Estuaries in Motion: Teaching Estuarine Flow Concepts through Video

by

Marina R. Cameron

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Environmental Engineering
(Honors Scholar)

Presented May 21st, 2015
Commencement June 2015

AN ABSTRACT OF THE THESIS OF

Marina Cameron for the degree of Honors Baccalaureate of Science in Environmental Engineering presented on May 21st, 2015. Title: Estuaries in Motion: Teaching Estuarine Flow Concepts through Video.

Abstract approved: ____

James Lerczak

A short (approximately 8 minute) video was created to explain key concepts in estuarine flow and numerical modeling of estuaries for high school students. Animation, real picture videography, and numerical model outputs were used to illustrate how scientists use physics and physics models to understand how flow in an estuary changes in space and in time. Tidal cycles, weather, and estuary shape were introduced as important environmental factors that govern the way the water flows in an estuary. Learning outcomes include student's ability to identify estuarine currents as a three-dimensional, time varying process and understand that numerical models are useful tools to understand how currents in an estuary work. The video was provided as curriculum for high school environmental science and physics teachers.

Key Words: Estuarine Modeling, Numerical Modeling, Estuary, Estuaries, Fluid Dynamics, Flow analysis

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Marina R. Cameron, Author

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Introduction

A short video was created to explain key concepts in estuarine flow and numerical modeling of estuaries for high school students. Multimedia animation and real-time videography illustrate how a numerical model is developed and used to solve real-world questions about estuaries using physics and physics models to understand how flow in an estuary changes in space and in time. The video caters to high school learning standards and provides a visual representation of models to address different learning styles. The video describes the conceptual development of numerical models used to describe the currents and mixing of an estuary. The video emphasizes how the laws of motion and which come from basic physic concepts govern the movement of water in an estuary. It is designed to give students a chance to take a look at the interconnectedness of the estuary as a system, as well as obtain a better understanding of fluid movement in the estuary.

Tidal cycles, weather, and estuary shape were introduced as important environmental factors that govern the way the water flows in an estuary. Learning outcomes include student's ability to identify estuarine currents as a three-dimensional, time varying process and understand that numerical models are useful tools to understand how currents in an estuary work. The video was provided as curriculum for high school environmental science and physics teachers.

Objectives

The objective of this project is to provide a basic understanding of estuarine current movement and modeling to high school students.

Learning outcomes

Learning outcomes include students' ability to identify currents as a three-dimensional time varying process, describe the environmental factors that control currents and should be included when building a numerical model, and identify several uses for a numerical model of an estuary. Students should be able to identify that a pressure gradient force from the tide drives fluid flow in and out of the estuary and that river outflow has seasonal variability.

After watching Estuaries in Motion, the student should be able to

- Define and understand salinity variations in an estuary
- List three uses for an estuarine numerical model
- List three environmental forces that control currents in an estuary
- Identify that currents in an estuary vary with space and time.

A lesson plan and quiz outlining more detailed learning outcomes, example answers and suggested grading are attached in Appendix I and II.

Materials and Methods

Production of the video consisted of real time video, visualizations made by a numerical model, and two-dimensional animation. The video was fully scripted and voice over from several voice actors was recorded. A curriculum was developed including a lesson plan, quiz, and additional learning activities. Major steps of the pre-production, production and post-production are discussed below.

Scripting

The video was scripted to include specific language to clearly communicate learning objectives. It was designed to improve students' digital media literacy about numerical models, as they are a significant tool used by scientists to understand complex environmental conditions. A script was assembled starting with research done to investigate national and state learning benchmarks for high school student understanding of earth systems. The scripting process included many iterations to organize the concepts to be portrayed.

It was important to avoid jargon in the video script in order to assure the message be communicated to high school students. It was assumed that the majority of students would have relatively low scientific estuarine vocabulary, so at the risk of oversimplifying and alienating students with a solid background in river or oceanic hydrologic processes, jargon was kept to a minimum. Concepts were presented at various levels of complexity to allow for students to grasp important pieces of understanding.

A submarine was used as a mental model to help students interpret water flow and identify how flows can be important for navigation. Critical estuarine concepts such as environmental factors that influence currents, depth and buoyancy were discussed.

The video script and storyboard are attached in appendices III and IV. Basic sound equipment was used in a sound room to record the script as voice over. Voice over correlated with the visual components created using real-time video, numerical model visualizations and two dimensional animation, which are discussed in the following sections.

Real Time Video

Video-equipment and a camera team were essential to the footage production of the video. High definition Cannon camcorders were used to capture video of the estuary

The video used time lapse of the tidal flats to show time variability of flow throughout a day, highlighting changes in the estuary over a tidal cycle. A challenge in the project was that camcorders used did not all have a time-lapse setting that could run dawn until dusk. To solve this issue, camcorders were connected to power and one was set to continuously save to a hard drive in order to capture a full tidal cycle. Preparation for recording included research for high tidal range, obtaining a secure location for filming time lapse of tidal flats with access to power, and assembling a camera team to capture clips from the estuary. Weather was also an important aspect in filming, as a gray day is not as visually appealing to an audience. Fortunately, the criteria aligned on a day, and the camera team traveled to Newport, Oregon before dawn to capture a full day of footage. The time-lapse camera ran dawn until dusk.

To film a satisfactory time-lapse, the weather could not be foggy or rainy, there had to be a high disparity between the high and low tide amplitudes, and filming had to run dawn until dusk. To predict weather and tidal amplitude, weather forecasts and tidal charts published by NOAA were consulted (Yaquina, NOAA). The tidal coefficients in tide tables show the difference in height between the consecutive high and low tides at a given area (The Tides, 2015). This is important for visual appeal to show a satisfactory change between the covering and uncovering of tidal flats. As tides are formed by gravitational forces of the sun and moon, tidal coefficients are calculated from the parameters of the celestial bodies (The Tides, 2015). This concept is explained more thoroughly in the discussion section on tides.

The video was filmed in various locations along the Northwest and Southwest Yaquina bay estuary. The time lapse video was filmed from a private home North of the mudflats. Filming also took place on the Highway 101 bridge across the estuary, from the Newport Marina South of the estuary, and off of Port Dock North of the estuary.

Numerical Model Visualizations

A numerical model of the Yaquina Bay Estuary was produced by Emily Lemagie using The Finite Volume Community Ocean Model (Chen, 2003, 2006) as part of her graduate research at Oregon State University. Visual representations produced using this model were used to show the currents in an estuary and the transport of water-borne materials in the estuary initially released from various points in space and time into the model velocity field.

Animation

Investigation of several animation styles was crucial to select a proper medium. . The Figures 1, 2 and 3 below were made with Blender, Sketchup, and Adobe Flash respectively to investigate the user interface and the applicability of animation programs. The final video used Adobe Flash, as it produced a satisfactory animation given the time and personnel constraints of this project.

