Newport Back Bay Fluid Flow

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Abstract

Water qualities including oxygen, salinity, temperature, and pH are all important qualities of estuaries and coastal systems. They are important to the many animals and aquatic species that can be found there. At the Newport Back Bay, an estuary in Southern California, the mixture of freshwater and saltwater is a delicate environment that many animals have adapted to. We monitored the fluctuations in these qualities throughout the bay using a refractometer on water samples, and also a multi-probe to collect data in the bay over several weeks. We analyzed the effect of fluid flow in the bay and how it disperses these qualities to be able to predict what effects would be seen if there were to be a change in the inflow from either the San Diego Creek (SDC) at the northern end of the estuary, or the Pacific Ocean at the southern end. Fluid flow determines the spread of freshwater and saltwater in the bay, and thus the unique estuarial results caused by this interaction.

1 Introduction

In this study, we analyzed fluid flow of Upper Newport Bay (UNB) and Lower Newport Bay (LNB) to predict water flow patterns and dispersion of various nutrients such as salinity, pH, temperature, and dissolved oxygen. Being an estuary, UNB is a mixture of freshwater and saltwater, making the fluid flow within the bay to be very important to the ecosystem. The salt and oxygen levels are critical to the development and health of the aquatic animals. In addition to the many fish and plants that prosper in the bay, there are also many species of bivalves that thrive in varying conditions of fresh and salt water. In the LNB, dredging is taking place to allow the passage of ships to the harbor. The water flow then disperses and spreads the uplifted sediment throughout the bay, disturbing the settled shellfish, plants, and fish.

Within the next decade, the Irvine Water Company plans on increasing the San Diego Creek (SDC) water flow into the UNB by ten-fold, dramatically increasing the flow of freshwater into the bay [11]. This new change of water flow can affect the sensitive bivalves and other animals in their relationship to the habitat. There have been many extensive studies into the affects of decreasing the amount of freshwater flow into an estuary, such as in San Francisco, which clearly depicts a negative outcome [1]. Such results include a reduction in natural nutrients and shellfish populations with the introductory of predatory marine animals. Although there are not many studies showing the effects of increasing the freshwater flow, it is predictable that there will be a negative outcome. The results could include reduced salinity and die-offs of salinity sensitive plants, fish, and shellfish. Many of the species that reside in UNB are endangered including the light-footed clapper rail. With the possible change in food supply and nutrients available due to the change in freshwater flow, these species may lose their homes and become extinct.

The dredging of LNB is viewed as a necessary action needed to allow movements of ships in the bay, and it is believed that any negative effects it has on the surrounding environment are negligible. Changes to water quality due to pollutants mixing with sediments, and changes in sediment transport are a couple effects known to be caused by dredging [6]. The water flow carries and disperses the uplifted pollutants and can be transferred to areas that were previously healthy. Although LNB is not the location for most of the endangered species living in the bay, it is still a location for fishing and for people to take part in water activities. The water flow dispersement of sediments and pollutants spreads throughout the bay, hurting the aquatic animals and the well being of people.

Modeling the bathymetry and fluid flow throughout UNB and LNB is essential in understanding the dispersement of freshwater from the SDC and pollutants from dredging. This knowledge will help predict the impact on the estuary and the many species that live there, ensuring their survival and ability to thrive.

