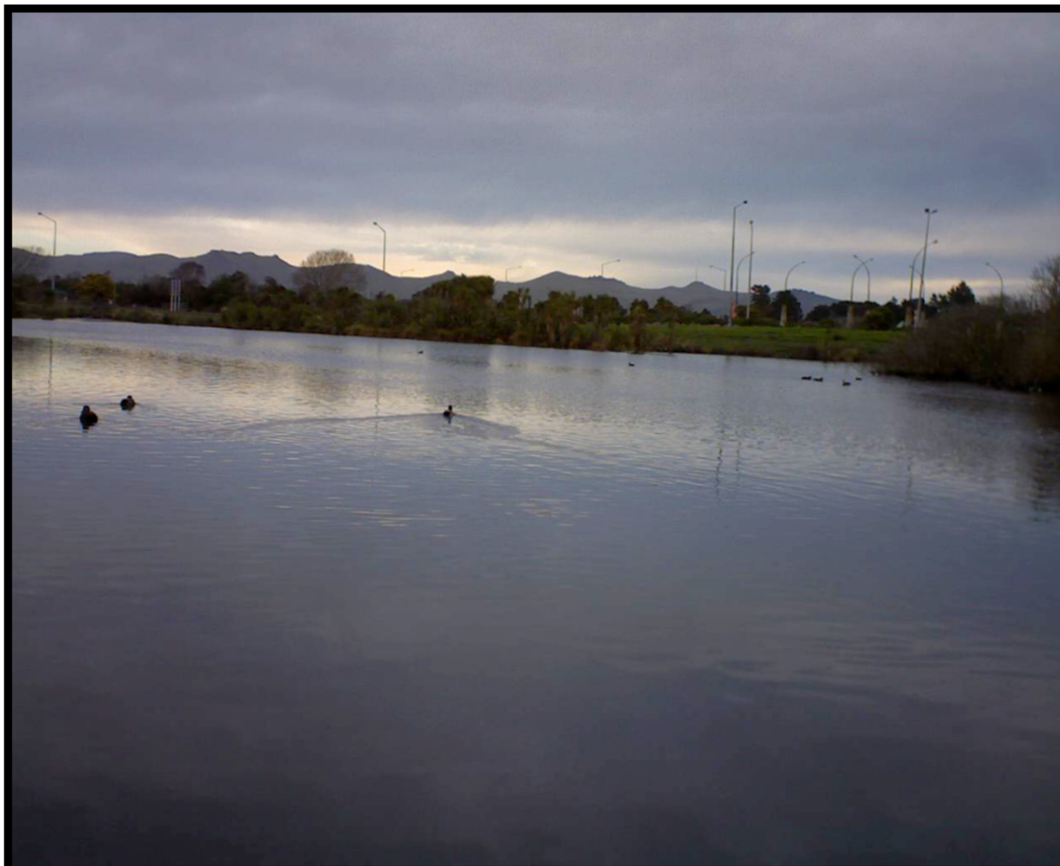
How is the salinity of Lake Kate Sheppard affected by its inflows and outflows? Are these salinity conditions favorable for īnanga spawning?



Alice Sai Louie, Hunter Guy Biddulph Jenkinson, Kristie-Lee Thomas, Osborne Melenamu and Rory Mackay

13/10/2015

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Contents

Executive Summary

- The aim of this research was to answer the following questions; how is the salinity of Lake Kate Sheppard (LKS) affected by its inflows and outflows? Are these salinity conditions favourable for Inanga spawning?

- Avon-Ōtākaro Network (AvON) is interested in LKS as a possible mahingā kai site due to its suitability for īnanga spawning. Salinity is a dominant factor that governs the spawning of īnanga and is affected by environmental conditions such as rainfall, wind speed and direction.

- A conductivity, temperature and depth (CTD) logger was used to conduct spot tests throughout LKS and at adjacent locations including the connected Avon River, Travis Wetland and Western Water Body. Data collection was used to measure salinity profiles at high and low tides under a range of variable environmental conditions. These were also used to observe conditions after five days of dry conditions at high and low tide and after two days of rain at high tide. The data collected was then downloaded into the computer program Ruskin and was exported into Microsoft excel where it was processed and used to produce graphs for interpretation.

- Literature research has identified that the salinity requirements are between 0 - 20,000 ppm for successful Inanga spawning. Spot testing in and around the lake revealed trends of salinity with depth and it was found that the lake provides suitable conditions for the spawning of īnanga.

- Time was a major limitation during the research process as it was challenging to complete research methodologies within the twelve weeks. Continuous data was lost due to equipment failure. Time in the field was also governed by tidal limitations and specific weather requirements. More time would allow for better quality of data collection and more in-depth conclusions.

- The research conducted lead to more questions that are in need of further investigation. More salinity profiles could be collected at close time intervals (continuous measuring) during high and low tide to observe the advance and retreat of the salt wedge. Profiling during different seasons especially during autumn, when īnanga spawn, may also reveal new information as to the success of the species at this site. Investigations should be undertaken to examine possible factors that may act to prohibit īnanga migration. There are many other factors present that affect water quality and subsequently impact the īnanga habitat. The anomalous salinity values found in the Western Water Body should also be investigated.

1.0 Introduction

LKS is an anthropogenic lake created for flood mitigation and sediment trap (Zhang & Carrick, 2014). It is located in Anzac Drive Reserve and is connected to the Avon River, Travis Wetlands and the surrounding water bodies via a network of culverts. LKS provides a habitat for īnanga (whitebait) and served as a suitable spawning ground pre-earthquake. However, significant subsidence and sediment input due to liquefaction are reasons to predict considerable effects on lake conditions (Zhang & Carrick, 2014). These changes, as well as other aspects of hydrology are of interest to AvON, a network of individuals and organisations who aim to restore and redevelop mahingā kai sites among the residential red zone (with LKS listed as one of their potential sites). The concept of mahingā kai includes the recognition of cultural and heritage values, restoration of natural habitat, biodiversity, īnanga spawning, pathway connections, storm water treatment, food production and incorporates a way of thinking that involves and understands the protection and use of resources (Avon-Ōtākaro Network, 2013).

LKS is a tidally influenced lake with complex inflows and outflows. Saline waters enter the lake through the Avon River culvert. Fresh water is supplied by the Travis Wetland Catchment area and there are also influences of storm water runoff. A network of culverts connects these waterways creating turbulence within the water bodies affecting the vertical structure of the water column. Research on hydrological characteristics of LKS conducted by Barr, Keenan, Price, Townsend, & Young (2015) revealed spatial variation in salinity values. Thus an initial research question was posed: How is the salinity of Lake Kate Sheppard affected by its inflows and outflows? Are these salinity conditions favourable for Inanga spawning?