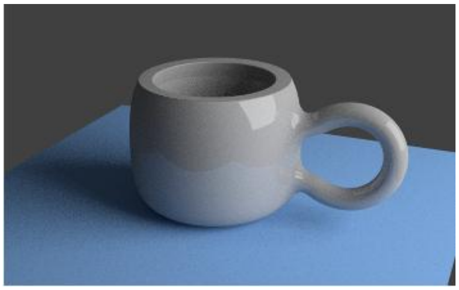


FIGURE 1: MUG MADE IN BLENDER

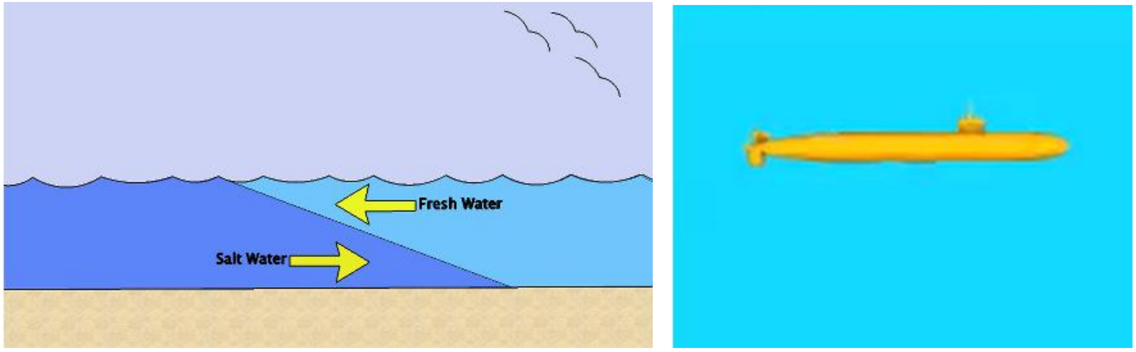


FIGURE 2: SCENES MADE IN GOOGLE SKETCH UP

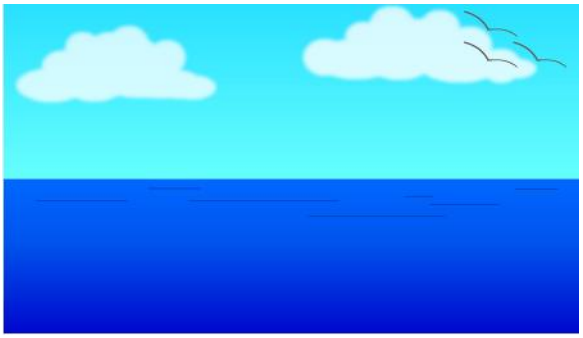


FIGURE 3: SCENE MADE IN ADOBE FLASH

Animation was used to display how currents in the estuary change in time and space. It was utilized to describe the salt water wedge that forms from density differences between fresh and salt water. It displayed how water flows at different speeds depending on depth within the estuary and time of the day.

In the video, an animated submarine was used as a mental model to display the physical forces that impact a parcel of water and its resulting movement. This was assumed to be a more interesting way to discuss and track the flow velocities of fresh water and salt water compared to describing the motions of a water parcel. It is useful to note that this toy submarine would not exhibit exactly the same behavior as water would, as it is a solid object with structure, however, if it is at the same density as the water, is relatively small and not self-propelled, it can be carried through an estuary much like a water parcel would be. Figure 4 below depicts the representative submarine shown with a path that matches the conceptual water path.

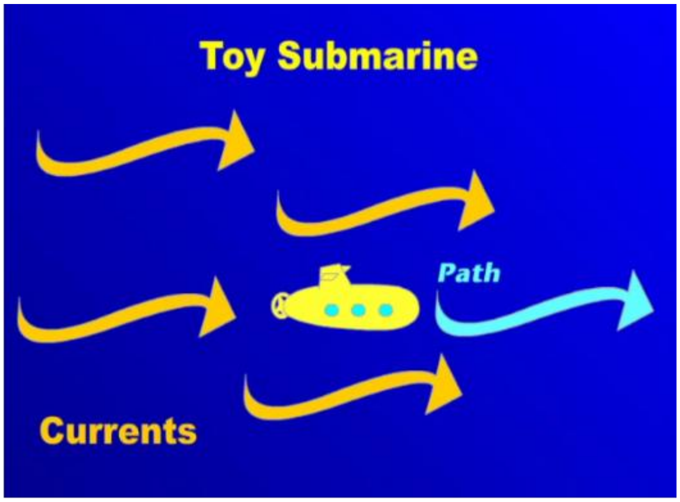


FIGURE 4: A SCENE DEPICTING THE REPRESENTATIVE SUBMARINE AS A WAY TO DESCRIBE CURRENTS IN AN ESTUARY. THE SUBMARINE IS SHOWN WITH A PATH THAT MATCHES THE CONCEPTUAL WATER PATH.

Provided Curriculum

A quiz with questions pertaining to the learning outcomes was provided to teachers in order for teachers to identify important learning outcomes from the video. Important concepts were identified by committee after reviewing state and national science and ocean literacy standards.

Results

The video can be accessed at the following link. It is 7 minutes 45 seconds in duration.

https://www.youtube.com/watch?v=g9xCSv3PZ6Y&feature=youtu.be

The advantage of a video is that it accommodates for both visual and auditory learning styles instead of one or the other. The styles of teaching these concepts are covered further in the following discussion section.

A lesson plan, learning outcomes and a quiz were also produced to provide a complete set of materials that is ready-to go for classroom use.

Discussion

In this section, basic concepts introduced in the video are explained in more detail. This section may be referenced by a teacher or student in order to gain more understanding about the estuary system. Furthermore, the development process and concept of the video is discussed.

Estuaries

Estuaries occur where a freshwater river meets saline waters of the ocean. Estuaries are highly dynamic bodies of water which change over different time scales. Significant time scales for an estuary are the daily change in tidal cycles, the spring/neap change in tidal range, the daily change in freshwater flow due to precipitation, and the seasonal change in freshwater flow, which can be driven by snowmelt or seasonal variations in precipitation.

The shape of the estuary also controls how water flows. Water through deep cut channels moves much faster than water over tidal flats. Furthermore, the water very close to the edge and bottom of the estuary typically moves slower than the water near the middle due to the frictional forces acting on the water from the non-moving estuarine bed. This is called a frictional boundary layer in a velocity profile, where it is assumed that water molecules directly in contact with the edge are held in place by frictional forces and turbulence causes drag on the water above the bottom. Away from the edge of an estuary, and out of this boundary layer, the velocity of water flow increases and may exhibit a variety of flow regimes.

The shape of the estuary also affects currents and transport properties of the water. The dynamics of an estuary play a part in pollution dilution, planktonic food dilution, and larvae distribution. Understanding the dynamic flow of estuaries can help us predict how an estuary might respond to changes.

Yaquina bay

The Yaquina Bay estuary is a small estuary about midway down Oregon's coast. It has a 252 square mile watershed (Bauer, 2011) and a 1.80 meter mean range of tide (Swanson, 1977). The Yaquina bay receives about 70 inches of rain per year, mostly between October and March, however rainfall is inconsistent and large variations in freshwater flow are common (Bauer, 2011).

Currents are important to estuarine ecosystem and biology. Developing a knowledgebase about the interactions contributing to currents can provide valuable foresight for estuarine management efforts such as native oyster rehabilitation or pollution reduction. Using numerical models to analyze the physics behind flow velocity enhances our understanding of the estuary as a system of physical interactions, and can aid us in evaluating the factors that cause change in the estuarine ecosystem.

Momentum and gravity

The movement of water can be understood through laws of motion. The density difference between salt water and fresh water can cause two layer flow where the top and bottom layer behave differently. This interaction between the fluids of different densities is critical in an estuarine numerical model. This density difference is introduced in the video as the salt water wedge caused by the buoyancy force.

The buoyancy force can be understood through Archiemedes' principle, where an upward buoyant force equal to the weight of the fluid displaced is exerted on a body immersed in water. If the object is more dense than water, the gravitational force from the weight of the object overcomes the upwards buoyancy force and the object sinks. Alternatively, if the object is less dense than the water, the buoyancy force overcomes the weight of the object and the object will float.

