CFD Simulation of Water Velocity Passing through Egg Frame Box

Delta smelt are an imperiled species endemic to the Sacramento/San Joaquin Delta. They are known as a keystone species, as many other fish prey on Delta smelt. Delta smelt live for about 1 to 2 years and have demonstrated high variability in spatial distribution and annual abundance. The decline of Delta smelt indicate that the Sacramento/San Joaquin Delta ecosystem is stressed and that it may no longer provide recreational, ecological, and commercial goods and services the people of California expect in the future.

The Fish Conservation and Culture Laboratory (FCCL) located in Byron, CA, houses a refuge population of Delta smelt in the case the species becomes extinct in the wild as well as a population that is kept for research purposes (Lindberg et al, 2013). The FCCL maintains a Delta smelt population in captivity as genetically diverse as possible to that of the population observed in the wild (Lindberg et al. 2013).

COMSOL Multiphysics was used to conduct the simulation based on a diagram from Lake Suwa Fishing Collectives manual (LFSC) as seen in Figure 1. Flow rates of 20 and 60cm/s was used to run the simulations of the river where Wakasagi egg frames are deployed. A replica of the Wagasaki egg frame box sitting near the edge of a river and 3D flow dynamics simulations were conducted (Figure 2). The models of the egg frame box (Figure 3) and the egg frame (Figure 4) are measured and simulated from the egg frames and egg frame box bought from the LSFC. The flow direction and area used in the simulations were modeled from the diagrams used found in the LSFC egg hatching manual that can be seen in Figures 1 and 2.

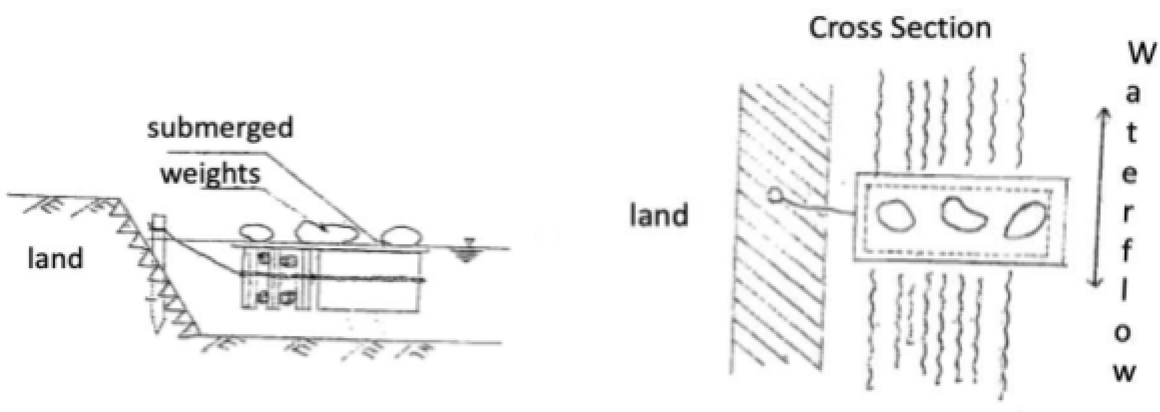


Figure 1: The diagram used to construct models for CFD simulations.