The aim of this research is to provide AvON with information on spatial variation of salinity (specific measurements of salinity after two days of rain and five days of no rain were acquired) and factors that may influence this variation such as tidal flow influences, bathymetry and climate conditions. This research builds on past discoveries and the information gained could be useful for habitat restoration, īnanga rehabilitation and greater opportunities for mahingā kai.

This report is structured with the main research focus on spatial variation of salinity in LKS with links to environmental factors that may influence this variability are discussed. Salinity profile graphs were constructed for various locations and overlayed on a base map of the area for high and low tides. Previous continuous data from Barret et al. (2015) was used to observe long term trends.

2.0 Theoretical Framework and Literature Review

Little research has been conducted at LKS except for the efforts of Barr et al. (2015), Keenan (2015), and Zhang & Carrick (AvON) (2014). Literature reviews were focused on investigating salinity, conductivity and density relationships of water bodies in similar situations to LKS as well as specific īnanga spawning requirements.

Barr, Keenan, Price, Townsend, & Young (2014) researched the tidal processes, Lake Bathymetry and various aspects of water quality in LKS. They found significant oscillations in the lake water level due to tidal influences which were mirrored by water quality changes and in particular, salinity. They also found spatial variation of temperature, conductivity, dissolved oxygen, pH, nitrate and redox potential levels which they related to changes in bathymetry (Barr et al., 2015). Higher salinity levels were measured near the Avon culvert and lower salinity levels were observed at the Travis Wetland culvert. We hypothesized that a tidally controlled salt wedge intrudes the lake from the Avon River culvert and this wedge would pool at the deep southern end of the lake. This salt wedge has implications on Inanga populations due to the specific conditions at which they require to spawn. This research also provided insight into considering environmental factors such as rainfall, wind speed and the inflows and outflows that may influence salinity.

Zhang & Carrick (2014) examined LKS as an exemplar mahingā kai site. They investigated the loss of īnanga habitat to lateral spreading and subsidence effects such as higher influx of sediment and inundation of vegetation which previously hosted īnanga eggs. Inanga eggs were found north of the jetty confirming they still inhabit the lake. It was also identified that the subsidence of LKS has intensified storm water runoff into the area. This is expected to contribute to water pollution, creating poor water quality for the ecosystem. This report also takes into account the crucial differences in water level and turbidity relative to the amount of rainfall.

Naftz et al. (2014) measured conductivity and temperature to determine density stratification and salinity cycles in Great Salt Lake, Utah which has similar catchment and anthropogenic influences to LKS. Data analysis revealed culverts influence distribution and cycling of salinity. Wind speed, duration and direction were the main stimulus of water flow which influenced suspended conductive ions in the shallow water column. It was also found that the lower water column was saline rich, high density and near-zero velocity except for strong wind events where salinity cycling was controlled by bathymetry. In relation to this, Becker, Luettich & Mallin (2010) found that tidal and river discharge are dominant mechanisms that influence salinity and circulation structures and Jamshidi & Abu Bakar (2012) suggest seasonal variations in temperature, salinity and density relationships exist.

Hicks, Barbee, Swearer, & Downes (2010) suggest salinity, geomorphology and temperature are key factors that determine successful spawning. Īnanga successfully spawn between salinity values of 0 – 20,000 ppm. Comparatively, fresh water has salinity concentrations of 500 ppm and seawater 35,000 ppm (Lenntech, 2014). They mention that īnanga spawning sites are generally associated with the upstream penetration of the salt wedge in New Zealand estuaries and tidal lakes. The location of spawning sites is influenced by the geomorphology, where they hypothesized that stratified estuaries would provide a greater extent of low salinity surface water than well-mixed estuaries.

3.0 Methods

This research has required the collection of water quality profile data from within LKS and its associated areas of inflow and outflow. Specific attributes of interest include water conductivity (which correlates to salinity), temperature and depth, of which govern the prosperity of the īnanga habitat.

3.1 Equipment

- Water quality data of the lake was collected using a range of CTD Loggers RBR, CT2X, Odyssey and handheld conductivity loggers. These instruments were used to measure conductivity (based on dissolved solids, which correlates to water salinity), temperature and depth (CTD). Tests were used to gather momentary water profile data throughout the lake, within the Western Water Body, Travis Wetland and Avon River areas. These loggers have been set to record data at 6 htz for detailed and accurate profiling of water quality changes with depth.
- A Garmin GPS was used to provide co-ordinates at each location of testing. This has been crucial for making accurate correlations between data in different areas and has also been necessary for input with specific software during data processing.
- A portable weather station was also set up on site from the 31st of August. Due to the lack of climate data for the LKS area, this has been necessary for the incorporation of environmental factors into the research. Important aspects recorded were wind speeds and precipitation. It measured rainfall (to the nearest 0.2 mm), the average wind speed, direction and maximum wind speed (gust). Wind was measured from 3 m height and temperature and humidity were measured from 1.5 m height.

3.2 Data Collection

All tests conducted at LKS were executed as spot tests, involving dunking the CTD loggers slowly into the water until the bottom was reached. This method was used to gather momentary water quality profiles within the adjacent water bodies and throughout the lake. In this research, it has been important to consider the variation of water characteristics relative to changes in environmental conditions. Tidal fluctuation and precipitation have been dominant factors that control the salinity, temperature and flow in the lake over time. Because of this, spot testing was conducted relative to specific time frames in accordance with variation in these conditions. Relative to Lyttelton harbour, LKS has a low tide lag time of 4:40 hours, which occurs approximately 1:30 hours before Lyttelton Harbour high tide, so this needed to be considered before all field work. Spot testing was implemented throughout the area at low and high tides after 5 days of no rain and at high tide after 2 days of rain, in order to understand the impacts of these conditions. It has also been crucial to consider the locations from which to collect data throughout the area. As LKS is connected to the adjacent Avon River, Travis Wetland and Western Water Body via culvert systems, the interaction of water qualities between these bodies may have been restricted. Because of this, spot testing has been situated within close proximity to the culvert systems to best represent the variation in water quality relative to external factors. These important concepts have governed the selected sites and timing of data logging throughout this research.

3.3 Data Processing

Various forms of software were used post data collection in order to manage the data. Ruskin was used for management of the RBR CTD logger and also for exportation of the raw data. Ruskin software outputs conductivity values in the unit milli-Siemens per centimeter (mS/cm) and salinity data in Practical Salinity Unit (PSU).

