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GLM-AED and the Urban Lakes Project (CAM Summer 2024)

Introduction

Road salt is used to ensure safety of people and drivers, by helping prevent ice formation on roads, sidewalks, and paths. Unfortunately, most of the road salt runs off into neighboring streams and lakes, making it a major pollutant of lakes and the top source of salinity in lakes. Normally, there is no feasible or easy way to remove salt from lakes. However, within the past 4 years, a group of Columbia researchers have discovered a way to possibly do so (Columbia Engineering).

This can affect the lake biosphere by stimulating algae growth, changing the lake chemistry, disrupting the habitat of freshwater fish and other organisms, and by forcing aquatic species to migrate or die off based on their saline sensitivity. Algae growth can create dead zones in the lake by starving certain parts of oxygen and degrading water quality and reduce biodiversity. Since microorganisms, fish, invertebrates, and other lake-dwelling creatures tend to be sensitive to saline concentration, an increase in this concentration from the natural concentration of the lake may severely disrupt the biosphere of the lake, causing a reduction in population or forced migration of these species to different parts of the lake, if the sudden increase doesn't kill them off entirely. The pH of the lake can be severely affected as well, depending on the composition (Mark S.).

Salt, or sodium chloride, when split, can react with water to change the pH of the solution it is in. Hydrogen is attracted to sodium and hydroxide is attracted to chlorine. Depending on the existing lake chemistry, an influx of salt can make the lake acidic or basic, but regardless of the change, many organisms are sensitive to the pH of their environment, especially larger organisms that can't adapt to changing conditions as easily (L. Lind).

There are specific times during the year when turnover events occur. These are also known as mixing events and happen when water from the top of the lake mixes with the bottom of the lake. In a saline-free lake, these are usually triggered by high wind speeds, sometimes through violent weather. However, as salt accumulates in the lake, parts of the lake may become stratified, and the salt will no longer equally distribute through the lake, but rather collect towards the bottom. This tends to form a gradient, with the least salt at the top, and the most at the bottom. This becomes an issue as the sections of the lake with the most salt usually become "dead zones" where the water is too toxic for lake life to live (L. Lind).

In the research done during the Summer 2024 session, it was a goal to see how a lake's initial salinity, inflow salinity, and morphometry affected how salinity distributes through a lake. The lakes of interest were Lake Como and lake McCarrons. Both lakes have similar surface area, but Como is very shallow while McCarrons is much deeper. To test how these variables affected the lakes, a software called the General Lake Model was used with the library for Aquatic

EcoDynamics, or GLM-AED as an abbreviated version. Both the model and library were developed by researchers at the University of Australia (Dan Paraska). AED is used to allow for fine tuning of hydrodynamics and simulation settings during the simulation. This software was used to simulate 25 years of salt buildup.

Research Goals

The goal of this summer's research was to accurately model Lake McCarrons and Lake Como. In this paper, we will mostly discuss the results of the testing of Lake McCarrons, being the more interesting lake, but the test process discussed was also applied to Como.

Methods

GLM-AED takes some input files: A meteorological data file, containing daily humidity, air temperature, radiation values, optional inflow and outflow files, dictating information about water flowing into the lake, as well as water flowing out of the lake, along with the simulation fine-tuned file and hydrodynamics file.

The model simulates the lake by dividing the lake shape, specified in the simulation file, into a lot of small slices, and simulates each layer of the lake individually, step by step. The size of the "step" can vary from one second to one day. The smaller the step, the longer the simulation, but also the higher quality the output data.

A large issue that we encountered during the simulation setup process is that the scaling for salinity in inflow files can have a massive influence on the simulation. At the end of the period of research, we were able to establish a factor of 0.008x from the measured salinity of the inflow for Lake McCarrons, which was measured in grams per cubic meter. This, along with a uniform value of 0.135 for initial salinity through the lake, allowed for accurate simulation results across 25 years of meteorological data.

The inflow and outflow files were generated by a model called STELLA developed by Dr. Chip Small's group with the Urban Lakes research project. The model primarily functions as a chloride model, which is adapted to salt in the inflow files it generates. During the second half of my work on the project, I focused on accelerating the process for testing by creating a script that varied values I specify.

The script generated graphs of temperature and salinity by depth, and we varied initial salinity, inflow salinity, and lake shape/morphometry. We noticed some trends in salinity, specifically that higher initial salinity reduced the time it took for the lake to reach the average expected value of 2 g/kg salt per cubic meter of water (Table A1), variations of inflow salinity drastically affected the average salinity of the lake (Table A2), and variations of lake morphometry severely altered salt retention of the lake (Table A3). For example, at 5 meters of depth, average salinity excluding saline spikes from high temperatures was around 1 g/kg. At 10 meters, it was around 1.5 g/kg. At 13.3 and larger depths, it equalized towards 2 g/kg, but 13.3 m of depth seemed to be the tipping point at which salinity averages filtered for ambient temperature are no longer dependent on depth. (In this case, the ambient temperature refers to the lake temperature of 12 degrees Celsius; this is found by removing the summer spikes of temperature towards 25 degrees Celsius and averaging the resulting temperature.)