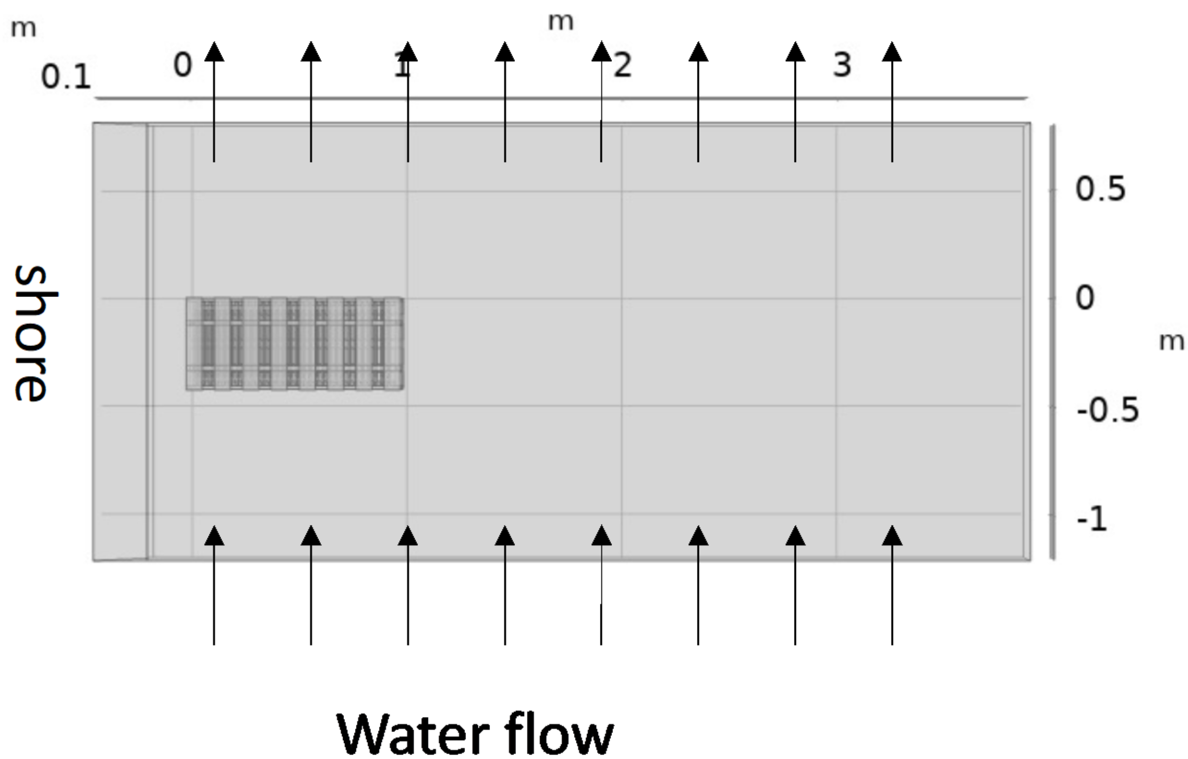


Figure 2: Horizontal view of simulation replicating the diagrams found in the LFSC egg management book.

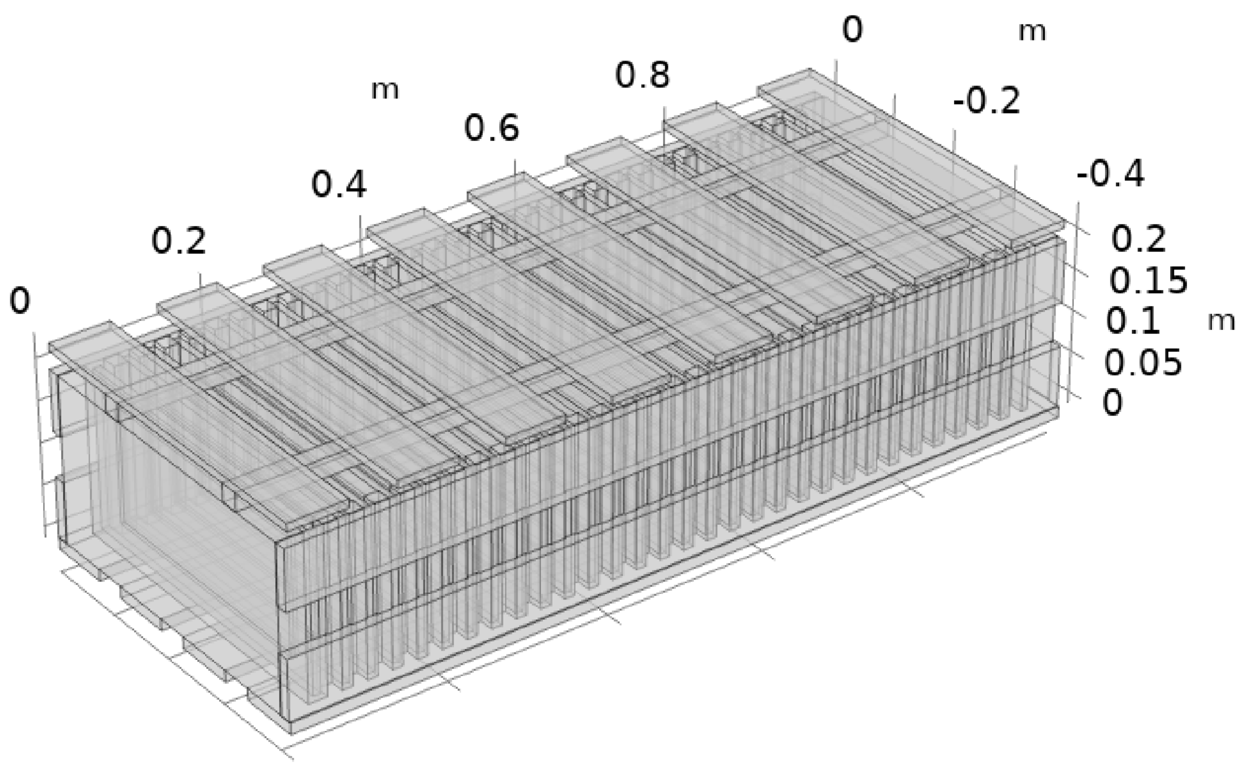


Figure 3: Life sized model for the egg frame box modeled on COMSOL Multiphysics.