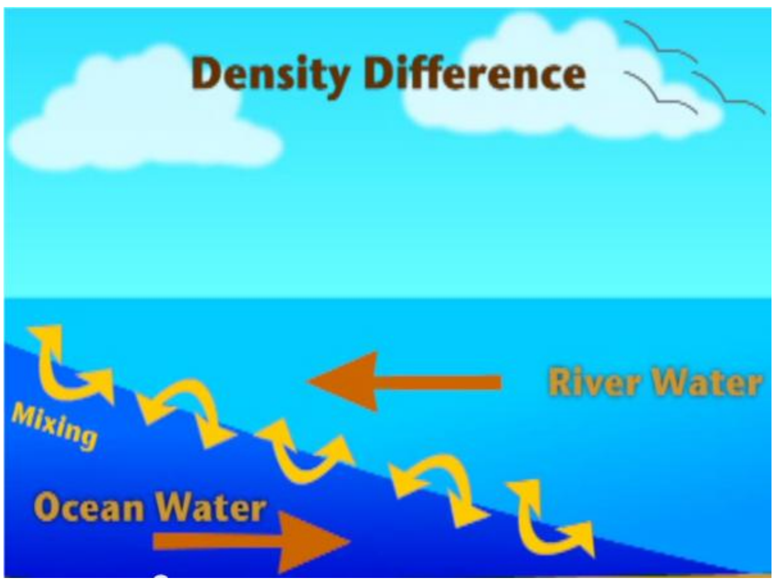
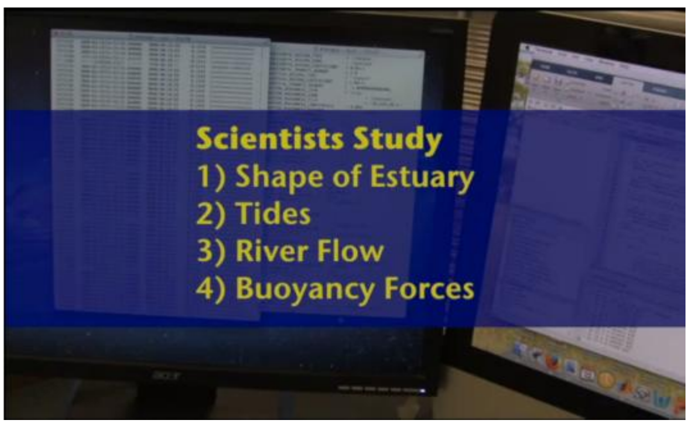


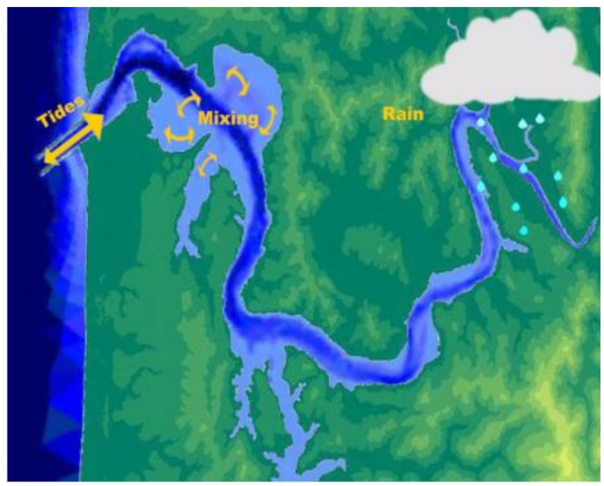
FIGURE 5: A SCENE DEPICTING THE SALT WATER WEDGE THAT OCCURS DUE TO DENSITY DIFFERENCES BETWEEN SALT WATER AND FRESH WATER.

Physics equations and principles come into play in fluid dynamics. The basic equations used in estuarine flow models are the Navier-Stokes Equations. These equations consider pressure, viscosity and mixing to describe the motion of viscous fluid (Munson, 2013).

To understand estuarine flow, we must recognize key driving forces and constraints. These include the shape of the estuary, the cyclic flow from tides, continuous flow from river and buoyancy forces which dictate interactions between salt water and fresh water. The shape of the estuary can change due to sediment transport and is typically measured locally by boat surveys with echosounders, however, satellite generated LIDAR can also be used. The cyclic flow of tides is predicted from lunar and solar cycles. The continuous flow from the river is influenced by precipitation, which varies on a storm by storm basis but also on a seasonal scale. These main driving forces are depicted in figure 6 (a) and (b) below.



(A)



(B)

FIGURE 6 (A) AND (B) DEPICT SCENES IN THE VIDEO DESCRIBING WHAT A SCIENTIST WOULD STUDY IN ORDER TO LEARN MORE ABOUT THE FLOW CHARACTERISTICS WITHIN AN ESTUARY. THEY WOULD CONSIDER THE SHAPE OF THE ESTUARY, TIDES, RIVER FLOW (WHICH IS INFLUENCED BY PRECIPITATION) AND BUOYANCY FORCES DRIVEN BY DIFFERENCES IN WATER DENSITY.

Environmental factors influence the estuarine system. For example, seasonal variability of river flow contributes to changes the salinity gradient in the estuary. There is a balance between mixing and the stratifying effect caused by density differences between freshwater and saltwater in the system. Mixing in an estuary is primarily from turbulence, which is generated by the frictional exchange of momentum when water is moved along the bottom of an estuary.

When there is low flow from the river, stratification is weaker and turbulent forces generated from the tidal interaction with the estuarine floor cause high amounts of mixing in the estuary. With relatively more mixing, a horizontal salinity gradient forms, such as what is shown in Figure 7 and the river water more slowly diffuses out of the estuary. With high river flows, sharper change between salty and fresh water occurs. This causes a more vertical gradient and freshwater might just flow out of the estuary at the surface. Salinity gradients formed not only depend on river flow, but also depend on buoyancy forces, the tides, and the shape of the estuary.

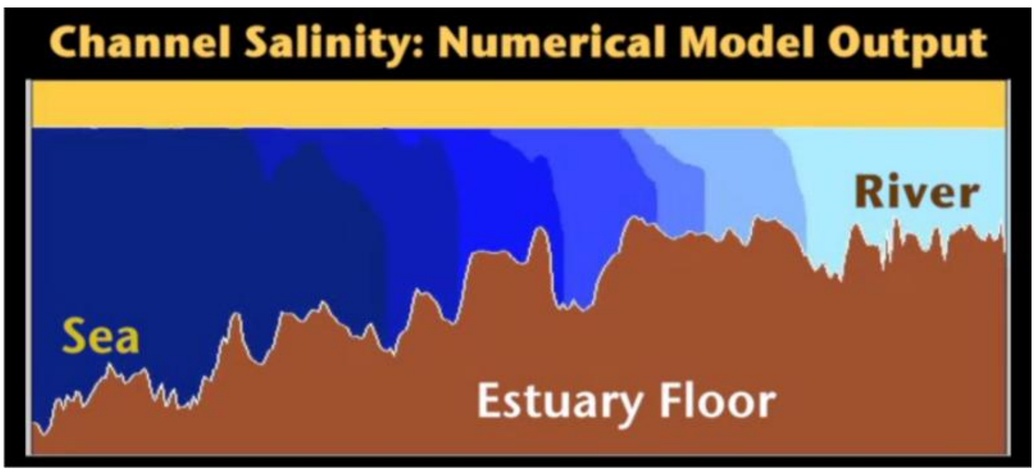


FIGURE 7: A NUMERICAL MODEL OUTPUT DEPICTING A PREDICTED SALTWATER WEDGE ALONG THE LONGITUDINAL PROFILE OF THE ESTUARY. SALT WATER IS DEPICTED AS DARK BLUE AND FRESH WATER IS DEPICTED AS LIGHT BLUE. HUES IN BETWEEN SHOW THE MIXING OF THE RIVER AND SEA WATER. IN THIS FIGURE, HIGH AMOUNTS OF VERTICAL MIXING OCCURS AND A HORIZONTAL GRADIENT IS OBSERVED. RIVER WATER MOVES OUT OF THE ESTUARY BY MIXING WITH OCEAN WATER.

