, resulting in greater temperature flux.

Eureka MANTA2 spot and continuous-testing (Table 2):

The locations were chosen to represent the relationship of LKS and the surrounding water bodies. Spot and continuous testing was completed during high-tide. The continuous testing was completed over a two hour period and while the measurements only characterise a specific time period, the data is representative of the general spatial distribution of variables within the lake. Each variable is discussed below;

Water Temperature (Figure 11): The warmest temperatures are located in the northern section of the lake. The shallow and narrow channel holds less volume; warming faster than the southern basin. The colder temperatures in the south are also influenced by influx of cooler water from the Avon River during high-tide.

Spot-testing reveals that river water temperature was warmer than LKS upstream from the culvert (*Table 2)*. This was due to the effect of urban heat island from the central city (Li et al., 2004).

Water Conductivity (Figure 12): The highest surface water conductivity is found at the Avon River culvert; the only source of saline water into the system. Levels gradually decrease moving north, increasing with distance from the culvert. It is important to note that conductivity increases with depth; saline water has a higher density. Measurement of the entire water profile would show a different conductivity spatial distribution in LKS. This may explain why conductivity is less in the shallower northern areas; the saline water is more likely to pool in the deep southern basin, pushing less saline water upwards to flow north. Spot-testing of conductivity (*Table 2)* showed there is varying levels throughout the surrounding water body system. This shows how conductivity levels are influenced by tidal changes, dilution from rainfall and depth.

Dissolved Oxygen (Figure 13): The dissolved oxygen (DO) level in water bodies is important for sustaining aquatic life (Utah State University, 2014). When DO levels drop below 5.0 mg/L the environment is considered to be stressed (Utah State University, 2014). DO levels

were above 10 mg/L in LKS; there were two areas of high concentration in the north and middle of the lake. These high concentrations may be attributed to the high number of aquatic and riparian plants, as they increase DO levels during photosynthesis (Utah State University, 2014). Saline water holds less DO than freshwater (James et al., 2003). Therefore, as testing was completed during high-tide average levels are likely to be lower. Similarly, warm water holds less DO than cold water (Blumberg & Toro, 1990). Therefore, it is likely that DO levels will decrease as temperatures increases into summer.

pH Levels (Figure 14): LKS exhibits a distribution of neutral pH water in the southern basin increasing in alkalinity northwards. Spot-testing revealed that the Avon River was neutral (*Table 2)*. Environment Canterbury recommends a pH range between 6.5 to 8.5 for safe drinking water (Environment Canterbury, 2014), LKS measurements were within this range. Increasing conductivity results in decreasing pH (James et al., 2003); due to testing close to high-tide, average pH values for LKS are likely to be lower.

Nitrate (Figure 15): Understanding lake nitrate levels is important as excess nitrate can be detrimental to health (Environment Canterbury, 2014). Ministry for Health New Zealand has a maximum limit of 11.3 mg/L for drinking water (Environment Canterbury, 2014). The maximum value measured in LKS was just over 7 mg/L. The highest nitrate levels were found in the north of the lake. These levels were mirrored by similar spot-testing values (*Table 2)* from the Travis Wetland culvert on LKS side, and the culvert connecting LKS to the water body west of Anzac Drive (*Figure 10).* This suggests that LKS has higher nitrate levels which move into the other water systems. Observations conclude that LKS has a population of ducks; this is likely to be a factor in the high nitrate levels.

Oxidation Redox Potential (Figure 16): Oxidation (positive) and reduction (negative) potential measures the ability of water to disinfect potential bacteria (Suslow, n.d.). ORP is important for understanding the survival times of harmful viral and bacterial pathogens like E.Coli and salmonella (Bastian & Brondum, 2009). The more positive the ORP value, the shorter the survival rates of these pathogens. The most positive levels were found in the southern basin (Figure 15), the highest ORP value was +120 mV (millivolts). The World Health Organisation recommends an ORP values of above +680 mV suggest water is in good microbial condition (World Health Organization, 2006). The current pathogen levels in LKS suggest survival rates of over 300 seconds, indicating a high reproductive rate (World Health Organization, 2006).