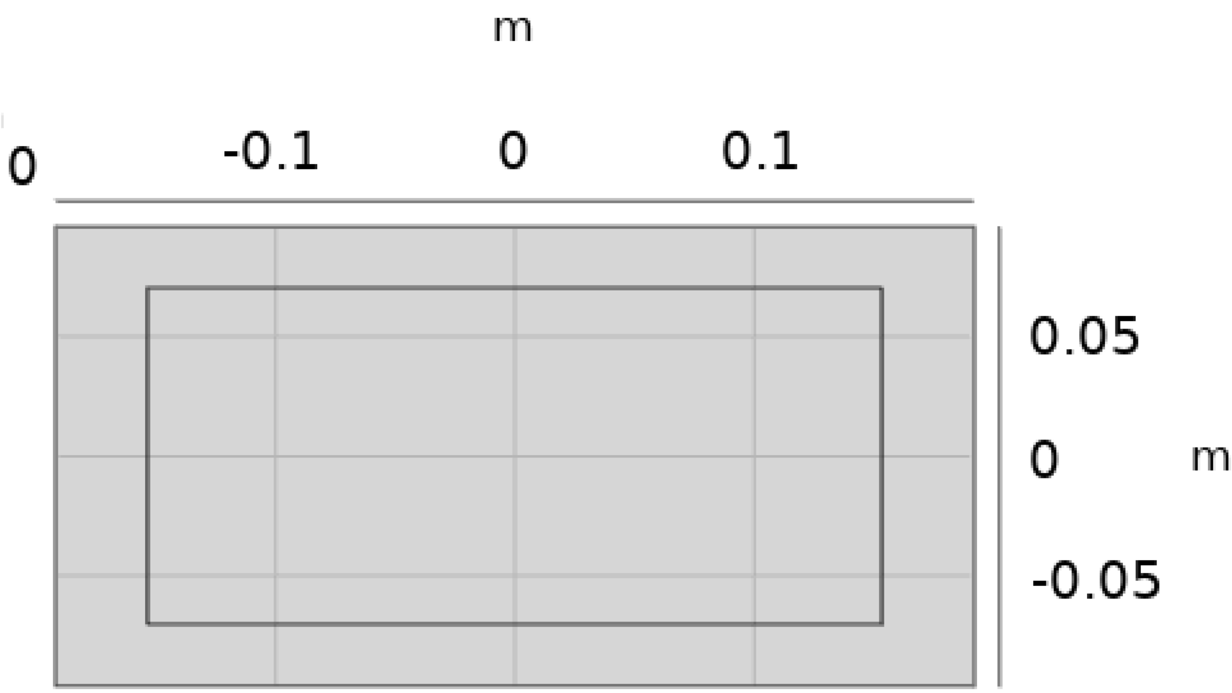


Figure 4: Life sized model for the egg frame modeled on COMSOL Multiphysics. The middle of the egg frames is simulated as a permeable material.

The fluid motion under the previously mentioned conditions was expressed by the Reynolds-averaged Navier-Stokes' equation in the form:

$$\rho(u \bullet \nabla)u = \nabla \bullet [- pl + K] + F$$

$$\rho\nabla \bullet \mu = 0$$

where u is the fluid velocity (m/s), pl is the fluid pressure (Pa), ρ is the fluid density (kg/m^3), K is the transport of turbulent kinetic energy (J/kg), F is the external forces applied to the fluid (N), and μ is the fluid dynamic viscosity ($N \cdot s/m^2$). Results from the simulations indicate that as the water flows through the box, the velocity of the water decreases substantially inside the box. The flow tended to flow around the box, especially for the high flow speed (60cm/s) tested. From the data obtained from the simulation, the water slows down significantly as it goes between the openings in the box and travels past the frames.

After the simulations were conducted, an ANOVA statistics test was conducted to evaluate which side of the egg frame had the velocity water flow velocity flow through it: the front, middle, and back. It was found that there was no significance (P-value = 0.09 in the 0.2 m/s test and 0.13 in the 0.6 m/s test, Tables 1) in the water velocity as the water flows from the bottom of the simulation and entered the three different sections from the front of the box (Figure 6), as long as it enters from the orientation shown in Figure 2.