Tides

Tides exchange nutrients in an estuary and provide a flow pattern essential to many estuary biota. An explanation of tides began to be developed with Newton's laws of gravity. Bernoulli's work with fluid motion and what he called "hydrodynamics" also contributed to what we now call the equilibrium theory of tides. This is a simplified model to help us understand tidal generation. In this theory, the main forces on the system are gravity, which attracts the Earth and the moon toward each other, and centripetal force, which involves the revolution of the earth and moon around their common center of gravity (Swanson, 1977). These forces are balanced and create two tidal bulges on opposite sides of the earth (one directly toward the moon and one directly away from it). There are two tides a day because the earth rotates through both bulges.

The Sun also has gravitational pull effecting tides, although its tide generating force is only about 48 percent as strong as the Moon's. The combination of the Sun and moon contributes to longer- term changes in the range of tide, meaning the difference between successive high tide and low tide. When the Sun lines up with the moon in relation to the earth, such as with a full moon and a new moon, tides have a more extreme range between high and low tides. These are called Spring Tides. Alternatively, when the sun is perpendicular to the moon in relation to the earth, like with the first and third quarter moon, the range of tides is small. Low-range tides are called Neap Tides.

To add another couple levels of understanding, the moon has an elliptical orbit around the earth, and tides vary depending on where the moon is at the point of orbit. Also, the angle between the Moon, Earth, and Sun makes a difference in tidal range and amplitude. With all of these cycles occurring simultaneously, it is important to understand that they interact with each other to influence the tide.

This tidal theory is a model for understanding tides. In reality, many other factors come into play. For example, ocean depth, fluid viscosity, placement of continents and rotation of the earth are additional factors that control tide dynamics, which don't get accounted for in the basic model described above (Swanson, 1977). A tidal model can be used to find the tidal elevation off shore to find the pressure gradient force in order to develop predictions of estuarine currents.

The pressure gradient force is a force that acts in the direction from high pressure to low pressure. Difference of sea level from the tides causes this pressure gradient to occur. When the weight of water causes a high pressure, water tends to flow from high to lower pressure. When the tidal level is high offshore, the pressure gradient force drives water flow into the estuary, and when it is a lower elevation offshore than in the estuary, then the pressure gradient force drives water out of the estuary, creating a cyclical back-and-forth flow.

Cyclical changes of the water elevation from tides expose and cover some areas along the estuary bank. Shallow areas during high tide are often exposed during low tide. The Yaquina estuary has shallow areas called mudflats which are exposed and covered in a diurnal pattern as shown in figure 8 (A) and (B) below from a scene in the video. A unique ecosystem has developed in these areas of periodic submersion.

(A) (B)

FIGURE 8: (A) AND (B) DEPICT TIDAL FLATS OF THE YAQUINA BAY ESTUARY DURING HIGH AND LOW TIDE

Outreach

Higher education must make a significant effort to incorporate emerging technologies, such as numerical modeling, into their curriculum. According to a journal article from the British Journal of Educational Technology published in 2013, “The failure to embrace emerging technologies in higher education courses can lead to pedagogies that risk alienating a generation of learners.” (Herrington, 2013). The video and lesson plan developed in this thesis encourage understanding of numerical models as important scientific tools that have room for design development and improvement.

Model basics

Numerical models are a modern and important method used to study fluid movement, such as the complex systems that make up estuaries. They are typically designed to develop informed solutions through iterative cycles of calculations, testing and refinement. Computers are great tools for performing these tasks in order to model what the flow in an estuary might look like. After a model is finished, it is important to perform a reflection on the data and its usefulness. As technology and understanding of environmental systems increases, current models can be used to produce more accurate future model design principles and enhance solution implementation (Maynard, 2002).

All empirical models have error, however, when making flow predictions, having models can be invaluable. Models are only as accurate as the structure of knowledge they are built upon, their assumptions, and the spatial and temporal resolution. A model can be simplified to learn and test a theory. In predictive flow modeling, it is crucial to understand the extent of simplifying assumptions and their effect on the model. Also, the model resolution, or essentially the size of the model grid, influences the accuracy of a model. Choosing a higher resolution can greatly reduce the speed to which a computer produces solutions for a numerical model. Simplifying assumptions and the extent of the model grid must be balanced when using a model to study a system.

Numerical models are built by choosing the domain. A domain can be visualized as a grid with fluid analysis at nodes such as in Figure 9. The computer simultaneously solves fluid dynamics calculations for the parcels of water within the grid.

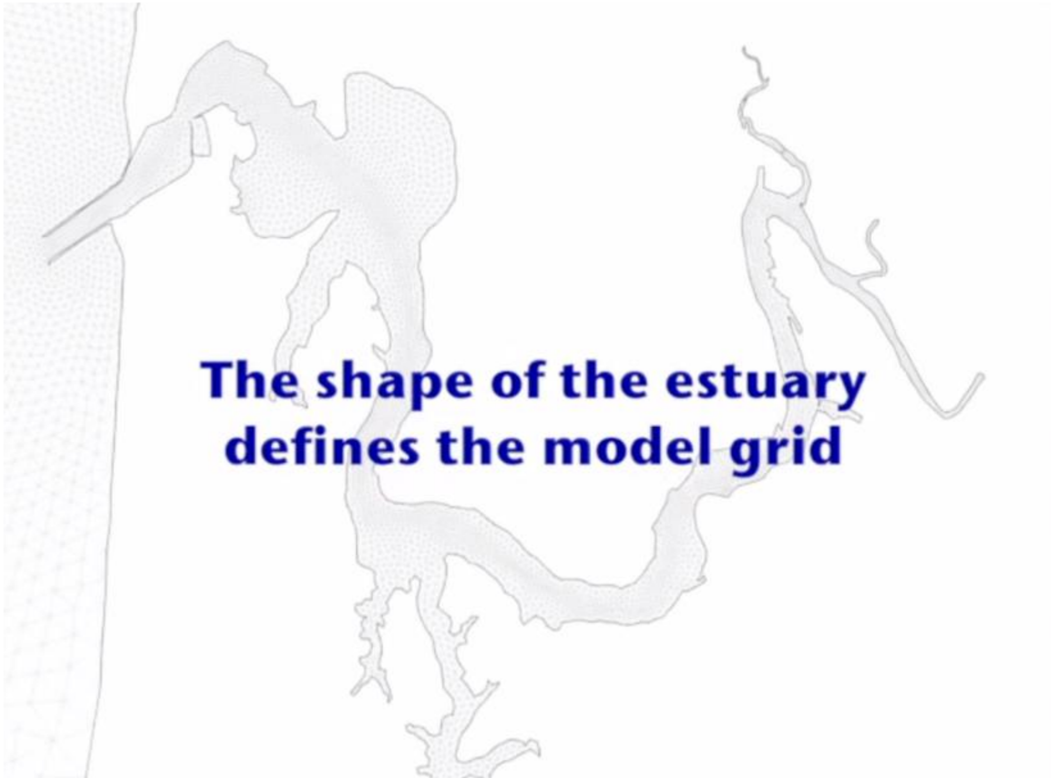


FIGURE 9: AN EXAMPLE OF A MODEL GRID. FLOW CALCULATIONS ARE PERFORMED ON PARCELS DEFINED BY GRID. THE SIZE OF THE GRID DETERMINES THE RESOLUTION OF THE MODEL.