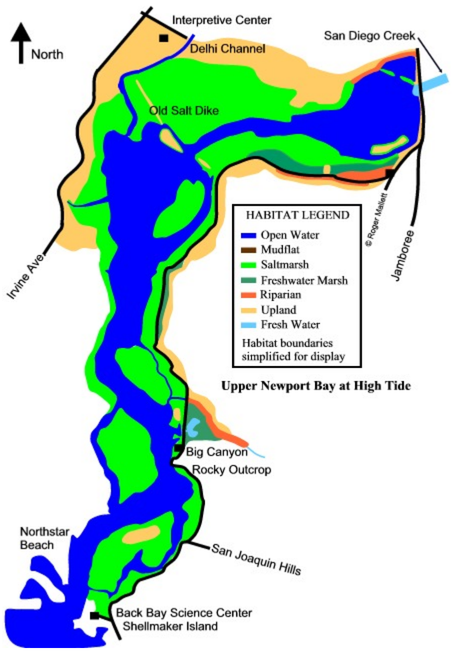
In particular, the many species of bivalves that reside in UNB and LNB are essential to the health of the harbor. The bivalves, which include various clams and oysters, mainly prey on the millions of phytoplankton that live in the water, which controls their numbers to a reasonable amount. If the bivalves were removed from the harbor due to inhabitable water conditions, the phytoplankton population would increase beyond control, thus causing eutrophication in the water [10]. This will eventually lead to hypoxic conditions, meaning a depletion of oxygen in the water, which would cause the other aquatic animals to lower in number. Thus, it is important to ensure that the water in the UNB and LNB is favorable for the bivalves.

Bivalves and other aquatic animals depend upon favorable water quality levels of oxygen, pH, salinity, and temperature. Modeling the variations of these nutrients is also beneficiary to see any fluctuations of the nutrients based on time, space, and fluid flow. It will enable us to have a better understanding of the environment in general, and make predictions of change in water quality based on a change of saltwater/freshwater fluid flow.

2 Methods

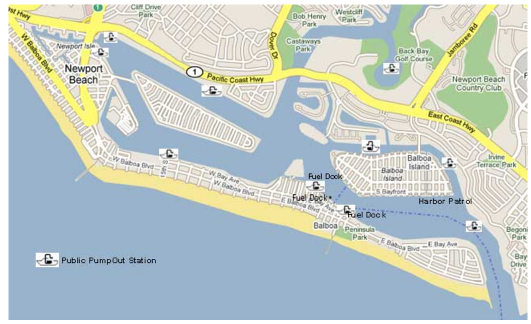
2.1 The Site

The Newport Bay is located in Southern California between San Diego and Los Angeles, and is broken up into the Upper Newport Bay and Lower Newport Bay. The UNB is classified as an estuary because it has the freshwater of the San Diego Creek flowing into it and the saltwater from the Pacific Ocean (through the LNB). It is about 5.5km in length and spreads about 1000 acres of total protected habitat. Since estuaries are unique combinations of fresh water and salt water, the UNB is home to many endangered species placing it in the protection of California Bays and Estuaries Policy [7].



Upper Newport Bay [4]

The LNB is the connecting harbor to UNB and the Pacific Ocean. It is a semi-artificial harbor formed by dredging during the 1900s. Most of the area is covered with private homes, docks, and businesses, including the two main islands Lido Island and Balboa Island. The 39.8 square miles of LNB is constantly in need of dredging for the upkeep of the harbor and the 9000 boats that reside there.



Lower Newport Bay [2]

2.2 Modeling Equations

A basic understanding of fluid flow was first needed to approach our problem. The St. Venant equations (SVE), or also known as the shallow water equations, provides a more theoretical approach to fluid flow. The SVE are a set of hyperbolic partial differential equations that describe the flow below a pressure surface in a fluid. The SVE is a combination of the continuity equation

$$V\frac{\partial A}{\partial t} + A\frac{\partial V}{\partial x} + b\frac{\partial h}{\partial t} = 0$$

and the dynamic, or momentum equation

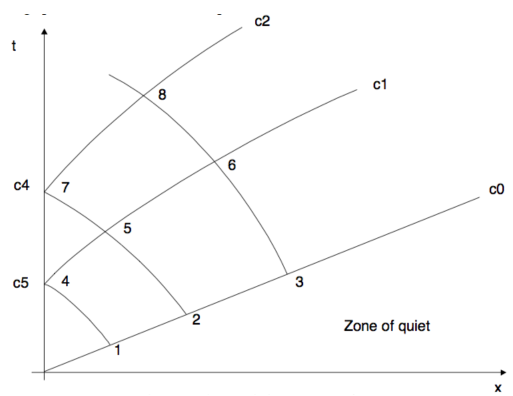
$$g\frac{\partial h}{\partial x} + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} = g(i - j)$$

where A is the cross-sectional area, h is the depth of flow, V is the mean velocity, b is the width of the top of the section, x is the position of the section measured from the upstream end, t is time, g is gravity, and ρ is the mass density of the fluid.