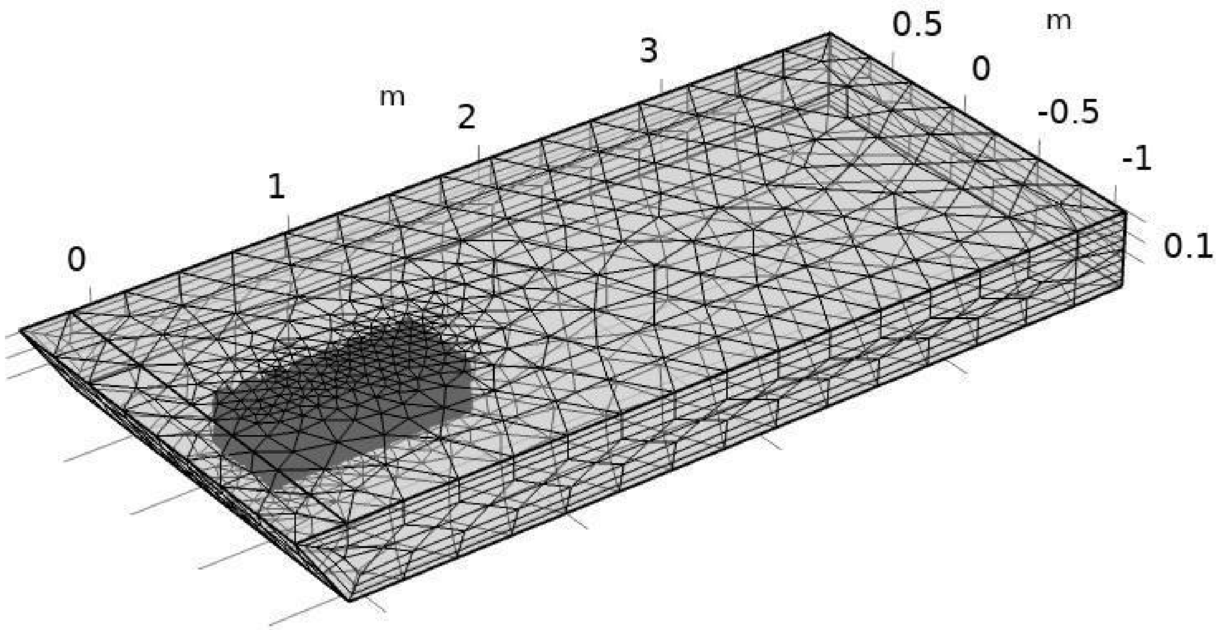


Figure 5: Mesh diagram of the box and surrounding water bodies for the simulations.

Figure 6: Diagram of the egg frame box splitting into 9 sections.

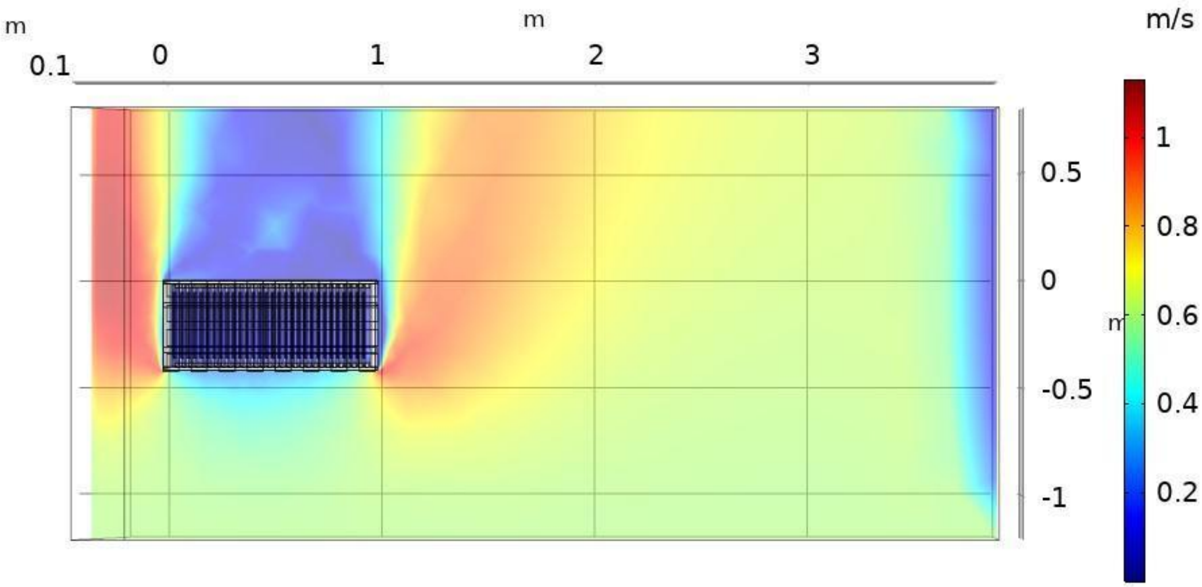


Figure 9: Horizontal view in the middle of the egg frame box with incoming flow of 0.6 m/s from the bottom of the figure to the top.