Data was categorised by latitude and longitude, conductivity, salinity and temperature for depths every 10 cm. Depths of 10 cm intervals were chosen in order to represent the data with the highest accuracy and to display any small anomalies that might be present. Once the data had been exported, processes were then undertaken to convert the information into a presentable format. This has been necessary in understanding the data and drawing conclusions from the research. Raw data was initially input into excel where it was cleaned of the irrelevant data recorded between locations of spot testing. It was then used to create graphs for means of visual representation. This allowed for a better interpretation of water profiles and how water characteristics changed with depth relative to external influences. These graphs were then used in conjunction with the GPS Co-ordinates and were overlain onto a LKS map to better understand the spatial distribution of high salinity water throughout the area. This has also allowed for an interpretation as to how tides, precipitation and wind impacts water quality in various areas.

4.0 Results

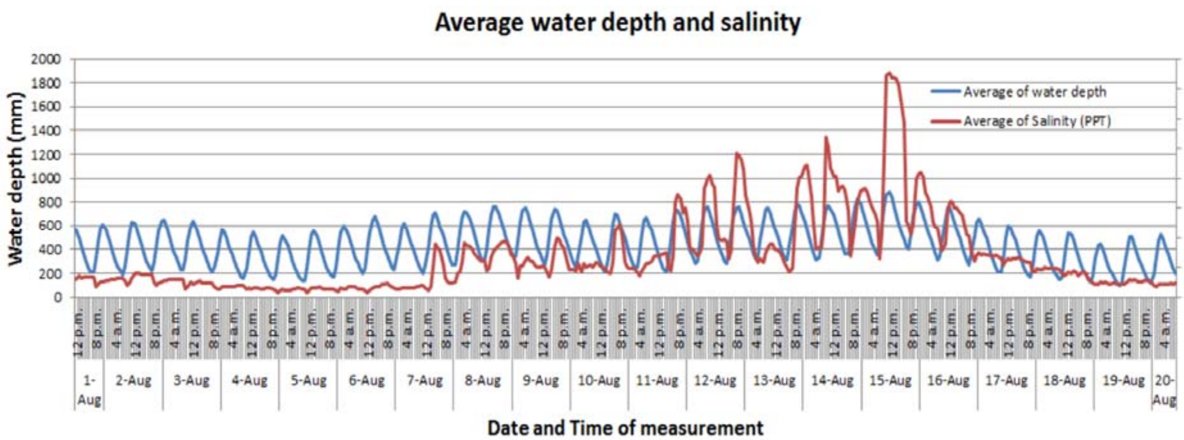


Figure 1: Graph showing a comparison between water depth and salinity levels. Retrieved from Barr et al. (2014). Reprinted with permission.

As shown in figure 1 there was a correlation between high tide and high salinity levels.

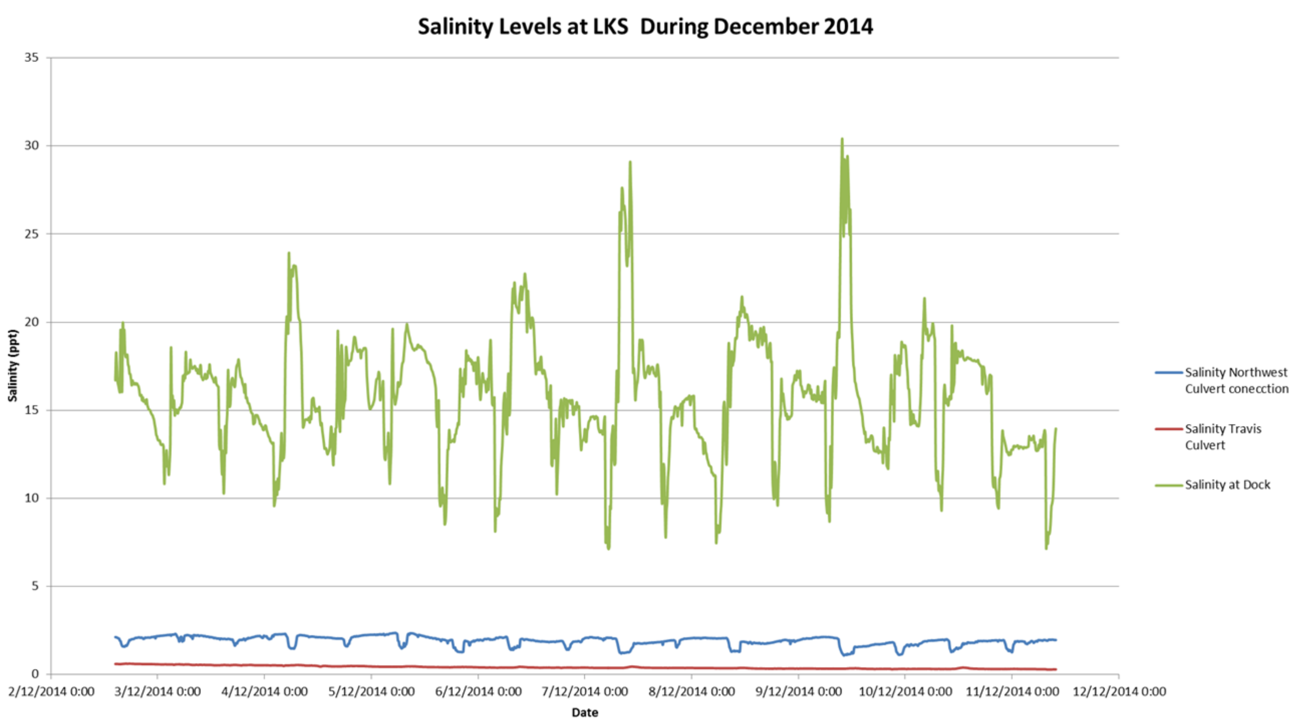


Figure 2: Salinity level at three different locations around LKS.

As shown by 2014 data in Figure 2, salinity levels were significantly higher at the dock, with values up to 30 ppm. Because of the lack of rainfall and high temperatures less dilution and more evaporation would occur, so salinity levels are expected to be significantly higher during summer.