In this form the equations cannot be solved explicitly, having us use the more convenient characteristic form of the SVE which is

$$\frac{d(v \pm 2c)}{dt} = g(i - j) \quad \text{for} \quad \frac{dx}{dt} = (v \pm c),$$

where c is the celerity, or speed of the wave. With this method, numerical solutions can be found.



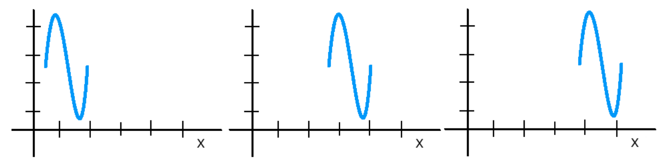
In the figure above, the graph represents a flood wave at the upstream end of a channel. The zone of quiet represents the part of the stream waiting for a disturbance, or effect from a flowing wave. For any point numbered on the graph, the velocity and celerity can be determine numerically by the two previous points having direct connection to it. For instance, the solutions for point 6 can be found using the velocity and celerity from points 3 and 5. The SVE provides a conceptual understanding for the basic introduction of fluid flow [9]. It allows us to solve numerically for specific points, but is difficult to apply for a grander scale.

In order to model the fluid flow within the Newport Bay, two partial differential equations were combined. These equations were the transport equation and the diffusion equation (based on Ficks Law of Diffusion).

The transport equation

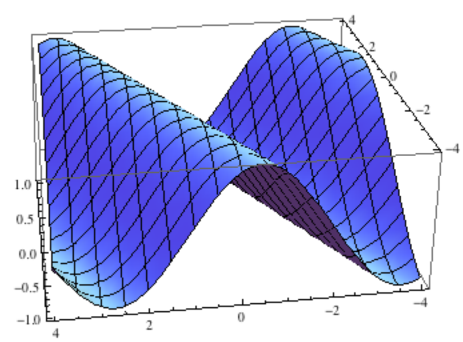
$$\frac{\partial u}{\partial t} = -k\frac{\partial u}{\partial x}$$

(where u is the concentration, t is time, x is the position, and k is a constant) is a linear, first order, partial differential equation with constant coefficients. It takes a function and moves it along an axis over time keeping the function in its same form.



Note that the equation simply shifts the graph

This equation is relevant to our eventual fluid flow model of the Newport Back Bay because it mimics the transitional nature of moving water. Much like how the transport equation represents a certain function moving in the positive direction of the x-axis (distance), so does the Newport Back Bay water current. We were able to solve this derivation using Mathematica and created a three-dimensional Model of the transport equation.



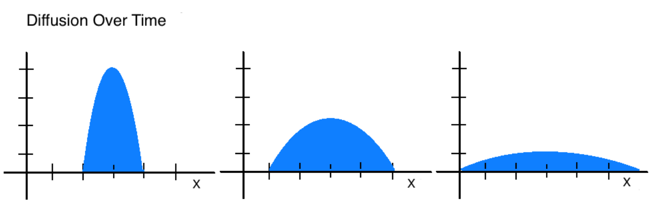
Transport Model

Unfortunately, the transport equation does not account for the spontaneity of hydrogen molecules in water. For this reason, solely using the transport equation for our research was not an option. In order to account for the random movement of water, we incorporated Ficks Law of Diffusion.

The diffusion equation

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x}$$

(where D is the diffusion coefficient, u is concentration, x is position, and t is time) is a partial differential equation describing the density dynamics in a material undergoing diffusion. In our case, our material is the water within the Newport Back Bay. The diffusion equation was derived using the continuity equation and implies that no matter is generated or removed. Graphically, the diffusion equation depicts the distribution of a substance over a distance x.