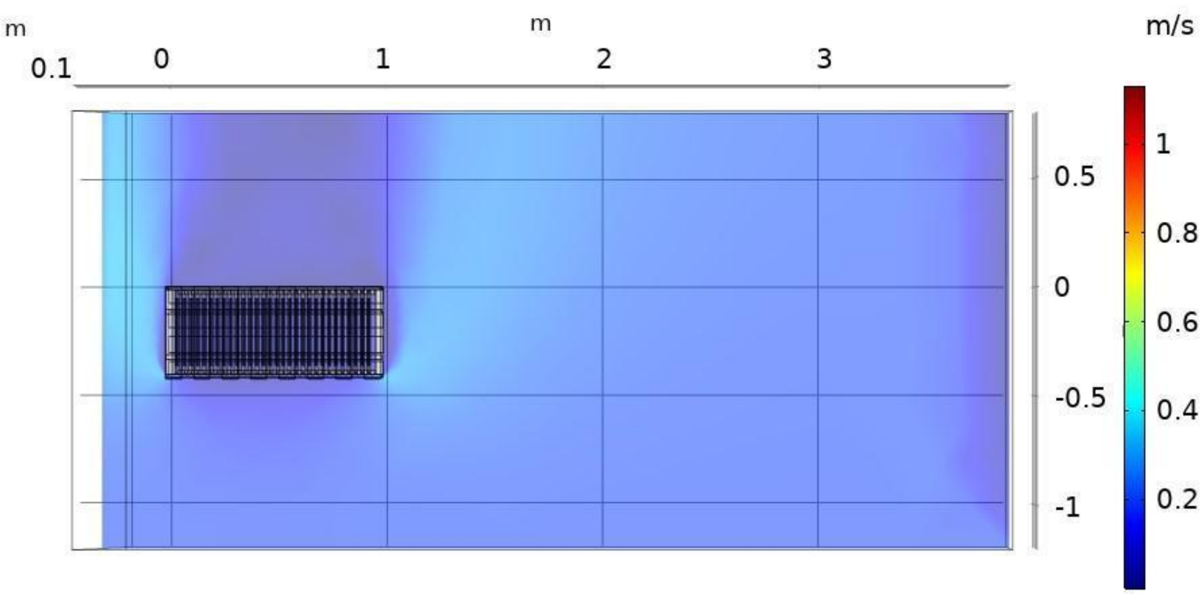


Figure 10: Horizontal view in the middle of the egg frame box with incoming flow of 0.2 m/s from the bottom of the figure to the top.

The next step would be to find a suitable location to deploy the egg frame box, which will be the objectives of this project. The objectives of this project are to find suitable locations and time to deploy egg frame box, and then to use real water velocity data to simulate what happens in the egg frame box under real conditions

Methods:

What is now needed is to find a suitable spot to deploy the egg frame box. The Spring Kodiak Trawl (SKT) is a yearly survey that takes place from January to May with the purpose of determining the relative abundance and distribution of spawning delta smelt. From the SKT, it can be seen that a majority of the ripe female delta smelt are found in Cache slough. With that being said, flow rate data and water depth was collected from USGS at two different stations in Cauche Slough. The first one, 11455385, is found upstream in the Cauche slough, and the second one, 11455420, is located downstream from it, as can be seen in Figure 11.

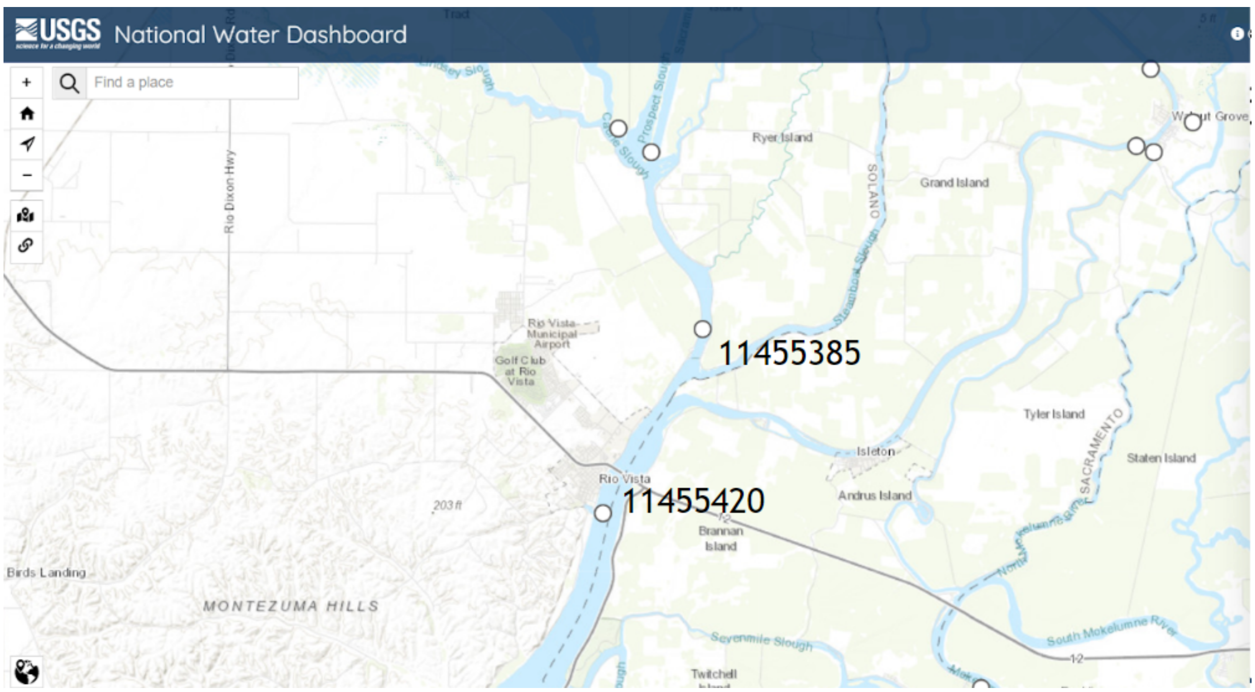
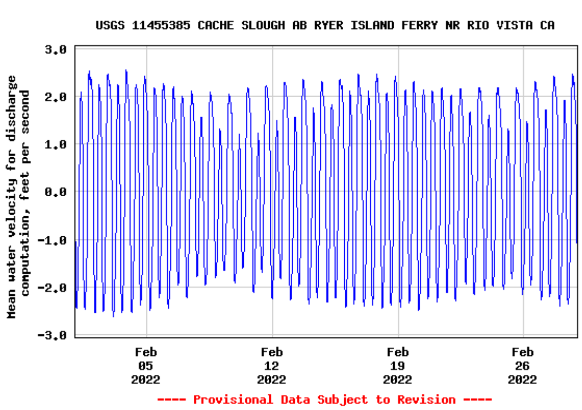


Figure 11: Map of Cache Slough with location of stations 11455385 and 11455420.