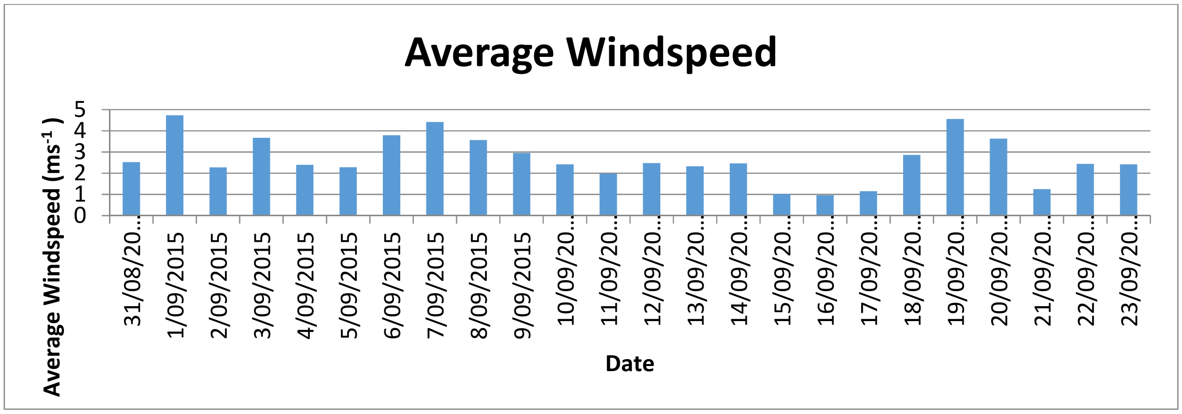


Figure 3: Graph showing the average wind speed values during data collection

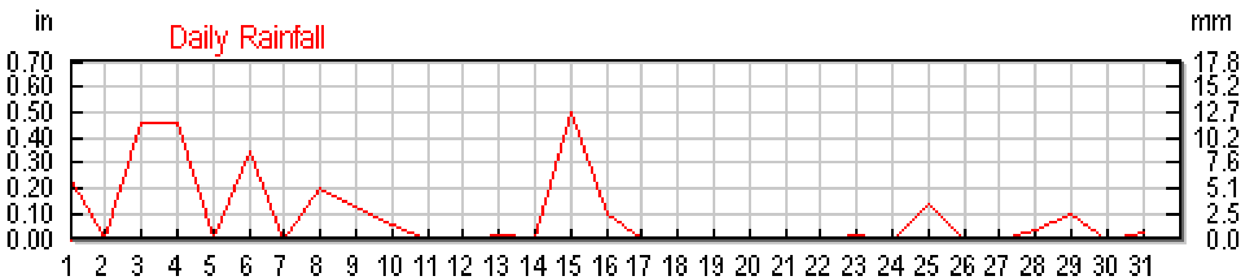


Figure 4: rainfall data for August 2015. Due to the weather station being absent for this month, this data has consequently been obtained from; http://www.nzwebnet.co.nz/wxwuhistory.php?ID=ICHRISTC4&month=8&day=30&year=2015&units=M&mode=3

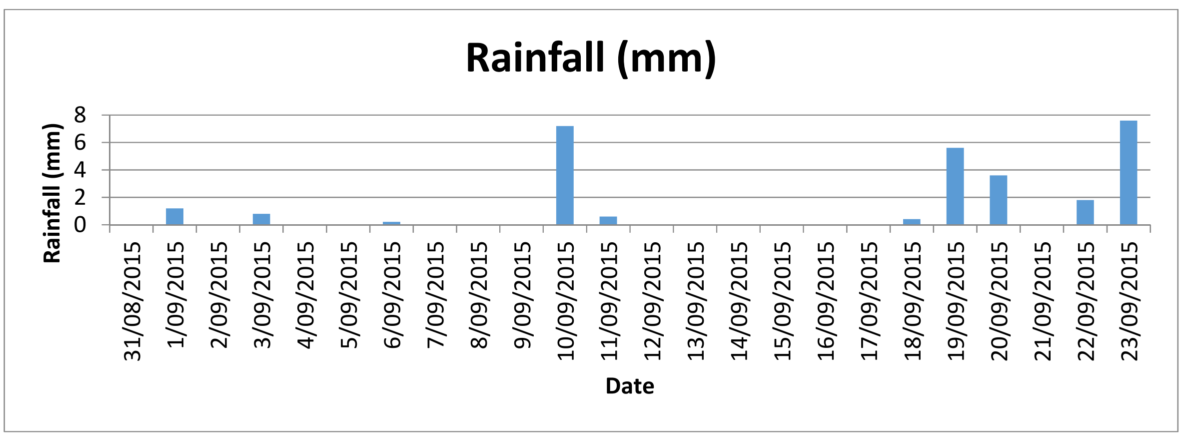


Figure 5: Graph showing rainfall during data collection from September.

Figures 1 and 2 are data sets obtained from (Barr et al., 2014). This allows for comparisons to be made between old and new data. Figure 3 shows the average wind speeds at LKS during September, allowing for interpretations of how wind speed affects the vertical structure of the water column. However this data isn't overly usefully with spot testing. A more detailed summary of the wind effects on salinities would have been made from continuous data, however this data was lost. Figures 4 and 5 show rainfall measurements on different days. This allows for clear identification of rainfall quantities before recording days. Consequently, this allows for an understanding on how much influence rainfall has on diluting the salinities within the lake.

Figure 6: Waypoints recorded in the Garmin GPS to maintain accuracy when re-visiting spot testing locations.