It should be noted that the model shows a perfect distribution over distance x, which is not entirely appropriate for our data but is a decent place holder.

Combining both the transport equation and diffusion equation we have a germane partial differential equation that is relevant to our research. The combination of the transport and diffusion equation

$$\frac{\partial u}{\partial t} = -k\frac{\partial u}{\partial x} + D\frac{\partial^2 u}{\partial x}$$

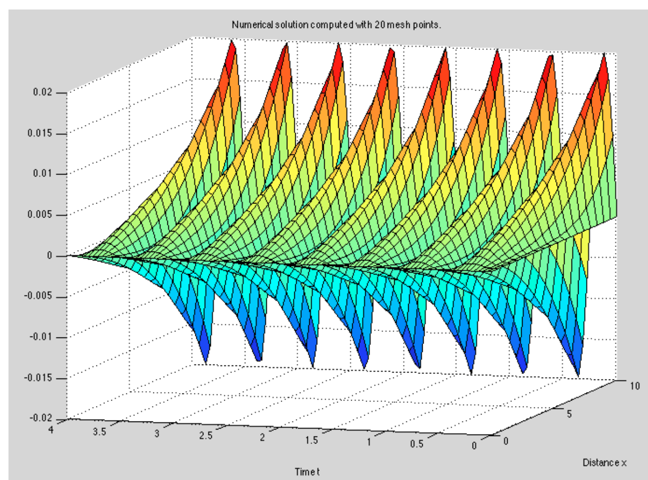
(where u is concentration, t is time, k is a constant, and D is the coefficient of diffusion) with the initial condition of $u(x, 0) = const.$ and boundary conditions of

$$u(0, t) = 0 \tag{1}$$

which represents the river flow and

$$u(L, t) = a * sin(bt) \tag{2}$$

which represents the changing tides from the Pacific Ocean with an oscillating function [3]. This equation is better suited to model water flow because it combines the forward acting motion of water with the transport term, but also accounts for the dispersion of water particles with the diffusion term. With this equation, we see a better projected water flow below.



Model of the Fluid Flow

In the above graph of the water flow, the following is represented: Along the "Distance X" axis, range is from 0 to 10, indicating the position of the San Diego Creek to the Pacific Ocean; the "Time t" axis represents 4 days; and the z axis indicates the height of the waves or water flow. From the graph there are two peaks and two troughs per day, which shows the high and low tides per day. These oscillations are of a higher values towards the ocean because it is greater affected by the tides, where the San Diego Creek end is not.

Although it produced a somewhat accurate model of the The Newport Back Bay fluid flow, there are some limitations. Multiple factors were not included such as salinity, temperature, and conductivity. It is our hope that in the future we will be able to generate a working equation that takes into account these aspects.

2.3 Data Collection

In order to properly model the fluid flow in UNB and LNB, it is important that we test the properties of the water. We need to view the varying qualities of the water to deliberate whether the water flow has effect upon those qualities. Unfavorable water quality caused by the water flow will negatively affect the bivalves and other aquatic species residing in the bay. With this data we can create models that depict the differences in the quality throughout the bay depending on time and space.

To collect the data needed to know the varying levels of pH, oxygen, salinity, and temperature throughout the bay, multiple trips were made there to physically collect water samples for later analyzation. Multiple methods and locations of water samples were taken between July 19th through August 13th, and with the aid of the Back Bay Science Center (BBSC), canoes and a pontoon boat were made available to us.

On July 19th, a group of three teams each used a canoe to travel in the bay. Team 1 traveled to the LNB, team 2 canoed within the UNB, and team 3 navigated into the restricted area of the top end of UNB with permission from the BBSC. Each team had about 20 plastic small sampling containers in which to collect water. At various time intervals, each team would take a water sample, and label it with the time and location using a combination of maps and GPS. In addition to the sampling done with canoes, a fourth team rode bikes along the UNB trail. Samples from this team were taken at various locations along the waters edge, and also charted the locations and times. The water sampling took place from about 9 am to about 12 pm. Once finished, the water samples were all measured with a refractometer provided by the BBSC to measure salinity.