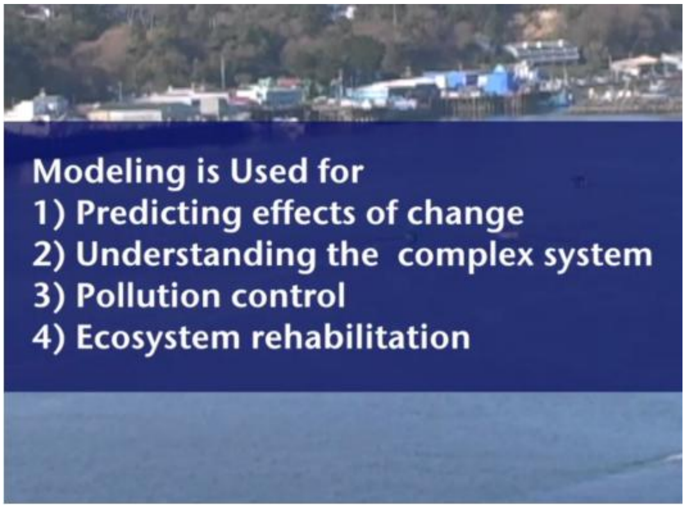
Importance of Numerical Models

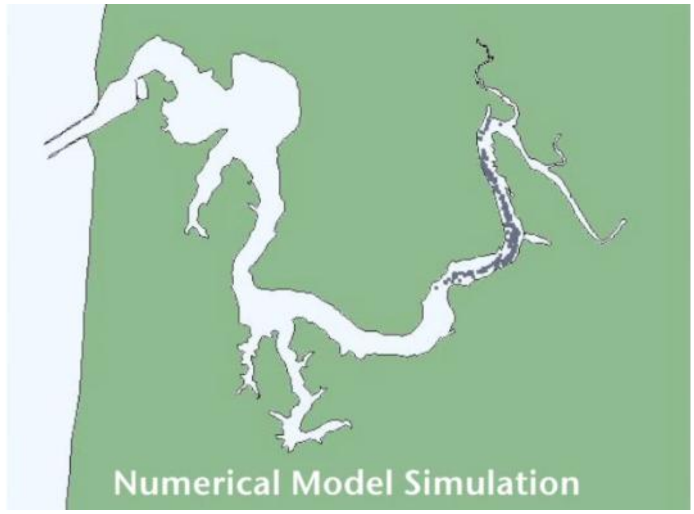
Numerical models use computers to generate solutions from physics and fluid dynamics principals to understand fluid flow in an estuary. It is a fundamental task using science as inquiry. Modeling can be used as an aid to guide native oyster rehabilitation so that the scientist can predict where to release oyster larvae. An estuarine model can help us understand the environment the oysters will be exposed to. It can help answer question such as: Where will the bulk of oyster larvae move in an estuary? Will they get trapped where water level is too low?

Will they be washed out to sea? What salinities will they be exposed to? What is the strength of currents they will be exposed to? These can help to optimize a location for oyster larvae release.

The model can also be used to track the fate and transport of pollution in the estuary. It can be used to estimate how fast the pollution will dissipate. Also, navigation and trade can be enhanced by a better understanding of how currents vary over time and space within the estuary. Furthermore, effects caused by planned or unplanned changes to the system can be better understood. The model can be used to study potential effects caused by landslides or development along the coast of an estuary. Figure 10 below depicts scenes from the video which display some potential uses for a numerical model (a) and how a model might be used for understanding pollution transport and dissipation (b). Figure 11 depicts a scene from the video in which orange dots representing toy submarines are released into the velocity field of the estuary.

It is important to note that an estuarine numerical model is not a completely accurate representation of currents. Models are only as useful as the assumptions that go into them. However, models don't necessarily need to be realistic to be useful. Sometimes, idealized models that use intentionally simplified physics or that have left out variables can be useful to study the relative impacts of different forces and to help develop the theoretical basis for observational work.





(A) (B)

FIGURE 10: (A) AND (B) DEPICTS SCENES IN THE VIDEO DESCRIBING WHAT MODELING CAN BE USED FOR. FIGURE 8(B) SHOWS A PARTICLE TRACKING MODEL SIMULATION THAT MIGHT BE USEFUL FOR REMEDIATION EFFORTS IN CASE OF POLLUTANT RELEASE.

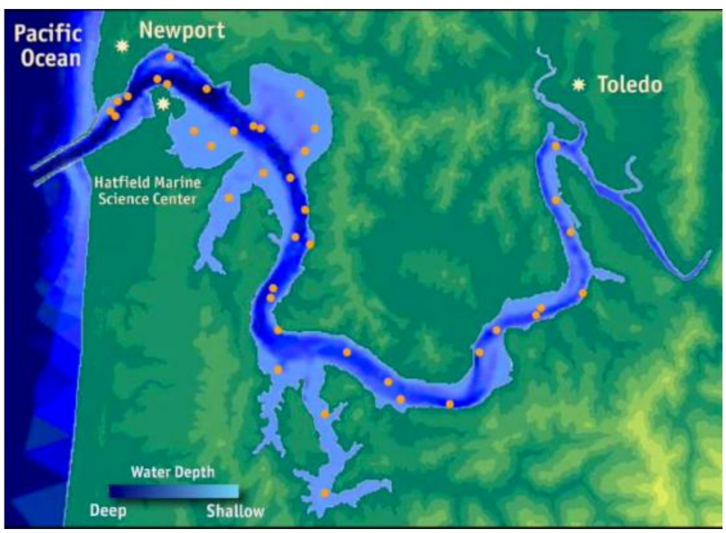


FIGURE 11: A SCENE FROM THE VIDEO THAT DEPICTS WHERE A SUBMARINE WOULD TRAVEL DEPENDING ON WHERE IT WAS INITIALLY PLACED WITHIN AN ESTUARY.

Conclusion

Estuaries are homes to diverse ecosystems, which rely on the currents and water movements, for instance, to deliver nutrients. On a basic level, currents just move in and out with tidal cycles, but other factors contribute to the currents in estuaries. Currents in an estuary change in time and space. In order to understand the movement of water in estuaries, we can use a model that can describe the whole system, as well as points within the system.

A numerical model is a sophisticated method to predict the currents of water in an estuary in a lot of places at once and over time. When this information is needed, it is much more cost effective and reasonable to use computer analysis rather than measurements for each place in an estuary.

Using a numerical model, one can simulate environmental variations such as winds, temperatures, and weather fluctuations and can simulate environmental events such as flooding or droughts. Numerical models can be used for experimentation to study an estuary under many different scenarios, including conditions that are not observed today.

It is important for young students to be exposed to the basics of flow modeling as these methods are used extensively in research. Models are constantly being developed and fine-tuned in the scientific community and developing a basic understanding of fluid flow modeling at a young age is valuable for developing a basic understanding of physical systems.

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Understanding Estuaries through Numerical Modeling

Oceanography & Physical Science

Grades 9-11

Background

This 8-minute video was created to explain key concepts in estuarine flow and numerical modeling of estuaries. Animation, real picture videography, and numerical model output were used to illustrate how scientists use physics models to understand estuaries. The video describes the interconnectedness of the estuary as a system, as well as the use of models for scientific inquiry, both being a part of National Scientific Education Standards. In the video, concepts such as the density difference between salt water and fresh water, and the pressure gradient force are explained. Tidal cycles, weather, and estuary shape are introduced as important environmental factors that influence the way scientists analyze flow in an estuary.