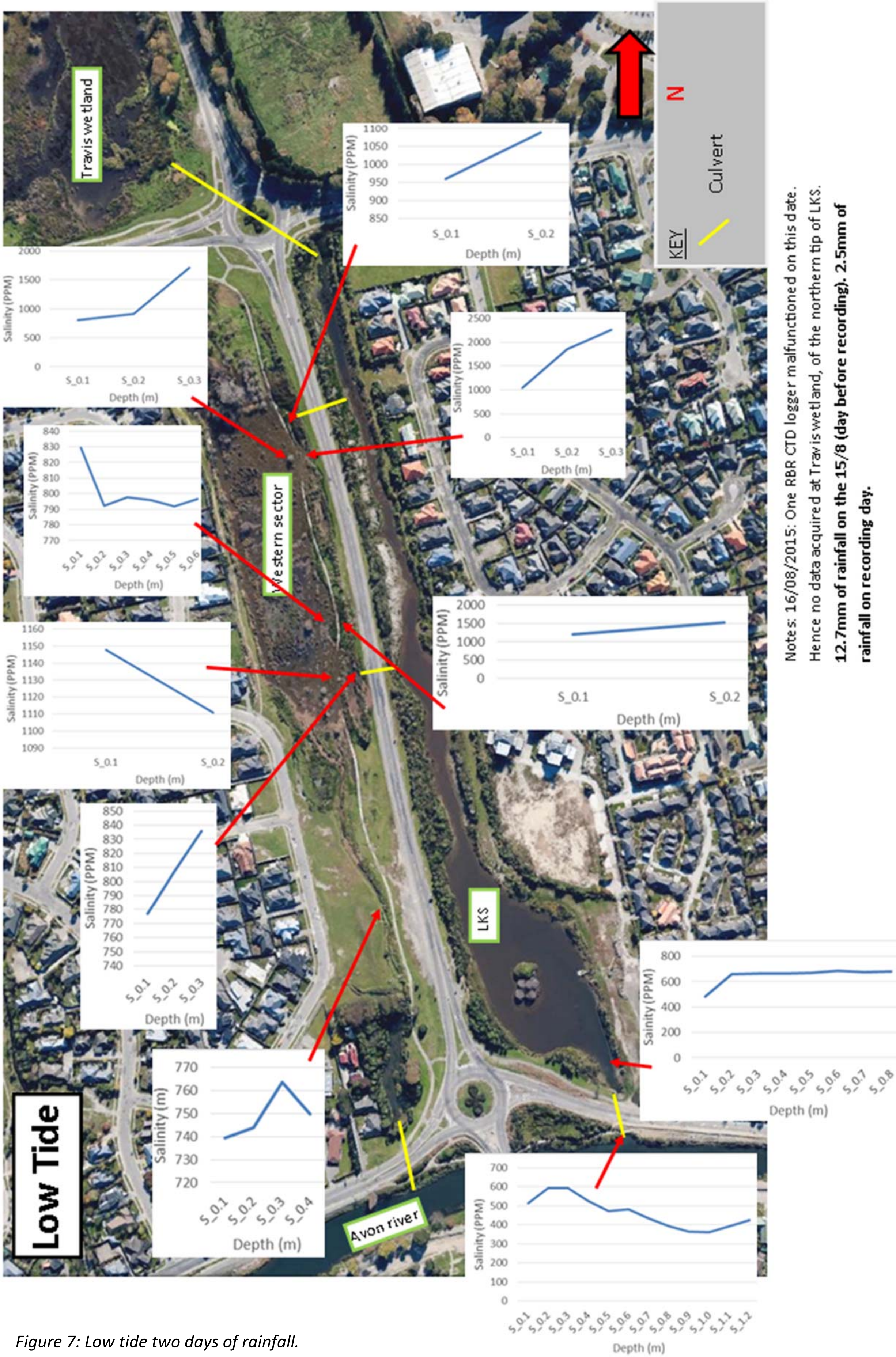


Figure 7: Low tide two days of rainfall.

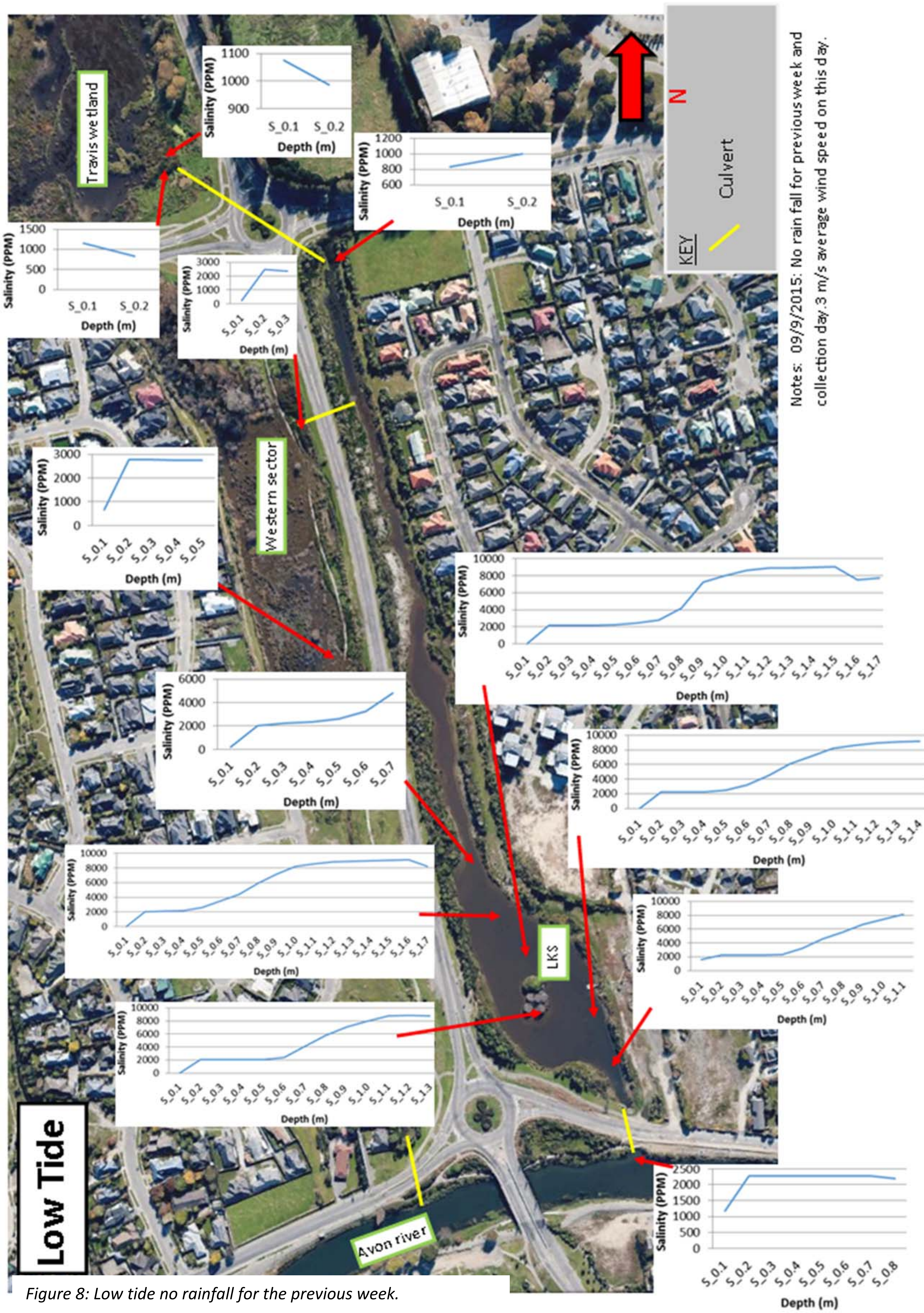


Figure 8: Low tide no rainfall for the previous week.

Figure 9: high tide after two days of rain fall.