On August 7th, a team went to the BBSC and used the pontoon boat to better extensively collect samples of the bay. We used a multi probe called the Manta-2 Multiprobe lent to us by Eureka Environmental Engineering which collected data including conductivity, temperature, pH, and dissolved oxygen. The probe was capable of setting how often and for what duration to collect data. It was also capable of being connected directly to a computer to upload the data found. The sampling done on the pontoon trip was broken up into two different ways. First, beginning at the BBSC at about 9 a.m., the probe was attached to the boat and towed alongside while it was submerged in the water. The probe was set to collect data every 1 minute, and every minute we would mark our position with a GPS. This process continued until reaching the SDC in the UNB. The second method using the probe began where the first method left off. We no longer kept the probe submerged, but instead collected data about every 1000 feet recording our time and location. We changed the settings of the probe to collect data every 2 seconds for the time we set it to "start" and "stop". At each new location, we lowered the probe into the water until it reached the floor of the bay, or until we ran out of tether to let it down, then slowly pulling the probe back up. The probe was collecting data at a single point but was detecting any change in the water based on its depth. This process continued until about 2 pm, traveling down into LNB, around both the Lido and Balboa Islands, so as to extensively collect data for all of Newport Bay.

In addition to the pontoon trip, the probe was used on additional days throughout July ***th and August 13th. For these various days, certain docks were located throughout the UNB and LNB. We attached the probe to the dock and submerged it into the water about one meter down. The probe would be set to collect data about every 5 minutes for the duration of 24 to 48 hours. The locations of the docks included Hill's Boat Service in LNB, Pearson's Point in lower UNB, a buoy in UNB, and a couple other locations spread throughout the bay. The overnight data collection would allow for comparison of different locations with more time and space parameters. Compared to the other methods of data collecting with the probe, the overnight method provided data on different values caused by the change from day to night, and also from the tides.

Multiple comparisons were made to verify the data collected was accurate. Water was taken from the dock of the BBSC and we used the refractrometer to test the salinity, and we verified that it matched the salinity of the water taken close to the BBSC with the sampling containers. Water from the same location was then taken and diluted, to ensure that the refractrometer would indicate the change in salinity. The multi-probe was connected to a computer and was placed in controlled water before being used in the bay. It correctly read and inputed data for the time designated, and when the probe would be pulled out of the water, it immediately showed a change in all the fields it was collecting data. Thus the information accumulated was the most accurate first-hand data to be collected.

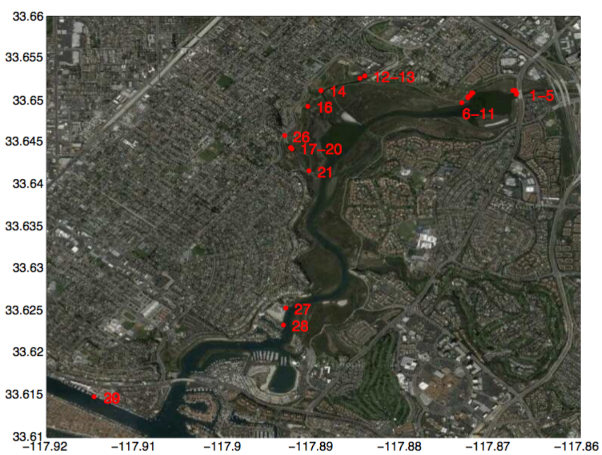
As it turned out, we collected our data when the weather was similar to the other data collection days. This may sound like a trivial notion, but the weather can have a major impact on the water properties, especially in regards to the percentage of oxygen. For example, if the weather was cloudy every day, then the amount of sunlight reaching the water would be decreased. Thus, the phytoplankton that depend on the sunlight for photosynthesis will die and diminish the amount of oxygen that the phytoplankton produce overall [5]. Fortunately for us, it was sunny most days we collected research, so if there was a decrease in oxygen levels in our collected data, we know that it does not have to do with variable factors such as the weather.