As a result of this testing of morphometry variation, we were able to confirm the behavior of Lake Como's low saline retention was indeed because of its depth rather than other factors, such as the inflow or outflow configuration or other differing factors. In fact, Como and McCarrons were very similar in terms of saline output when McCarrons was scaled down to 3 meters deep.

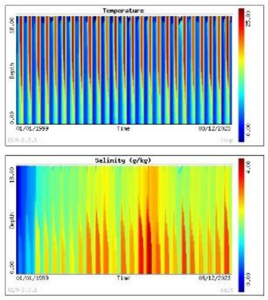
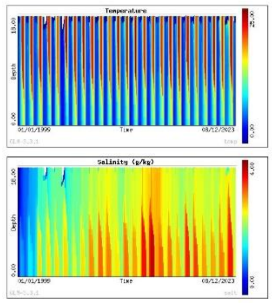
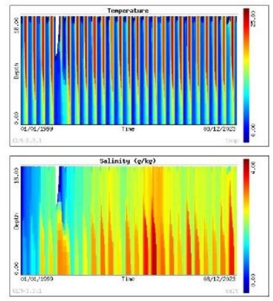
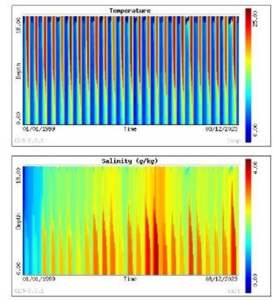
Future Directions

The primary objective of the Urban Lakes project is to create a methodology to produce accurate data based on predicted data from a chloride model, generalized for all lakes in Minnesota. The next step is to begin to develop a more efficient way of simulation testing. By examining output data rather than supplying possible values for each variable to test, a "Newton's Method"-esque resimulation technique can be used to refine simulations to desired outputs. Additionally, the use of other models for accurate simulations will be useful along with further development of a tool I am developing to simplify the process of lake simulation. Rather than changing parameters individually, it would automatically make the needed changes while the application simulates.

Appendix

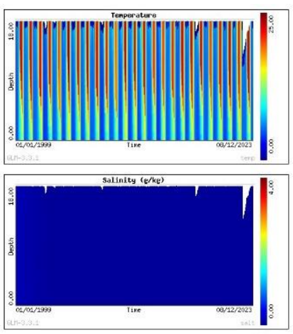
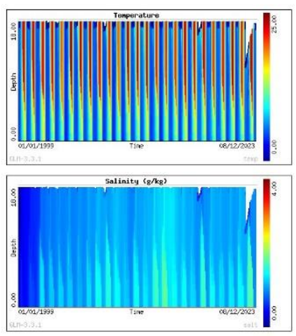
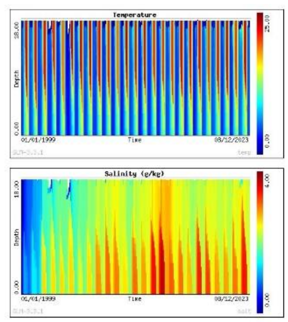
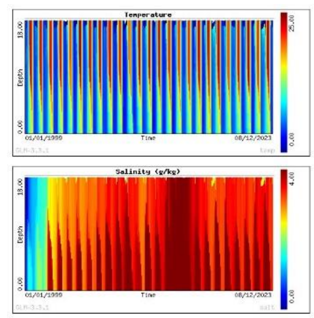
A1

Initial Salinity (g/kg)

0.0	0.135	0.25	0.5
			

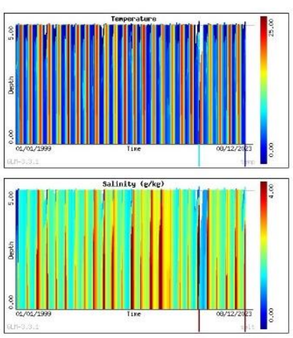
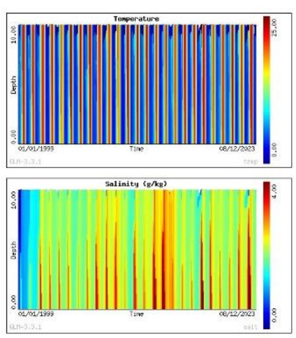
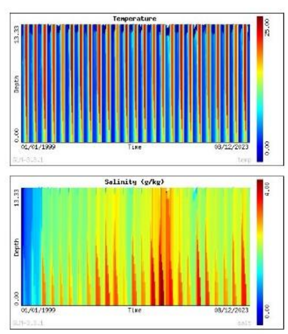
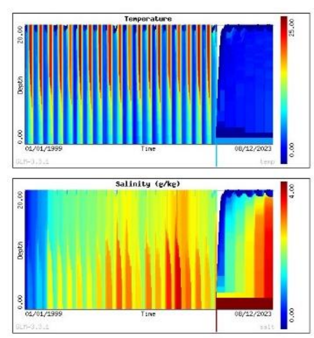
A2

Inflow Salinity (g/kg)

0.0	0.5	1.0	1.5
			

A3

Morphometry (depth m)

5m	10m	13.3m	20m
			

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