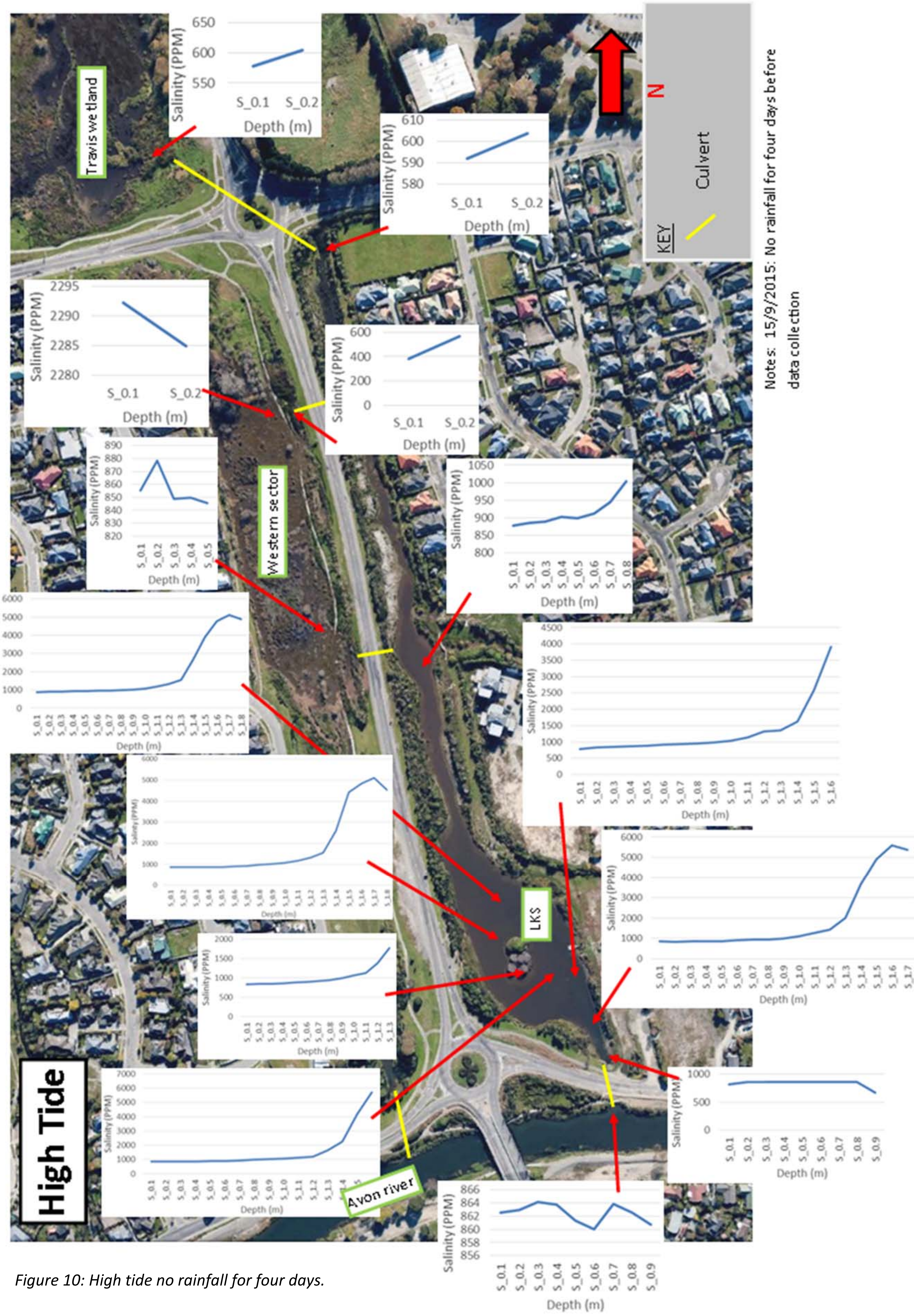


Figure 10: High tide no rainfall for four days.

Results have been obtained from the processed spot testing data. Consequently four maps have been created, conveying the spatial relationships and trends of salinity throughout LKS at low and high tides. This shows the advancing salt wedge as the tide rises, directly affecting the salinity concentrations within the water column at different locations. Different rainfall events are also incorporated into these, allowing for a visual explanation into the direct effects on salinity.

Figure 6: Low tide two days of rainfall

Due to the added water input into the lake from Travis wetlands and added flow in the Avon River the overall salinity concentrations of LKS are considerably lower than those recorded at low tide with no rain (figure 7). Anomalies are seen in the Western Water Body, with a negative trend showing salinity decreasing with depth. This also occurs at the inlet on the Avon River side. This provides an insight into how the inflows of LKS directly affect the salinity concentrations and structure within the water column.

Figure 7: Low tide no rainfall for the previous week

When comparing Figure 6 to 7 the added meteoric water can be seen to significantly impact the concentrations of salinity, with added turbulence destroying vertical structure. Water column profiles show good vertical structure. Most locations displayed a positive trend, however anomalies are still present in the Western Water Body and Travis Wetland. Salinity decreases further north in the lake; this is seen on all four days.

Figure 8: High tide no rainfall for four days

High tide with no rain shows clear vertical structure. Successfully portraying the advancing salt wedge as the tide pushes inland. An intense spike in salinity can be seen at approximately 1.3 m depth, representing this. This is analogous to our initial hypothesis. However, there are still anomalies present in the western water body.

Figure 9: high tide after two days of rain fall

The effects of rainfall are clearly seen within the vertical profiles, dramatically affecting the water column, obscuring the salt wedge of the advancing high tide. Profiles tend to show a more linear relationship between salinity and depth and in many cases having a slight negative trend. Anomalies are again present in Travis wetland.

These figures illustrate trends and relationships of salinity with depth. It has been identified that low tide on both rainfall and no rainfall days has higher salinity concentrations than those recorded on both high tide days. Low tide with no rain tends to peak in salinity concentrations at a depth of 0.7 m from 2000-4000 ppm to a maximum of 9000 ppm. However, high tide no rain peaks at a depth of 1.3 m from 1000 ppm to 5000 ppm. These findings open up further discussion as to how the flow characteristics of LKS directly affect the salinities concentrations and behaviour.

5.0 Discussion

5.1 Tidal Influences

It was found that Salinity concentrations were significantly higher during low tide. This could be attributed to effects of low tide drainage where high salinity waters from the Western Water Body are drawn into the lake, increasing salinity. The culvert connecting to the Avon appeared to be highly turbulent, promoting mixing within the water column, disturbing vertical structure and obscuring the advancing salt wedge.

This year's data found the highest salinity values were at 'lksf' (figure 6), reaching 5500 ppm. Tidal effects in this area are negligible due to the stagnant water observed. Due to shallow depth and high salinity recordings, it is believed that evaporation is the controlling factor at this location.