2.4 Data Results

Once we finished collecting our data, we proceeded to upload and analyze the data at UC Irvine at the Center for Complex Biological Systems. There we connected the probe's PDA to the computer and it automatically uploaded a spreadsheet with all the data it collected, including the pH, conductivity, oxygen, temperature, depth, and time. Below is a small sample of the collected data.

DATE	TIME	Temp deg C	SpCond uS/cm	HDO %Sat	pH units	ORP mV	Depth m
8/4/12	12:29:17	24.29	39980	107.9	7.91	227	0.44
8/4/12	12:32:34	25.38	39880	114.8	8.04	216	0.32
8/4/12	12:35:32	25.07	39360	168.9	8.03	213	0.42
8/4/12	12:38:38	25.07	39320	125.9	7.92	214	0.38
8/4/12	12:42:08	24.94	39510	105.9	7.92	211	0.45
8/4/12	13:11:18	24.93	44100	104.6	7.88	192	0.44
8/4/12	13:13:32	25.38	44090	103.5	7.87	187	0.41
8/4/12	13:16:44	25.41	43980	101.1	7.87	192	0.39
8/4/12	13:18:34	25.83	43770	101.9	7.88	196	0.4
8/4/12	13:21:19	26.08	43250	105.9	7.88	200	0.39
8/4/12	13:32:00	26.64	42170	111.6	7.95	206	0.32
8/4/12	14:07:20	27.89	3255	102.7	8.24	159	0.49
8/4/12	14:15:40	28.06	3453	103.6	8.13	177	0.52
8/4/12	14:37:03	26.1	21070	92.2	7.71	209	0.53
8/4/12	14:51:16	25.57	46670	102.3	7.33	182	0.37
8/4/12	14:52:36	25.59	46670	130.3	7.21	102	0.36
8/4/12	14:58:41	24.56	6090	104.8	8.09	24	0.35
8/4/12	15:01:03	24.44	4030	103.1	8.12	-32	0.37
8/4/12	15:05:05	22.48	29750	98.6	7.61	68	0.38
8/4/12	15:06:55	23.1	9644	83.7	7.97	29	0.34

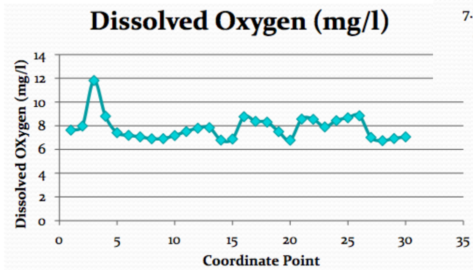
With this data, multiple charts, maps, and graphs were put together to show the variations, if any. First, to have a general scope of where exactly our data was taken, a map with increasing numbers indicate the general pathway and sites we took.



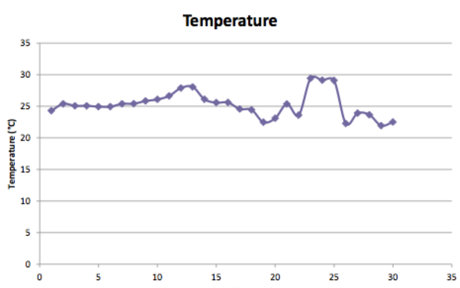
The majority of the data collecting sites were taken in the center of the bay, and a few were taken closer to the side of the channel. We wanted more data from the center of the channel because it would better reflect the effects of the fluid flow, and we wanted to be able to more accurately compare the changes from UNB to LNB. A chart was made indicating the temperature, conductivity, pH, and dissolved oxygen according to the sites on the map.

