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Memorandum

To: Michelle Mifflin, Manager Engineering, **Otago Regional Council**

CC: Daniel King, Operations and Maintenance Lead, **Otago Regional Council**

From: Melanie Vermeulen, Greg Ryder, **Ryder Environmental Limited**

Date: 10 March 2021

Subject: **Otago Regional Council – Kaikorai Lagoon Investigation**

Dear Michelle,

Please find below a draft summary of our observations of Kaikorai Lagoon, including results of water quality sampling, following the recent fish kill that coincided with the mechanical opening of the lagoon mouth in February.

We are happy to clarify any comments or other aspects raised in the memo.

Regards,

Melanie Vermeulen
Environmental Scientist

Greg Ryder
Environmental Scientist

Ryder Environmental Limited

Background

Ryder Environmental was engaged by Otago Regional Council to provide preliminary information on the water quality of Kaikorai Lagoon following unexplained fish deaths, possibly linked to warm temperatures, low dissolved oxygen and the opening of the coastal mouth in February 2021. A description of the sampling methods and a brief summary of the sampling results to date are presented below.

Sampling methods

Sampling was undertaken at one location in Kaikorai Stream on Brighton Road (an ORC State of the Environment monitoring site) and at eight locations within the lower Kaikorai Lagoon to provide representative coverage of the physico-chemical parameters present at the time of sampling (Figure 1). The estuary was sampled at short notice on 26 February 2021 around the mid-flow tide between 11:30 am and 2:00 pm and with an antecedent dry period of 72 hours.

At each sampling location, general site observations were made and photos taken. Field staff waded into the water body to a distance that was safe to do so considering water depth and substrate (sinking/getting stuck). Distance from wetted edge, depth of water and GPS location were recorded.

Information on the physicochemical parameters of temperature (°C), conductivity (µS/cm), dissolved oxygen saturation (%) and concentration (mg/L) was gathered using a calibrated hand-held YSI Professional Plus Multi-parameter instrument at a water depth of between 10-20 cm (Table 1).

Figure 1. *Locations of water quality sites sampled on 26 February 2021 at Kaikorai Lagoon. Inset: Location of site sampled at Kaikorai Stream.*

Sampling Locations

Kaikorai Stream (1)

At the Brighton Road Bridge, the Kaikorai Stream is approximately 2 m wide, has a maximum depth of around 0.6 m and has a predominantly cobble substrate with no shading. The streambed was covered in thick mats of brown periphyton (~90% cover). The riparian zone comprised native and exotic shrubbery, exotic grasses, boulder riprap and cobbles/gravel. Some rubbish was seen on the banks and within the channel. The water was clear and did not have an odour. A bully was observed swimming in the area.

Plate 1: Upstream at Site 1 Kaikorai Stream

Plate 2: Downstream at Site 1 Kaikorai Stream

Plate 3: Midstream at Site 1 Kaikorai Stream

Plate 4: Instream at Site 1 Kaikorai Stream

Kaikorai Lagoon (2)

This site is located about 60 m upstream and west of the Brighton Road Bridge and about 30 m upstream of two large stormwater culverts and 40 m downstream of old piles on the true right side. The estuary is approximately 80 m wide to the opposite bank and the water was light brown with low clarity. The substrate was predominantly mud with a black anoxic edge that was approximately 1 m wide with a lot of suction when walked over. There was dead green algae and wind driven scum on the wetted edge and a slight marine odour. The riparian zone comprised a boulder and cobble wall with sparse vegetation.

Plate 5: Upstream at Site 2 Kaikorai Lagoon

Plate 6: Downstream at Site 2 Kaikorai Lagoon

Plate 7: Midstream at Site 2 Kaikorai Lagoon

Plate 8: Instream at Site 2 Kaikorai Lagoon

Kaikorai Lagoon (3)

This site is located about 30 m upstream and east of the Brighton Road Bridge on the true left side. The estuary is approximately 90 m wide to the opposite bank and the water was light brown with low clarity. The substrate was predominantly mud with a black anoxic edge that was approximately 0.3 m wide with a lot of suction when walked over. There was dead green algae and wind driven scum on the wetted edge. The riparian zone comprised reeds, salt meadows and shrubbery.