Inflow and outflows of LKS determine the migration of the 'salt wedge' which advances upstream with the push of high tide. The salt wedge can be observed in the salinity profiles (Figure 7) dominantly at high tide but also at low tide showing a spike in salinity at depth. Consequently, these have been controlling factors over the spawning location of īnanga, which is focused at the freshwater end of the salt wedge (Environment Southland, 2014).

5.2 Weather Influence

The salinity profiles show that rainfall causes dilution and wind facilitates turbulent mixing. These factors should contribute to disturb the normally graded salinity structure in the lake, obscuring the salt wedge. The 9th of September had the highest wind speeds recorded during testing, with average wind speeds of 2.96 ms^{-1} and maximum gust speeds of 6.68 ms^{-1}, as shown in Figure 3. However, the salinity profiles from the 9th September displayed a clearly stratified structure. This indicates that greater wind speeds may be required for sufficient mixing of the lake in order to change the salinity structure. On the 23rd of September there was 7.6 mm of rain this caused significant dilution, as shown in Figure 7, where salinity concentrations were up to ten times lower due to the addition of meteoric water. The rainfall also acted to distort the linear gradients of the salinity profiles, as shown in Figures 5 and 8, suggesting that precipitation could be a large contributing factor to mixing within LKS.

Research on the influence of lake morphology on water quality found that lake surface area can be used to predict the effects of wind on a lake. Water bodies with smaller surface areas and large beds of aquatic vegetation do not experience much mixing (Moses et al., 2011). This may explain the high salinity values in the shallow Western Water Body.

5.3 Effects on īnanga Spawning

It can be stated with confidence that the salinity concentrations within LKS are within the suitable range for successful īnanga spawning as proposed by Hicks et al., 2010. Inanga spawning occurs in autumn during high spring tides (Figure 10) within 500 m of the incoming 'wedge' of high salinity water; yet within the freshwater reaches (Environment Southland, 2014). This freshwater to seawater interface is present at LKS, indicating that it is a likely spawning location.

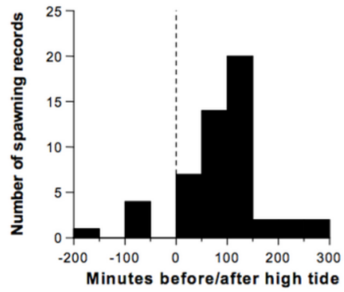


Figure 11: Graph showing the onset of spawning relative to high tide. Retrieved from Richard & Taylor, (2002.)

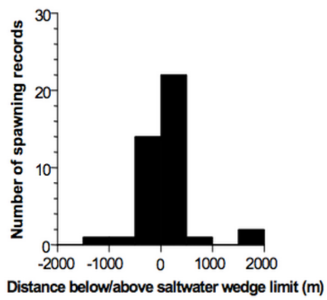


Figure 12: Graph showing the relationship between the spawning locations and proximity to the salt water wedge. Retrieved from Richard & Taylor, (2002).

5.4 Further Research

- More salinity profiles of the water should be collected throughout LKS at high and low tides, especially during autumn, when īnanga spawn to observe season trends.
- Continuous data is needed to gain a clearer understanding of how the salinity profiles evolve with the change in tide. Weather effects on this evolution will also be seen.
- Further investigations are required to determine if more native vegetation should be planted in the Riparian zone of LKS in order to restore īnanga spawning habitat, as this is where īnanga lay their eggs (Richardson & Taylor, 2002).
- Investigations should be undertaken to determine if the culverts in and around LKS allow īnanga to migrate. This has recently been discussed with the AvON and they will be further examining this.
- Further water quality testing should be conducted in order to improve insight into the conditions of LKS.
- The anomalous salinity values found in the Western Water Body and at Travis Wetlands should be investigated.
- Engineers Without Borders wish to create a hydrological model of LKS, our data will be useful for this.

5.5 Anomalies

The salinity profiles measured within Travis Wetlands and the Western Water Body follow opposite trends relative to other test sites. After no rain a reverse salinity gradient was observed at Travis wetland during low tide. This structure was also observed within the Western Water Body at low tide with rain. These trends could be caused high levels of evaporation within shallow water bodies. However, within the current study this has not been proved and as such, further research should be conducted in these areas.

6.0 Limitations

- It was difficult to determine when the logger had reached the bottom of the lake at locations due to poor visibility and drag from water flow.
- Malfunctions with the RBR CTD and CT2X recorders limited the expanse of the final data sets, preventing the collection of any continuous data throughout the time of this research. Two CTD recorders were found to be faulty when organising available equipment at the start to the project. These recorders were sent away for inspection and repairs, however these recorders were not fixed in time for implementation in the field. A catastrophic failure of a CT2X recorder meant four weeks of continuous data was lost. Water had infiltrated the recorder, consequently damaging and corrupting the hardware inside (figure 13). With recording devices limited already, the loss of this valuable data was a cruel setback. As a group it was decided that data from previous years could be used replacing this lost data.

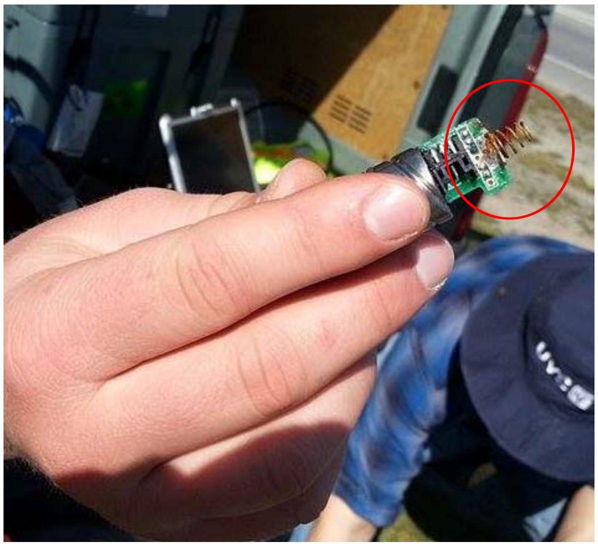


Figure 13: Picture shows the top cap of the CT2X that failed, allowing water into the unit. The spring for the battery circuit is rusted, indicating that the equipment had failed a week or more before we realised.