6.4 Mahingā Kai

When considering suitable water quality to support īnanga populations, the water measurements recorded at LKS were within recommendations prescribed from National Institute of Water and Atmospheric Research (NIWA).

- The temperature readings show that LKS has a reasonably large temperature range during the winter and spring seasons *(Figure 7 & 8)*. These temperatures create a range possible for īnanga habitats, however further research is required. Īnanga spawning and the development of juvenile īnanga occurs over the summer period, between spring and autumn (Richardson & Taylor, 2002). *Figure 8* displays a warming trend, it is likely that the temperature of LKS will reach the ideal 20˚C for hatching juvenile īnanga over the summer season.
- The near neutral pH profile of LKS (*Figure 14 & Table 2)* provide favourable conditions for īnanga. Īnanga do not spawn in pH 10.5 and above (Richardson & Taylor, 2002).
- Īnanga can survive in dissolved oxygen rates as low as 3 mg/L^{-1} for up to 48 hours (Jowett, 2002). The lowest recorded measurement within the main water body was 10.36 mg/L^{-1}*(Figure 13)*. This suggests LKS has dissolved oxygen levels favourable for supporting īnanga *(*Richardson & Taylor, 2002).
- Tidal data shows *(Figure 2)* that LKS is heavily influenced by tides*.* This is beneficial for īnanga as they may use the strong tidal currents to swim up the Avon River into LKS.
- The bathymetry survey highlighted LKS has variable depths throughout the system *(Figure 5)*. Research indicates that īnanga would take advantage of these variable depths, as they provide the ability for fish to escape external pressures such as solar radiation and wind driven turbidity (Jowett, 2002).

6.5 Limitations

- Due to the vast amount of unknown features for potential testing, it was difficult to choose only three hydrological characteristics. The inclusion of more variables is likely to affect conclusions.
- It would have proven beneficial to measure flow rates for the culvert systems. This was attempted early in the project, but later abandoned due to minimum time for setting up suitable experimentation.
- The amount of field sampling days was limited to suitable tides and significant distance.
- The equipment availability and cost limited the inclusion of important variables; water quality tests such as E.Coli and faecal coliform were not completed.
- Conclusions were made by comparing relevant existing literature and the patterns of primary quantitative data. Although knowledge gained from prior literature assisted in building the conceptual framework, a greater knowledge base may have produced conclusions with more relevance to the wider Christchurch Avon-Ōtākaro waterway network.

- Previous experience with equipment was limited. Foreknowledge regarding appropriate times, locations, and methods for data collection may have assisted in time saving. Therefore, more relevant data may have been collected.
- Time was a large determinant in the research. With more time, a greater quantity and quality of data could be collected.

Considering the limitations listed above, the conclusions drawn from this research project are still accurate to the best of this project's ability and can be used for future research.

7.   Conclusion

Investigation revealed significant tidal oscillations in Lake Kate Sheppard. These fluctuations were mirrored by changes to various aspects of water quality, in particular salinity. Temperature, conductivity, dissolved oxygen, pH, nitrate and oxidation redox potential levels showed various spatial distribution patterns, affected by changes in bathymetry. A bathymetric map was produced of the lake, this revealed a deeper southern basin and tidal island. The lake gradually becomes a shallow channel moving northward. The total volume of Lake Kate Sheppard during a high-tide is 31,102 m³. Lake Kate Sheppard is linked to a larger waterway network; there are culvert connections to the Avon River, Travis Wetland, and Anzac Drive Reserve.

These findings are base-line representations of the hydrological characteristics in Lake Kate Sheppard. This will supply the Avon Ōtākaro Network with initial hydrological measurements relevant to mahingā kai. These results are only indicative, further research is required to ensure Lake Kate Sheppard's success as a mahingā kai exemplar.