Plate 9: Upstream at Site 3 Kaikorai Lagoon

Plate 10: Downstream at Site 3 Kaikorai Lagoon

Plate 11: Midstream at Site 3 Kaikorai Lagoon

Plate 12: Anoxic mudflats at Site 3 Kaikorai Lagoon

Kaikorai Lagoon (4)

This site is located about 30 m downstream and east of the Brighton Road Bridge on the true left side. The estuary is approximately 130 m wide to the opposite bank and the water was light brown with low clarity. The substrate was a mixture of sand and mud and there was dead green algae on the wetted edge. The riparian zone comprised mainly grasses and shrubbery.

Plate 13: Upstream at Site 4 Kaikorai Lagoon

Plate 14: Downstream at Site 4 Kaikorai Lagoon

Plate 15: Midstream at Site 4 Kaikorai Lagoon

Plate 16: Instream at Site 4 Kaikorai Lagoon

Kaikorai Lagoon (5)

This site is located about 250 m downstream and east of the Brighton Road Bridge on the true left side. The estuary is approximately 220 m wide to the opposite bank and the water was clear with high clarity. As the tide was low-ish, extensive sand flats were exposed and the wetted channel was narrow. The substrate was predominantly sand and with no vegetation in the vicinity.

Plate 17: Upstream at Site 5 Kaikorai Lagoon

Plate 18: Downstream at Site 5 Kaikorai Lagoon

Plate 19: Midstream at Site 5 Kaikorai Lagoon

Plate 20: Instream at Site 5 Kaikorai Lagoon

Kaikorai Lagoon (6)

This site is located about 430 m downstream and east of the Brighton Road Bridge on the true left side. The estuary is approximately 300 m wide to the opposite bank and the water was clear with medium clarity. As the tide was relatively low, extensive sand flats were exposed and the wetted channel was narrow. The substrate was predominantly sand and with no vegetation in the vicinity. A small flock of pied oystercatcher were spotted on the sandflats.

Plate 21: Upstream at Site 6 Kaikorai Lagoon

Plate 22: Downstream at Site 6 Kaikorai Lagoon

Plate 23: Midstream at Site 6 Kaikorai Lagoon

Plate 24: Instream at Site 6 Kaikorai Lagoon

Kaikorai Lagoon (7)

This site is located about 500 m downstream and west of the Brighton Road Bridge on the true right side. The estuary is approximately 280 m wide to the opposite bank and the water was clear with medium clarity. The substrate was predominantly sand and the riparian zone comprised salt meadows and rushes.

Plate 25: Upstream at Site 7 Kaikorai Lagoon

Plate 26: Downstream at Site 7 Kaikorai Lagoon

Plate 27: Midstream at Site 7 Kaikorai Lagoon

Plate 28: Instream at Site 7 Kaikorai Lagoon

Kaikorai Estuary (8)

This site is located about 430 m downstream and west of the Brighton Road Bridge on the true right side. The estuary is approximately 315 m wide to the opposite bank and the water was light brown with low clarity. The substrate was predominantly mud with a black anoxic subsurface layer that was exposed when walked on. The riparian zone comprised salt reeds and shrubbery.

Plate 29: Upstream at Site 8 Kaikorai Lagoon

Plate 30: Downstream at Site 8 Kaikorai Lagoon

Plate 31: Instream at Site 8 Kaikorai Lagoon

Plate 32: Anoxic mudflats at Site 8 Kaikorai Lagoon

Kaikorai Lagoon (9)

This site is located about 180 m downstream and west of the Brighton Road Bridge on the true right side. The estuary is approximately 170 m wide to the opposite bank and the water was light brown with low clarity. The substrate was predominantly coarse sand with occasional green seaweed. The riparian zone comprised a narrow stony beach, rock and concrete block wall and shrubbery.

Plate 33: Upstream at Site 9 Kaikorai Lagoon

Plate 34: Downstream at Site 9 Kaikorai Lagoon

Plate 35: Midstream at Site 9 Kaikorai Lagoon

Plate 36: Instream at Site 9 Kaikorai Lagoon

Physico-chemical data

Table 1. *Physico-chemical water quality data of Kaikorai Stream and Kaikorai Lagoon from a survey undertaken on 26 February 2021 around mid-flow tide.*