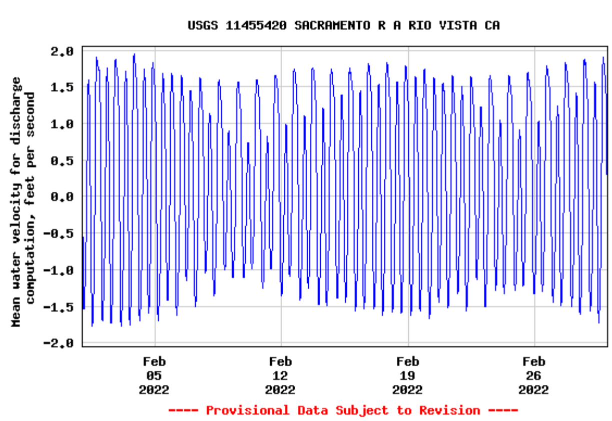


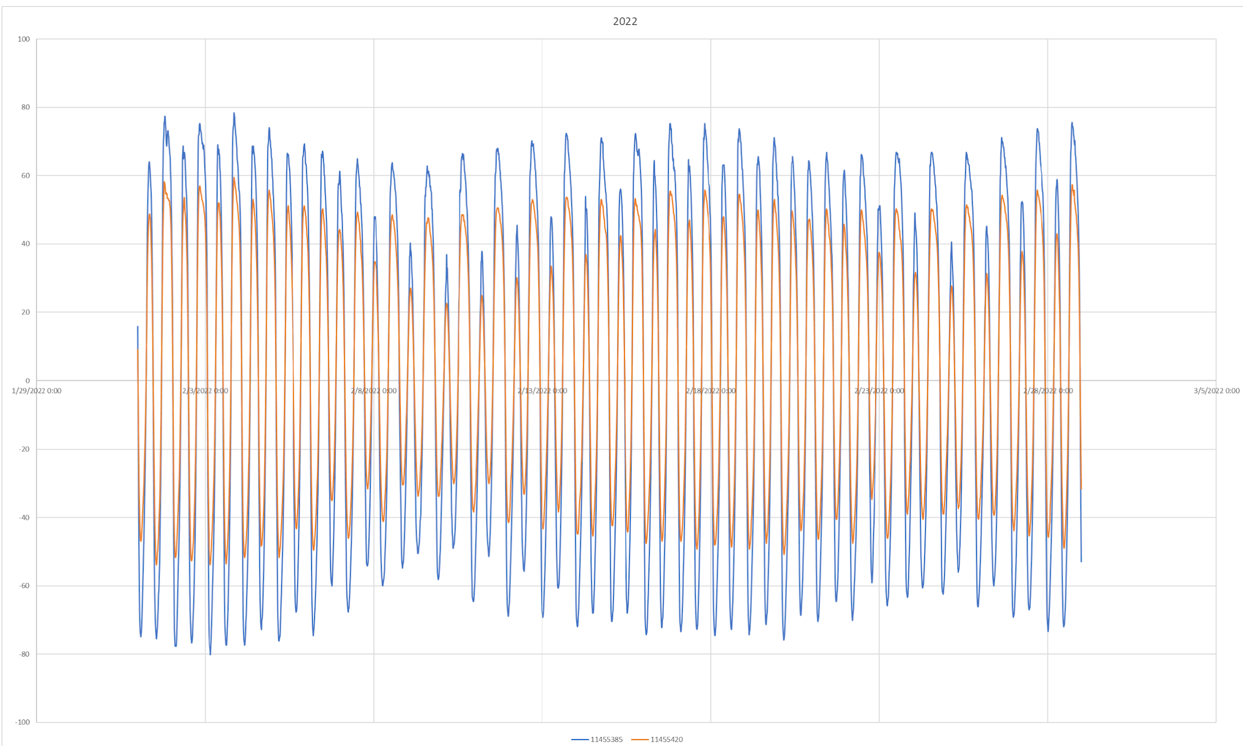
Figure 12: Mean water velocity for discharge in ft/s for stations 11455385 and 11455420.