8.   Acknowledgments

9.   References

Avon-Otakaro Network. (2013). Our Charter. Retrieved September 10, 2014, from Avon-Otakaro Network: http://www.avonotakaronetwork.co.nz/about-us/charter.html

Barendregt, A. and Swarth, C.W. (2013) Tidal Freshwater Wetlands: Variation and Changes. *Estuaries and Coasts* (36), 445-456. doi: 10.1007/s12237-013-9626-z

Bastian, T., & Brondum, J. (2009). Do Traditional Measures of Water Quality in Swimming Pools and Spas Correspond with Beneficial Oxidation Reduction Potential? *Public Health Reports, 124*(2), 255–261.

Blumberg, A., & Toro, D. (1990). Effects of Climate Warming on Dissolved Oxygen Concentrations in Lake Erie. *Transactions of the American Fisheries Society,* 119, 210-223.

Conductivity (2010). Oxford University Press. doi:10.1093/acref/9780199571123.013.m-en_gb-msdict-00002-0170930

Environment Canterbury. (2014). Measuring water quality. Retrieved October 9, 2014, from Environment Canterbury: http://ecan.govt.nz/advice/your-water/water-quality/pages/measuring-water-quality.aspx#pH

James, K., Cant, B., & Ryan, T. (2003). Responses of freshwater biota to rising salinity levels and implications for saline water management: a review. *Australian Journal of Botany, 51, 703-713.*

Jowett, I. G. (2002) In-stream habitat suitability criteria for feeding inanga (Galaxias maculatus), *New Zealand Journal of Marine and Freshwater Research*, 36:2

Lenntech, 2014,. Water Conductivity. Retrieved from http://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm

Li, Q., Zhang, H., Liu, X., & Huang, J. (2004). Urban heat island effect on annual mean temperature during the last 50 years in China. *Theoretical and Applied Climatology, 165-174.*

Manga, M., and C. --Y Wang (2007). "Earthquake Hydrology." 4 Vol. (p. 293--320).

Moses, S., Janaki, L., Joseph, S., Justus, J., & Vimala, S. (2011). Influence of lake morphology on water quality. *Environmental Monitoring and Assessment*, 443-454.

Richardson, J. & Taylor, M. J. (2002). A guide to restoring inanga habitat. *NIWA Science and Technology Series* (50), 31.

Stenseth, N., Mysterud, A., Ottersen, G., Hurrell, J., Chan, K., & Lima, M. (2002). Ecological Effects of Climate Fluctuations. *Science, 297*(5585), 1292-1296.

Suslow, R. (n.d.). Oxidation-Reduction Potential (ORP) for Water Disinfection Monitoring, Control, and Documentation*.* Los Angeles: University of California.

TuTiempo. (2014, September). Climate in Christchurch. Retrieved October 9, 2014, from TuTiempo.net: http://www.tutiempo.net/en/Climate/Christchurch/09-2014/937800.htm

Waltham, N., & Connolly, R. (2013). Artificial tidal lakes: Built for humans, home for fish. *Ecological Engineering*, 60, 414-420. doi:10.1016/j.ecoleng.2013.09.035

World Health Organization. (2006). Guidelines for Drinking-water Quality: First addendum to volume 1, Recommendations*.* World Health Organization, 2006.

World Health Organization. (2006). Guidelines for safe recreational water environments. Geneva: WHO.

Utah State University. (2014). *Utah Water Quality: Dissolved Oxygen*. Retrieved September 9, 2014, from Utah State University: http://extension.usu.edu/waterquality/htm/whats-in-your-water/do

Zhang, A., & Carrick, S. (2014). Lake Kate Sheppard: An exemplar mahingā kai site? Christchurch: University of Canterbury.

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9. Appendices

Appendix 1. The remote controlled jet boat used to gather bathymetry data

Appendix 2. Towing the MANTA around LKS to gather pH, Nitrate, OPR and Dissolved Oxygen

Appendix 3. One way valve at main culvert at the input/out from LKS into the Avon-Ōtākaro River.

Appendix 4. The in-situ CT2X situated on the dock to the Eastern side of LKS.