Sampling site	GPS coordinates (NZTM)	Distance from wetted edge (m)	Depth of water (m)	Conductivity (µS/cm)	Temperature (°C)	Dissolved oxygen (%)	Dissolved oxygen (mg/L)
1	E1400072, N4913370	1	0.2	135.7	15.2	116.7	11.8
2	E1397747, N4910969	3	0.3	18329	19.6	103.0	9.2
3	E1397849, N4910957	6	0.5	16479	18.0	94.8	8.4
4	E1397747, N4910899	8	1.5	42702	15.8	78.3	6.2
5	E1397656, N4910677	30	0.2	25478	18.2	95.3	8.1
6	E1397603, N4910503	3	0.3	26370	19.0	100.3	8.3
7	E1397538, N4910421	2	0.5	30586	20.1	110.7	8.9
8	E1397435, N4910576	6	0.5	25339	25.0	113.9	10.4
9	E1397589, N4910782	5	0.5	33749	18.9	101.0	8.1

The Australia and New Zealand Guidelines for Marine and Freshwater Quality (ANZG 2018) do not provide default guideline values (DGVs) for estuarine environments and so their use for this survey is very limited. For site 1 located on Kaikorai Stream, the River Environment Classification is Cool Dry Low-elevation and DGVs are provided by ANZG 2018 for conductivity and dissolved oxygen saturation. The conductivity at site 1 exceeds the 80th percentile DGV of 116 µS/cm and is indicative of nutrient enrichment, not unexpected for a catchment dominated by urban and rural land uses. The dissolved oxygen saturation exceeds the 80th percentile DGV of 101% and is likely the result of high periphyton biomass, as observed (Plate 4).

High readings for conductivity at the lagoon sites will be the result of marine (saline) influence from the opening of the lagoon mouth and possibly nutrient enrichment from sedimentation as observed by brown coloured water with low clarity at some sites. Using the DGVs for Cool Dry Low-elevation as a rough guide for the estuary sites, site 4 located near to the Brighton Road Bridge had a dissolved oxygen saturation that was lower than the 20th percentile of 81%. Water temperatures for all the sites were below the upper lethal temperature of most New Zealand species 28°C - 34°C (Richard *et al.* 1994).

Discussion

There are a variety of potential causes for fish kills in freshwater/estuarine environments, including toxicants, disease and environmental stressors (e.g. salinity, high temperature, low dissolved oxygen concentration). Fish can avoid adverse environmental conditions by swimming to another area, but if a large proportion of the waterway is affected or the adverse conditions appear rapidly, they may be unable to relocate quickly enough, and a fish kill may occur.

The Kaikorai Lagoon fish kill observed on February 20 2021 included smelt, flounder, giant bullies, trout and inanga. Fish & Game Otago staff visited the site at 4 pm and reported that the "water was very warm to the touch and any remaining fish appeared stressed" (Otago Daily Times, 22 February 2021). However, meteorological data downloaded from the Musselburgh weather station (located approximately 9.5km east of Kaikorai Lagoon) indicates that ambient air temperature and daily global radiation were not particularly high (for summer) on that day or in the days leading up to February

20 2021 (Figure 2). This data suggests that climate conditions were not extreme for this time of the year and so may not have exacerbated water quality conditions in the lagoon at the time.