Index	Temperature	Conductivity	pH Levels	Dissolved Oxygen
1	24.29	39980	7.91	7.63
2	25.38	39980	8.04	7.97
3	25.07	39880	8.03	11.81
4	25.07	39360	7.92	8.8
5	24.94	39320	7.92	7.41
6	24.93	39510	7.88	7.19
7	25.38	44100	7.87	7.06
8	25.41	44090	7.87	6.9
9	25.83	43980	7.88	6.91
10	26.08	43770	7.88	7.17
11	26.64	43250	7.95	7.51
12	27.89	42170	8.24	7.79
13	28.06	3255	8.13	7.84
14	26.1	3453	7.71	6.79
15	25.57	21070	7.33	6.88
16	25.59	46670	7.21	8.76
17	24.56	46670	8.09	8.37
18	24.44	6090	8.12	8.3
19	22.48	4030	7.61	7.5
20	23.1	29750	7.97	6.78
21	25.35	9644	7.86	8.56
22	23.59	37580	8.15	8.54
23	29.41	2185	8.13	7.9
24	29.12	6577	8.22	8.43
25	29.08	7274	8.2	8.67
26	22.27	6823	7.82	8.84
27	23.9	1983	7.75	7.01
28	23.65	46720	7.83	6.74
29	21.94	47770	7.95	6.92
30	22.5	47540	7.94	7.06

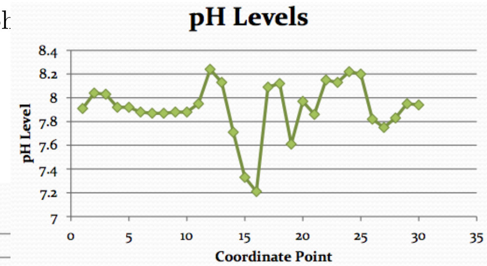
With this data, we were able to generate graphs reflecting the change in water quality from the SDC moving south towards the Pacific Ocean. In each graph the x-axis represents the index, or the site number marked on the map. The following were the graphs generated:



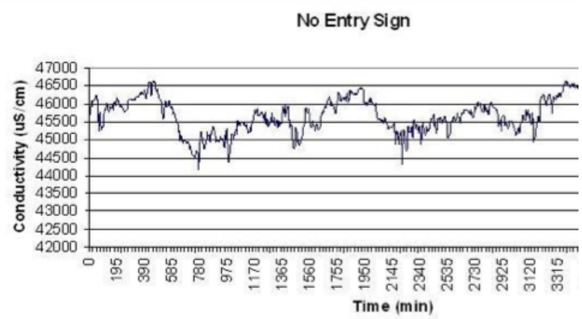
In the above graph it is seen that the dissolved oxygen remains fairly stable from the UNB to the LNB.

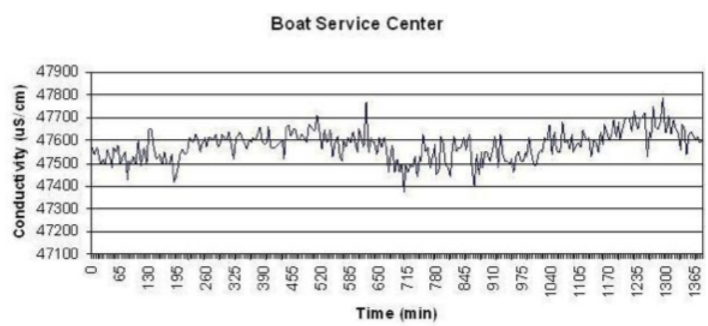


Temperature as well remains fairly stable throughout the bay, with only minor temperature increase towards the Pacific Ocean. This may be caused by the Lido and Balboa Islands in LNB, which may slow the water flow. Whereas UNB has no major land objects like islands to impede the speed of the flow. Thereby the water is constantly moving unable to keep the heat as well as the flow in the LNB does.