- No previous experience with equipment meant valuable time had to be used to understand the basics before going into the field. Although this meant we lost a week of data collection, this was needed to ensure the data was collected correctly.
- Time was the biggest limitation while conducting this research project. Attempting to have all data collection, data processing and reporting done within twelve weeks was challenging. If there was a longer deadline, the expanse and quality of data would have been a lot better. This would therefore allow for more accurate conclusions to be made.
- Weather conditions when taking spot measurements in the field has affected depth recordings. Some days the recorders have measured a minimum depth of 0.2 m, which is incorrect. This could be an atmospheric effect or due to the sensor not being calibrated correctly.
- Accurate climate data of the LKS area has been recorded from a portable weather station. However, this data has only been available from the 31st August and as such; prior climate data has been obtained using a different source.
- The scope of our research was very narrow, being limited to only salinity and temperature data. It is likely that other numerous water quality aspects in which would impact the spawning of īnanga. Such factors could include faecal matter, E.coli bacteria and various forms of storm water runoff contaminants. Due to limited time and resources, testing for these characteristics could not be implemented within our study.

7.0 Conclusion

It has been found that the salinity data collected from LKS has been well within the recommended ranges established by previous research indicating that the lake provides suitable conditions for the successful spawning of īnanga.

Regardless of the fact that no continuous testing could be completed, the spot data that has been collected will assist AvON by providing additional information to their database to help restore īnanga habitat and greater opportunities for mahingā kai. The data will also be of use to Engineers Without Borders who plan on inputting the collected data into a hydrological model of Christchurch's waterways.

The results have also highlighted areas of unexpected and anomalous salinity profiles, which raise opportunities for future research in LKS. However, for the scope of the research question these areas have not been elaborated on. It is also crucial to recognize that salinity is not the only factor controlling the prosperity of īnanga within the lake. Alternate water characteristics such as faecal matter, E.coli and storm water contaminants are also likely to govern the success of īnanga spawning. These components however, are beyond the scope of our research due to limitations with time and resources.

8.0 Acknowledgments

The following research was guided by technicians of the Geography department at the University of Canterbury, with thanks to Kurt Joy & John Thyne. Bryan Jenkins, a representative member of the AvON also helped to supervise this research. A special thanks to Justin Harrison for his ongoing commitment and assistance throughout the research process.

9.0 References

Avon-Otakaro Network. (2013). Our Charter. Retrieved October 7, 2015, from Avon-Otakaro Network: http://www.avonotakaronetwork.co.nz/about-us/charter.html

Barr, E., Keenan, D., Price, V., Townsend, N., & Young, H. (2015). *Hydrological Characteristics of Lake Kate Sheppard.* Christchurch: University of Canterbury.

Becker, M. L., Luettich, R. A., & Mallin, M. A. (2010). Hydrodynamic behaviour of the Cape Fear River and estuarine system: A synthesis and observational investigation of discharge–salinity intrusion relationships. *Estuarine, Coastal and Shelf Science, 88*(3), 407-418. doi:10.1016/j.ecss.2010.04.022

Environment Southland. (2014). *Potential Inanga Spawning Areas in Southland Rivers.* Invercargill, New Zealand: Hicks, A., Leigh, B., & Dare, J.

Hicks, A., Barbee, N. C., Swearer, S. E., & Downes, B. J. (2010). Estuarine geomorphology and low salinity requirement for fertilisation influence spawning site location in the diadromous fish, Gallaxias maculatus. *Marine and Freshwater Research 61* (p. 1252–1258).

Jamshidi, S., & Abu Bakar, N. B. (2012). Seasonal variations in temperature, salinity and density in the southern coastal waters of the Caspian Sea. *Oceanology,52*(3), 380-396. doi:10.1134/S0001437012030034

Keenan, D. (2015). *Hydrological Dynamics of Lake Kate Sheppard*: University of Canterbury and the Avon-Ōtākaro Network.

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

Moses, S., Janaki, L., Joseph, S., Justus, J., & Vimala, S. (2011). Influence of lake morphology on water quality. *Environmental Monitoring and Assessment,182,* 443-454.

Naftz, D. L., Carling, G. T., Angeroth, C., Freeman, M., Rowland, R., & Pazmiño, E. (2014). Density-stratified flow events in great salt lake, Utah, USA: Implications for mercury and salinity cycling. *Aquatic Geochemistry, 20*(6), 547-571. doi:10.1007/s10498-014-9237-8

Richardson, J., & Taylor, M.J. (2002). Reprinted with minor revisions 2004 A guide to restoring īnanga habitat. NIWA Science and Technology Series No. 50. 31 p.

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

Appendices

Appendix 1: Photos

Figure A.1. A requirement of the research was to record information before and after specific rainfall events. Therefore a weather station was positioned beside LKS to provide local meteoric conditions so the identification of these specific conditions could be made.

Figure A.2. Research members using "thingy the dingy" to collect water profiles at geo-referenced locations around the lake.

Figure A.3: The use of a piece of string on the end of the RBR logger was used to lower the recorder into the water recorder the water profile at the given location. This was done at several locations throughout LKS, Travis wetlands and the Avon River.

Figure A.4: An Odyssey CTD logger was used to measure continuous data however due to misinterpreted lag times the equipment was not installed at true low tide thus the equipment was not placed deep enough and data wasn't collected at low tide.

Figure A.5: Installation of the first CT2X logger beside the jetty in LKS. A waratah was driven into the lake floor with the logger secured to it. This provided reassurance that the logger want move around, and makes it difficult for members of the public to interfere.

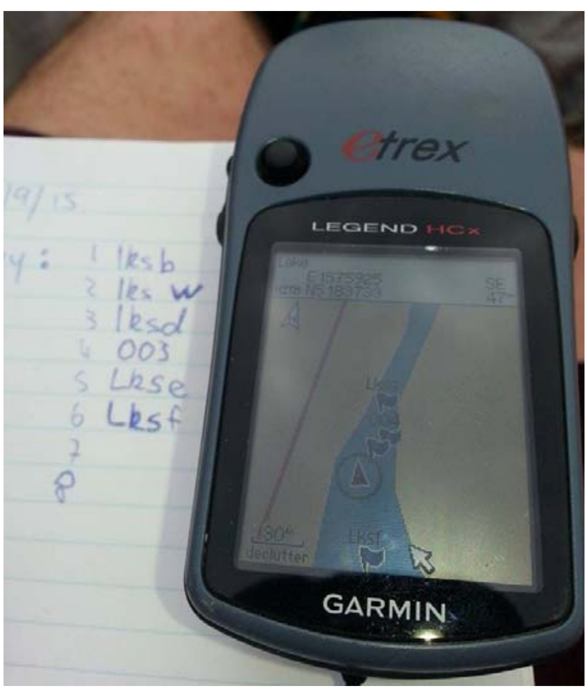


Figure A.6: Individual waypoints can be seen on the screen of the GPS, location order was recorded in a notebook.

Figure A.7: The CT2X logger that was stationed at the dock. This is the same unit that was damaged.