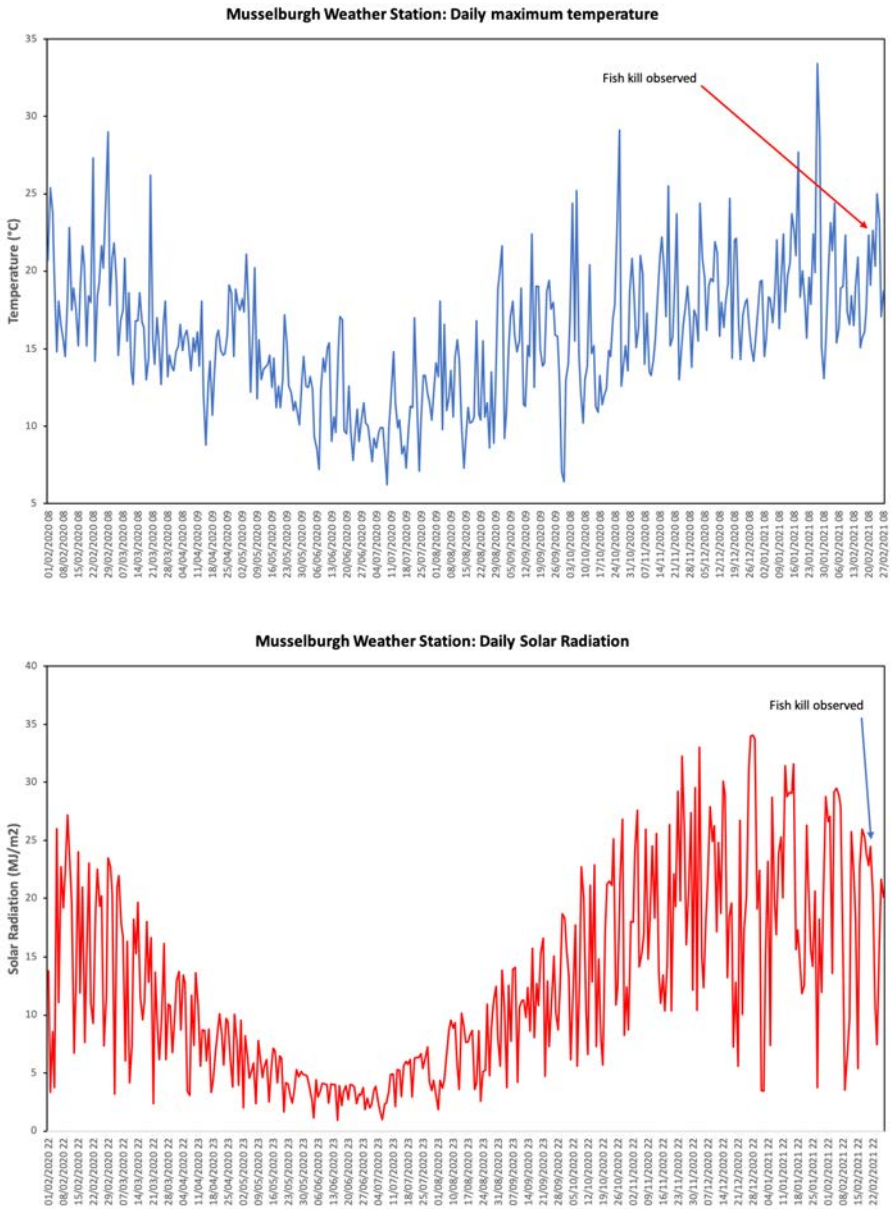

Figure 2. *Top: Daily maximum air temperature recorded at the Musselburgh weather station. Bottom: Daily solar radiation recorded at the Musselburgh weather station.*

Based on the observations made by Fish & Game Otago, it is likely that severe deoxygenation in the vicinity of the Brighton Road Bridge was a likely cause of the fish kill. Our observations found some evidence of oxygen depletion in the vicinity of the Brighton Road Bridge (sampling site 4, Figure 1 and table 1), but this was localised and not severe. However, our water quality survey and associated observations were undertaken six days after the observed fish kill event and, consequently, due to the length of time passed since the fish kill was observed, and the change in estuary conditions following the opening of the sand bar, it is difficult to attribute an exact cause based on our observations or other information available to us.

During our survey, sites 2, 3 and 4 had brown water with low clarity as a result of high sediment levels in the water column. Nutrient enrichment is likely considering surrounding land use, resulting in elevated plant biomass (including dead algae/seaweed which was observed along the shore), which draws oxygen from the water column during photosynthesis. Sites 2 and 3 had muddy substrate with a wide black anoxic margin (Plate 8) and anoxic subsurface layer (Plate 12). Normally, overlaying water remains well oxygenated and aquatic life is not adversely affected. However, disturbance of these sediments, which could occur with an influx of marine water when the estuary was opened, may mix these sediments through the water column increasing oxygen demand and potentially leading to rapid deoxygenation. In addition, there is potential for hydrogen sulphide gas (toxic to aquatic life as it interferes with respiration) to be released from the sediments, as a result of anoxic conditions. Site 4, nearest to the Brighton Road Bridge, had a dissolved oxygen saturation lower than the 20th percentile DGV. We accept that this is largely speculative on our part, but anoxic sediments do appear to be a widespread feature of Kaikorai Lagoon.