Discussion points: tidal ebb/flood, salinity, density, buoyancy, fluid physics

Learning Outcomes

Learning outcomes include students ability understand currents as a three-dimensional time varying process. After watching Estuaries in Motion, the student should be able to

- List main environmental forces in an estuary
- List uses for an estuarine numerical model
- Identify that currents in an estuary vary with space and time.

Activities

The following activities are options to aid in teaching this concept.

1. Estuaries in Motion: http://youtu.be/g9xCSv3PZ6Y
2. Salt water/freshwater density demo: http://www.youtube.com/watch?v=gx3yNjd7jE0
3. Tidal cycles: http://www.youtube.com/watch?v=9rkfk9TJ52I
4. Activities on NOAA website: http://estuaries.noaa.gov/

Evaluation

After the lesson, students should be able to identify uses for physics models in oceanography. They will be able to describe how the currents in an estuary affect each individual point the estuary and the system as a whole.

Materials

This lesson requires a television and internet connection to display an instructional video.

A quiz on major concepts of the video is provided.

Benchmarks

This Video meets the following State and National Benchmarks:

Unifying concepts and processes in science

- Evidence, models, and explanation.
- Change, constancy, and measurement

Science as Inquiry

- An appreciation of "how we know" what we know in science.
- Investigation to make systematic observations about the natural world, including the collection of sufficient and appropriate data.

Appendix II: Estuaries in Motion Quiz

Answer the following questions to the best of your ability. If you don't know the answer, it is better to write something than leave it blank.

1. How would you describe currents in an estuary?

   a. Example answer: The currents in an estuary change in time (for example, due to changes in river flow and tides) and in location (with strongest currents typically in the estuary channel and weaker currents over tidal flats). Currents at an individual point in the estuary affect the system as a whole. The shape, size, environmental interactions (such as tides, river flow, and buoyancy forces) cause currents in an estuary to change.

2. What are the primary environmental forces that affect currents in an estuary?

   a. Example Answer: Tides, river flow, and buoyancy forces

3. What are some ways that tides affect an estuary?

   a. Example Answer: Tides affect the pressure gradient force, mixing, and water level in an estuary.

4. As a scientist in the Pacific Northwest, you are asked to use a numerical model to predict how a shoreline construction project will affect the estuary as a whole. What is a relationship you could study using an estuarine numerical model?

   a. Example Answer: Changes in estuary currents, changes in salinity gradient

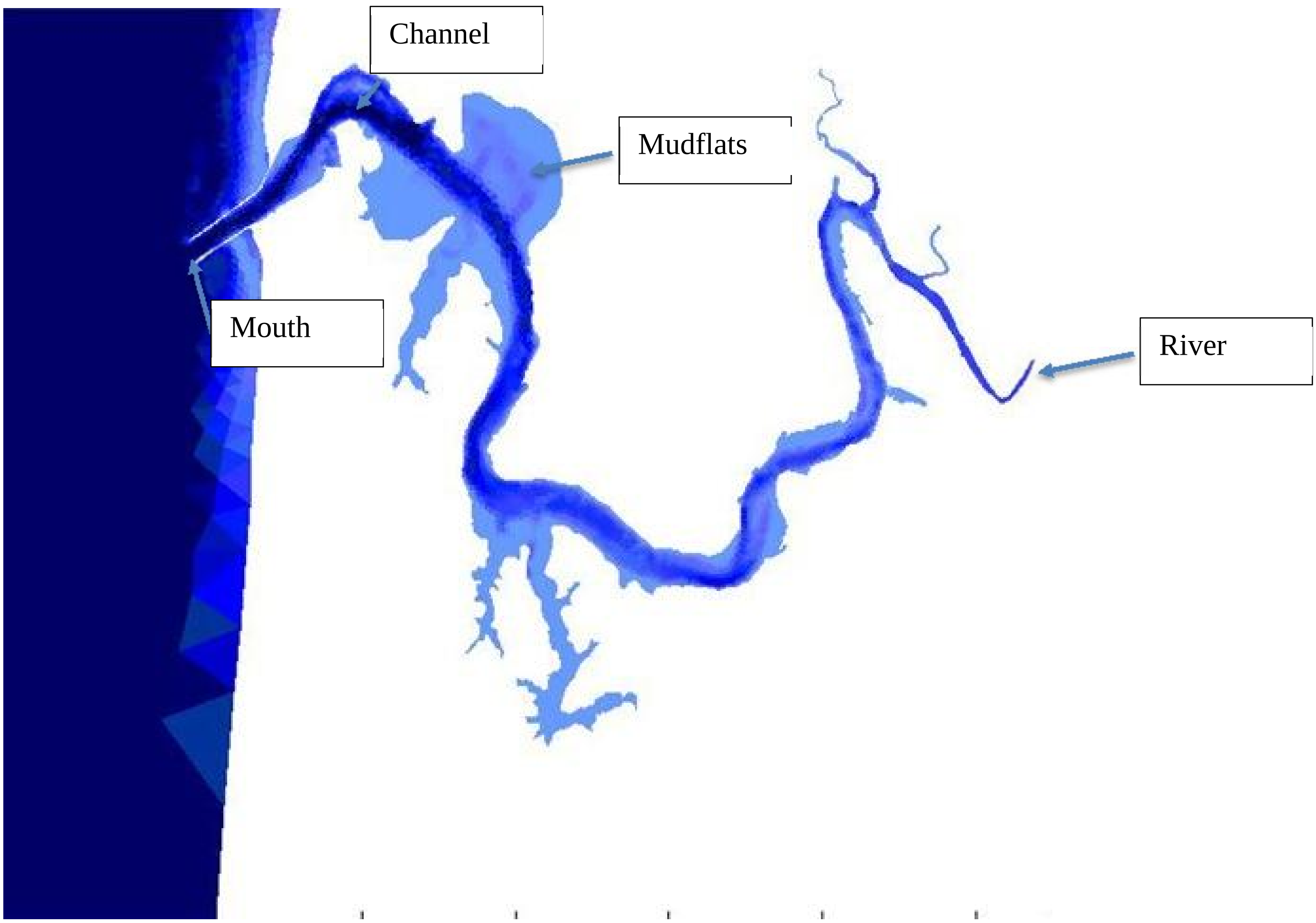
5. Describe Buoyancy forces

   a. Example Answer: Buoyancy forces are caused by differences in density between salt water and fresh water. The density difference impacts currents because salt water tends to sink below freshwater due to buoyancy forces.

6. How would you use a numerical model to study a pollution spill in an estuary?

   a. Example Answer: You could use a numerical model to track where the pollution will go and how it will be diluted by mixing within an estuary.

7. Below is the Yaquina bay estuary where deeper water depths are identified in darker blue and shallow water depths are identified in lighter blue. Identify a shallow mudflat, a deep channel, the river, and the mouth of the estuary.



Name: ___________________________ Date: _________________

Estuaries in Motion Quiz

Answer the following questions to the best of your ability. If you don’t know the answer, it is better to write something than leave it blank.

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3. What are some ways that tides affect an estuary?