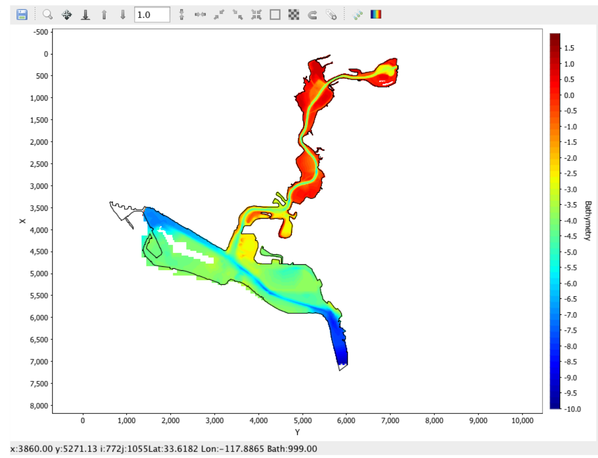


The pH levels is seen to fluctuate as the sites move closer to the Pacific Ocean, which could be due to the greater interaction of freshwater and tidal saltwater in the LNB.





Conductivity doesn't measure the amount of salt in the water directly. Conductivity measures how easily electricity can pass through the water. Since salt water is a better conductor than freshwater, the higher the conductivity, the larger amount of salt is present in the water. The variations of conductivity is very apparent in the two graphs shown above. The first figure shows the conductivity taken by the probe at a "No Entry Sign" in the uppermost part of UNB, and has about an average conductivity of 45500. The second graph shows the conductivity at a boat service center in the LNB fairly close to the Pacific Ocean which has about an average conductivity of 47700. These graphs reflect our predictions that the salinity of the water will increase as we move closer the Pacific Ocean.



3 Software

3.1 ELCOM and CAEDYM

In order to properly model the Newport Back Bay, we needed a software that would be able to use the specific data from the bay, including the floor of the bay, so that we would be able to predict any changes that the flow of water may have on the surrounding environment. Fortunately, Dr. Felix Grün (UCI Cell and Developmental Biology) was able to acquire a software from the Centre for Water Research, based in Western Australia, that has the capability to meet all of our goals. This software, entitled *Estuary, Lake and Costal Ocean Model* (ELCOM) uses bathymetry data and boundary conditions in order to predict the the hydrological changes in a given aquatic environment. Our group generated a bathymetry model using data gathered from Resource Management Associates, Inc. (RMA) when conducting a water quality study in 2008 [8].

Another similar program lent to us by the Centre for Water Research was the *Computational Aquatic Ecosystem Dynamics Model* (CAEDYM), which focuses more on the ecological studies of a given environment.

In order to run simulations in either ELCOM or CAEDYM, the user application *Aquatic Realtime Management System* (ARMS) was also acquired from the Centre for Water Research. ARMS reads the bathymetry data (which is in the format of rows of numbers) and converts it to a user-friendly map that is color coded to show the depth of the bay at a certain point. It is also possible to edit the bathymetry data through ARMS as opposed to trying to edit the lines of code that ELCOM is dependent upon.

Unfortunately, due to time constraints and the complexity of understanding how the program works, we were not able to model Newport Bay using these programs as we intended. Various errors did not allow us to effectively use the program in the time frame given, especially considering we did not successfully install the program until halfway through the research.

4 Conclusions and Future Work

The freshwater and saltwater mixture of the Newport Back Bay estuary is a unique, delicate environment, reliant upon the water flow to distribute the nutrients. The conductivity and salinity distribution throughout the bay is of vital importance, which is highly fluctuant from the UNB to the LNB. The bay's inflows of water from the SDC and the Pacific Ocean need to be monitored to ensure the survival of animals that have adapted to the varying water quality distribution through the bay. The variations of pH, oxygen, and temperature are also of importance to the ecosystem of the bay, but may be seen to have greater variations with a greater change in flow of water for from either the SDC or Pacific Ocean. This can be modeled with further testing and utilization of ELCOM and CAEDYM, which we hope to use to model the UNB using the given bathymetry data.

To be able to make better models and graphs, we wish to continue collecting data of the bay over a longer period of time. For instance collecting data during the spring months will provide data of a higher freshwater inflow from the SDC with rainfall and mountain runoff. We plan on uploading all this data into our modeling software to generate better models and movies depicting the fluctuations of nutrients over time, as well as the water flow throughout the same given period to make correlations. These models can then be distributed to the Back Bay Science Center and commercial industries for their use and protection of the Newport Back Bay.

References

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