There are a number of potential sources of contaminants to the lagoon, including landfill leachate from the two landfills located in the upper reaches of the lagoon, the Green Island Wastewater Treatment Plant, and stormwater and overland flow from urban, industrial and rural areas. Our understanding is that the DCC Green Island landfill has a contained leachate collection system, and the Green Island Wastewater Treatment Plant is a contained system also, therefore contamination from these sources seems unlikely unless there was some failure associated with the containment system. To our knowledge, no accidental or deliberate discharges of contaminants to Kaikorai Stream or Abbotts Creek, or from the surrounding catchment of the lagoon, were reported at time, or prior to when, the fish kill was reported. If a significant discharge were to have occurred from any of these locations, it is likely that dead fish would have been observed in areas further upstream of the Brighton Road Bridge. It is also worth noting that there was no significant rain in the Dunedin area in the eight days leading up to when dead fish were reported (Figure 3).

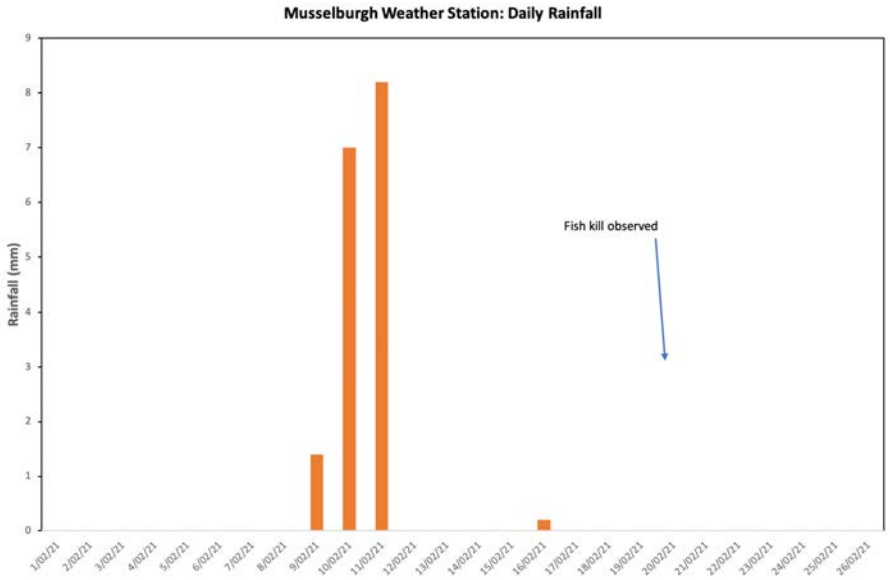

Figure 3. *Daily rainfall recorded at the Musselburgh weather station.*

Conclusion

There is no factual cause and effect relationship associated with the February 2021 fish kill in the lower Kaikorai Lagoon. While the mechanical opening of the lagoon mouth to the sea preceded the reported fish kills in the lower lagoon, suggesting it may have played a role, there is no strong evidence to support this relationship, or how it might have resulted in fish deaths. Nonetheless, the finding of fish deaths does raise the issue of how future mouth openings should be managed in terms of ensuring that potential adverse environmental effects are avoided.

We are aware of other South Island ICCOLS (intermittently closing and opening lakes and lagoons) that are mechanically opened to the sea (e.g., Waituna Lagoon - Southland, and Te Waihora/Ellesmere - Canterbury), where no fish kills have been reported as a result of this activity. However, there are examples from overseas of unexpected outcomes, including fish kills, resulting from mechanical lagoon openings (e.g., Hadwen 2006). Consequently, we suggest that the following matters be considered when contemplating future mechanical mouth openings:

- Monitor dissolved oxygen levels and water temperatures within the lagoon prior to any decision to open;
- Arrange for mechanical openings to coincide with incoming tide (to avoid sudden drops in water levels and dissolved oxygen levels as well as increase exposure and death of aquatic vegetation which can cause odours);
- Enable mechanical openings to coincide with rainfall (if possible);
- Open mouths on windy days rather than hot, still days;
- Aim for natural openings rather than mechanical openings by scraping the beach berm prior to heavy rainfall;
- Aim for winter openings (i.e., cooler conditions), which are environmentally better than opening during summer.

References

ANZG 2018. Australian and New Zealand guidelines for fresh and marine water quality. https://www.waterquality.gov.au/anz-guidelines/

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Otago Daily Times (2021) Hundreds of fish found dead in estuary. *Otago Daily Times*. Retrieved from https://www.odt.co.nz/news/dunedin/hundreds-fish-found-dead-estuary

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