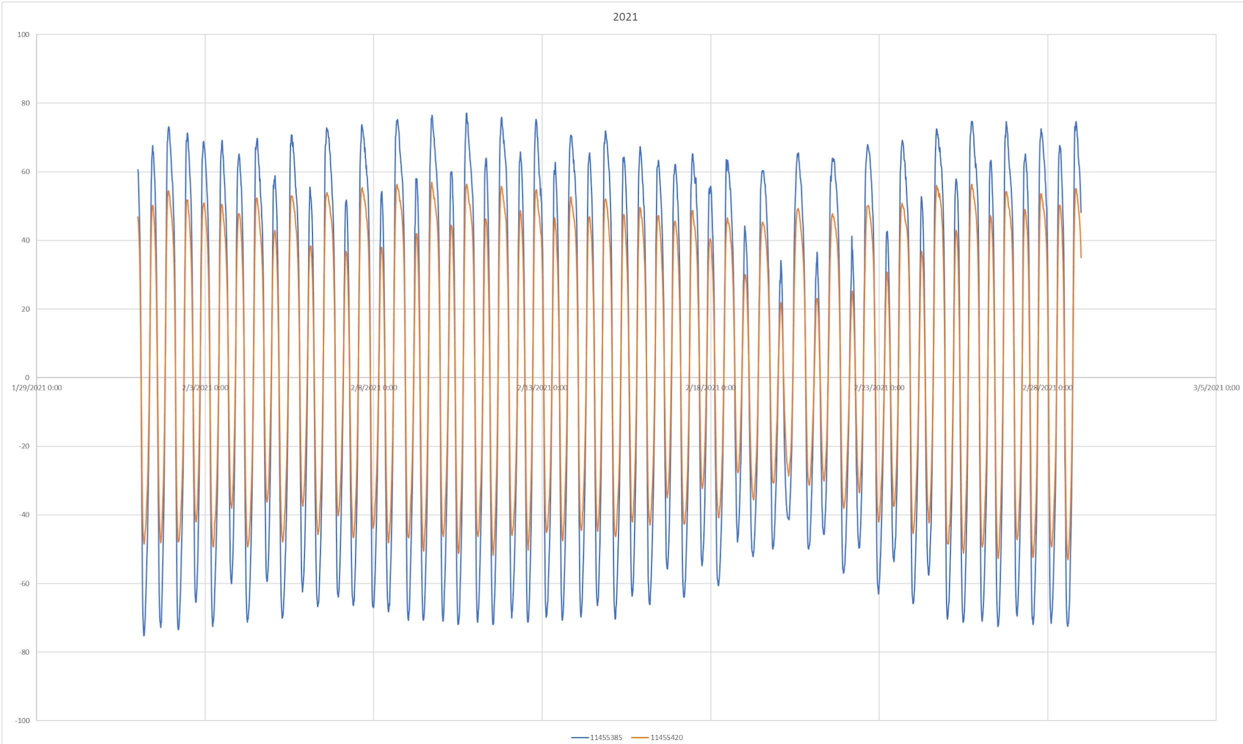
Using the flow rate and water depth data, flow velocity can be determined using the following equation:

$$Q = AV$$

where Q is the volumetric flow rate (m3/s), A is the cross sectional area of flow (m2), and v is the velocity (m/s).

Another piece of information found from the paper by Kurofomi et al, was that a majority of the ripe female delta smelt were found in the month of February. Thus, to simplify the data calculations, data from the stations was only extracted from the month of February. Only data from the last three years were used for comparison between the two stations as seen in figure ###.