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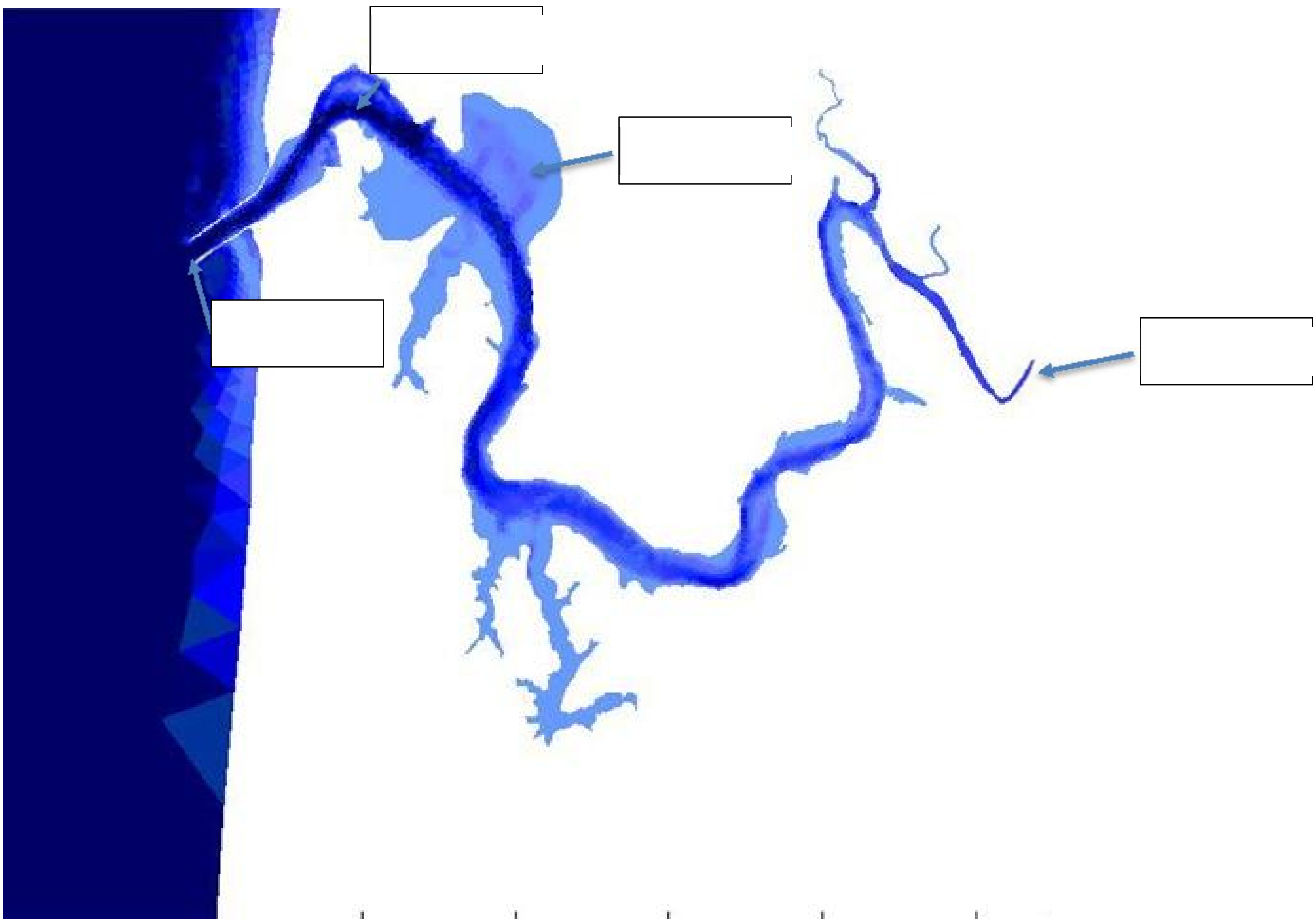


Appendix III: Script

The script used for the instructional video is below. It repeats the concept of how water flow changes in an estuary depending on time and location – a key concept identified in development. The video uses model outputs to give a direct visualization of what can be produced using a numerical model.

1) LEARNING OUTCOMES (Not displayed – written to keep objectives in mind through scripting process)

Define and understand the cause of a saltwater wedge.

List three uses for an estuarine numerical model

List three environmental forces that are considered when a model is built.

Identify that current in an estuary vary with space and time.

2) TIME LAPSE OF TIDE

Tide moves in and out, buoy is shown.

"What is an estuary? An estuary is a region where a river meets the ocean, where freshwater and saltwater mix."

Footage of Yaquina Bay on a clear day

"Estuaries are homes to diverse ecosystems, which rely on the currents and water movements, for instance, to deliver nutrients. On a basic level, water movements - or currents - just go in and out with the tides, but other factors contribute to the currents in estuaries. In order to understand the movement of water in estuaries, we can use a model that can show us the whole system, but first let's discuss the physical forces that influence current magnitude and direction."

LIST (Real pictures)

Overlay a bulleted list:

WATER FLOW

- Shape of the estuary
    - Environmental forces
    - Tides
    - River Flow
- Buoyancy forces

"For a more accurate description of estuary currents, you must consider the shape of the estuary and the environmental forces acting on the water. First let's take a look at how the shape of an estuary affects currents."

Pop up image estuary with a still title at the top "Shape**"** label estuary characteristics.

3) ESTUARY SHAPE (From real picture/aerial photography/satellite image)

"Different physical characteristics, like deep, narrow channels or wide and shallow mudflats affect the movement of water. The depth and path of an estuary influence the direction and strength of currents. As we look closer we see that the mouth of the estuary, the mudflats, and upstream in the river will have very different flow dynamics. "

Estuary from the side showing the salt wedge Title at the top.

“After shape, we look at environmental forces: tides, river flow and buoyancy forces”

4) ENVIRONMENTAL FORCES – TIDES

Salt wedge with water level shift like a see-saw

“Tides move ocean water in and out of the estuary over about a 12 hour cycle. They also cause mixing of fresh water and salt water.”

5) ENVIRONMENTAL FORCES – RIVER FLOW

Rain cloud while the river flow increases

“Freshwater flow to the estuary is primarily dependent on rain. The amount of rain can change day to day, with the seasons and the climate.”

6) ENVIRONMENTAL FORCES – BUOYANCY FORCES

“A very important factor in estuary currents is the density difference between ocean water and river water. Salt in the ocean makes seawater denser and heavier, in other words, “less buoyant” than fresh water. The density difference impacts currents when these two water sources meet and mix in an estuary. Ocean water tends to sink and flow below fresh water. We call these forces “Buoyancy forces.””

VISUALIZATION OF EBBING AND FLOODING TIDE

“Quick review: What do scientists need to study if they want to model estuary currents? They must consider the shape of the estuary, tides, river flow, and buoyancy forces.”

7) ESTUARY FOOTAGE

When studying estuaries, scientists strive to understand and predict properties such as currents, salinity and temperature at specific times. This information is vital to study the effects of human development near estuaries. Physical laws of motion govern the behavior of the fluid, and analysis of the physics allows us to predict the motion of the water.

Illustrate the transition from big picture general questions into the specific HOW question of how we use a model to do this

8-9) ESTUARY NUMERICAL MODELS – Live video with picture of Emily working on computer, zoom into computer monitor and she is working on SMS the grid program

One way to study estuary currents in order to address these needs is to use a numerical model. A numerical model is a computer program that uses equations that describe these physical laws to calculate how the shape of the estuary, tides, river flow, and buoyancy forces affect currents throughout the estuary.

Submarines pop up in fresh and saltwater region:

10) ESTUARY MODELS – SHAPE

TOP VIEW OF ESTUARY, SUBS POP UP AND RED X'S APPEAR IN AREAS OUTSIDE OF ESTUARY DOMAIN

Models numerically calculate the water motions at certain points, this creates a network of points in a three dimensional grid that represents the shape of an estuary. Once shape is defined, the model is built upon with environmental forces such as tides.

Let's take a closer look at how the physics is applied in a model by looking at an object suspended in the water – like a submarine. Let's assume it's a toy submarine without a motor so it will move with the currents surrounding it."