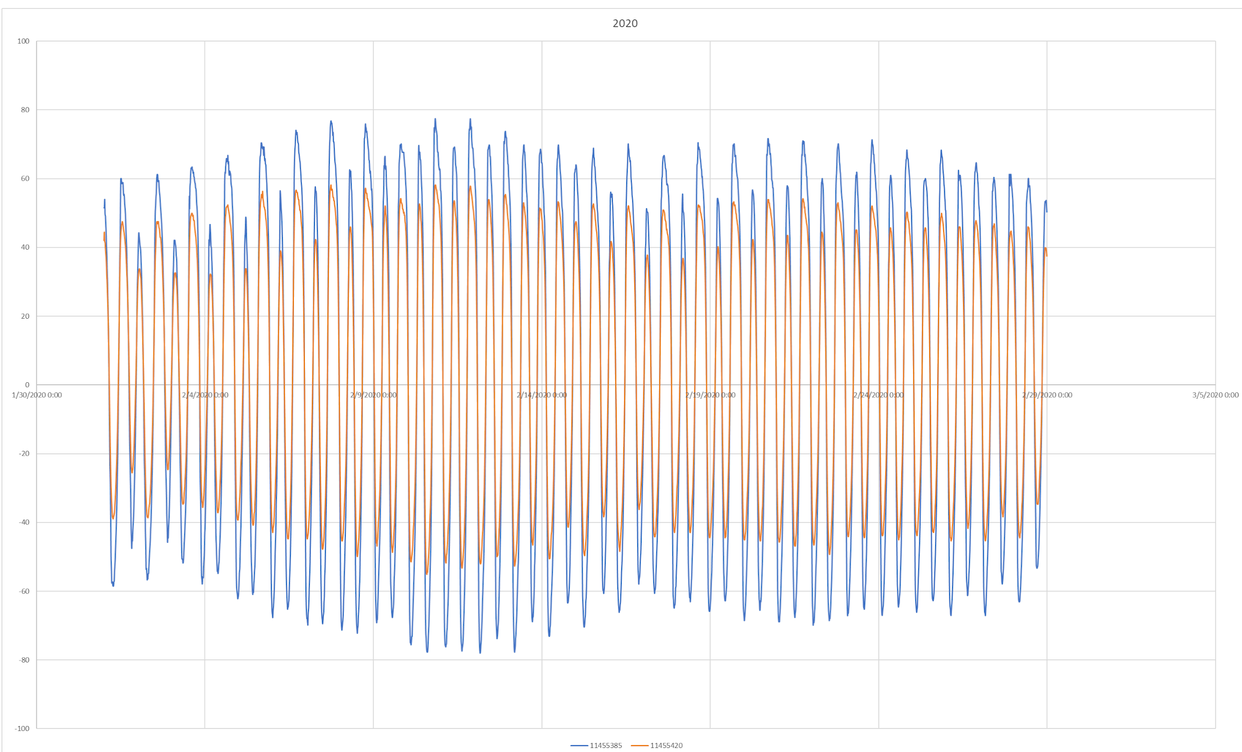


Figure ##: Mean flow velocity for discharge in cm/s for stations 11455385 and 11455420 for February 2020, 2021, and 2022.

From the graphs shown, it can be seen that water velocity in the first station, 11455385, would have adequate flows for deploying the egg frame box, while the second station wouldn't have adequate flows. With this information, I've decided to select a location near the first station to deploy the egg frame box.

Results:

To quantify the water velocity data further to be able to find the best 4th day span to deploy the egg frame box, each flow velocity data was given a value depending on its respective velocity as shown in the following table:

V>60cm/s → 1
V>50cm/s → 0.75
V>25cm/s → 0.4
V>10cm/s → 0.1
V<10cm/s → 0

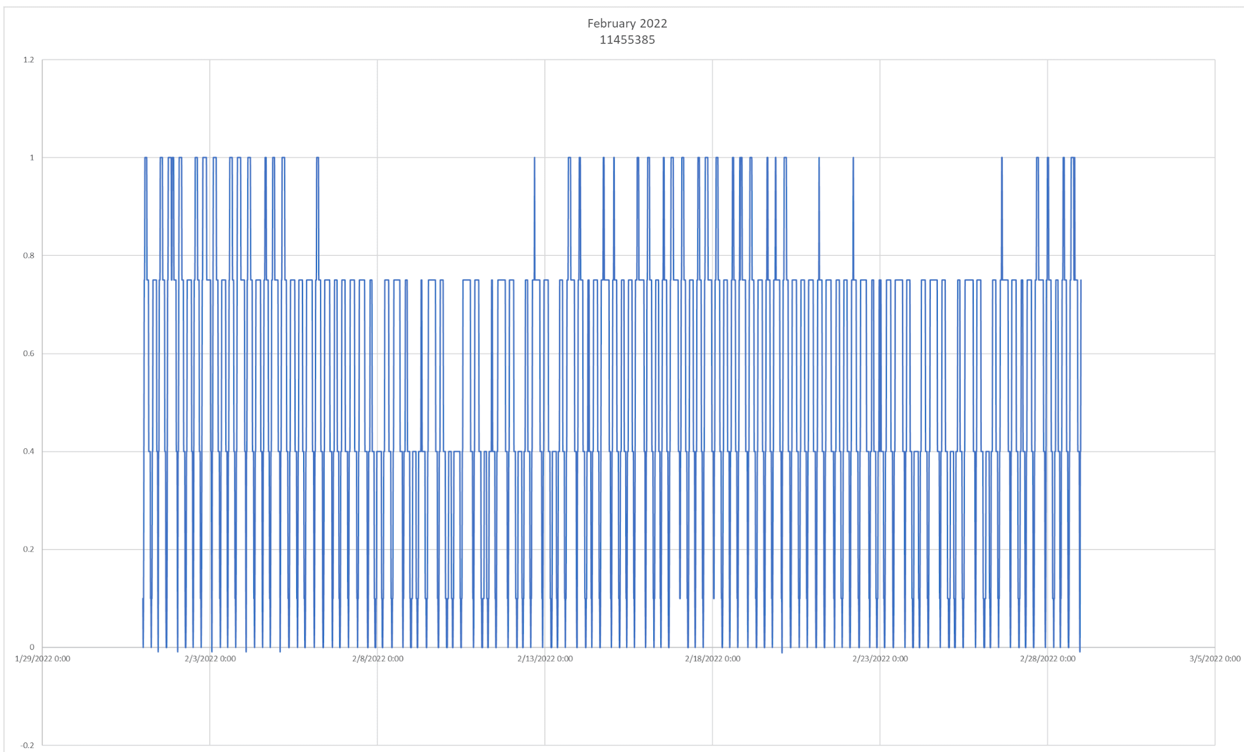


Figure ###: Given values inputs for month of February 2022 in station 11455385.

The values are inputted into a linear graph, as seen in figure ###, to determine which days would be best to deploy the egg frame box.

Discussion:

With the information gathered, it can be concluded that the egg frame box used for hatching wild, larval Wakasagi in Japan can also be deployed in the Sacramento/San Joaquin Delta, more specifically, Cache slough, for the hatching and releasing of wild, larval Delta smelt.

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