11) ESTUARY MODELS – TIDES

ZOOM TO SIDE VISUALIZATION OF TIDAL FORCES IN FULL SCALE ESTUARY

(sea level tilt shown, arrows show sub direction of movement and currents). Visualization of simple toy submarine on blue background

Here is a cross section of the estuary where the ocean is on the left and the river is on the right. Tides produce a pressure gradient force due to tilting of the water surface by changes in sea level. For example, when water is high at the estuary mouth compared to within the estuary, the pressure gradient force is directed inland and water moves into the estuary. High tide and low tide happen when the pressure gradient force changes direction.

Text definition: Pressure gradient force: The force directed from high pressure to low pressure

When the tide is coming in, the net flow of the water is into the estuary. When the tide is ebbing, or going out, currents, our submarine reverses directions.

12) ESTUARY MODELS – RIVER FLOW

ARROWS DESIGNATING MORE RIVER FLOW FROM RIGHT SIDE OF SCREEN (dark water is saline and light water is fresh)

River flow determines the amount of freshwater flowing through an estuary. A scientist predicts or measures actual river flow for a model.

13) ESTUARY MODELS – BUOYANCY FORCES

ANIMATION IN THE SALTWATER WEDGE

Now let's think about how currents change with depth. Our submarine will sink to where its density matches that of the fluid around it – that is, it goes to the depth where it is neutrally buoyant. Neutral buoyancy: The density of the submarine is equal to the density of the water. Buoyancy forces upwards balance with gravitational forces downward. (Statement pops up)

Density differences affect the direction and magnitude of currents at different depths. Let's take a look at what this means for our submarine. If our submarine was at neutral buoyancy with salt water, it would move faster than a lighter submarine moving with fresh water as the tide comes in. Freshwater flows over ocean water as it tries to flow out of the estuary. The submarine on the top will be faster than the submarine on the bottom when the tide is going out.

14) REVIEW ESTUARY NUMERICAL MODELS

Using the numerical model developed by Emily Lemagie, points on the model where the physics are analyzed are shown. The points go from black to yellow when the narrator mentions them.

"An ocean or estuary circulation numerical model calculates these physical forces caused by the environment and resulting water currents over a region of an ocean or estuary.

Yellow dots are released in the model to show possible paths the submarine can take.

"Using the currents calculated by the numerical model, we can predict the path the submarine will take when it is released at different times and at different locations in the estuary. The submarine is only one example, but knowing how things are transported in an estuary is useful for a lot of reasons."

VISUALIZATION OF ACTUAL FLOW AND A MODEL PREDICTING FLOW

15) BENEFITS OF NUMERICAL MODELING

Representative

A numerical model is sometimes the only way you can predict the currents of water in an estuary in a lot of places at once. What you get out of a model depends on what you put into it. Using a numerical model, you can simulate environmental variations such as winds, temperatures, and weather fluctuations and you can simulate environmental events such as flooding or droughts.

Numerical models can be used for experimentation because you can study an estuary under many different scenarios, including conditions that aren't observed today. Numerical models are a great tool for research to see how sensitive the estuary currents are to individual factors because you can change one variable at a time, and see the magnitude of the effect.

16) USES OF NUMERICAL MODELS

YAQUINA BAY MODEL TOP VIEW

Chemical spill

"So why do we care? Say there's a chemical spill at this point of the estuary. We could model the flow of the chemicals. This is important if we need to treat the area or flag it as unsafe."

Oyster release in the ideal spot

"Or maybe we're restoring native oyster habitat and want to know the best spot to release them so that they don't go too far upstream or go out into the ocean."

17) REVIEW

TEXT ON SCREEN IS DISPLAYED

Numerical modeling:

- Calculates the physical forces and currents caused by the environment. These forces vary within the estuary and over time.
- Models allow us to understand how an estuary works, both as a whole, and at each individual point.

Numerical modeling is used for

- Predicting effects of change
- Understanding the current state of a complex system
- Pollution Control
- Habitat and ecosystem Rehabilitation

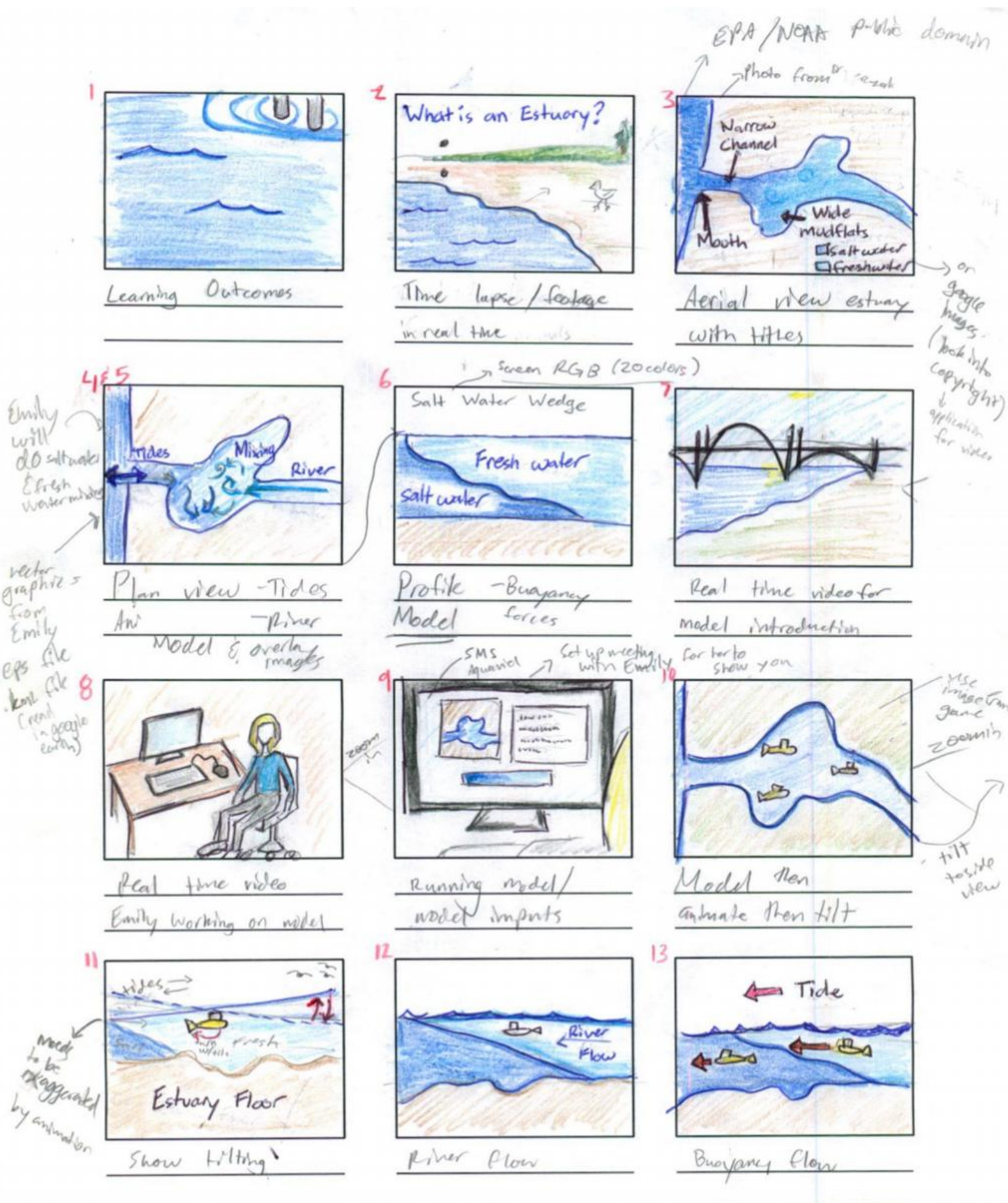
CREDITS

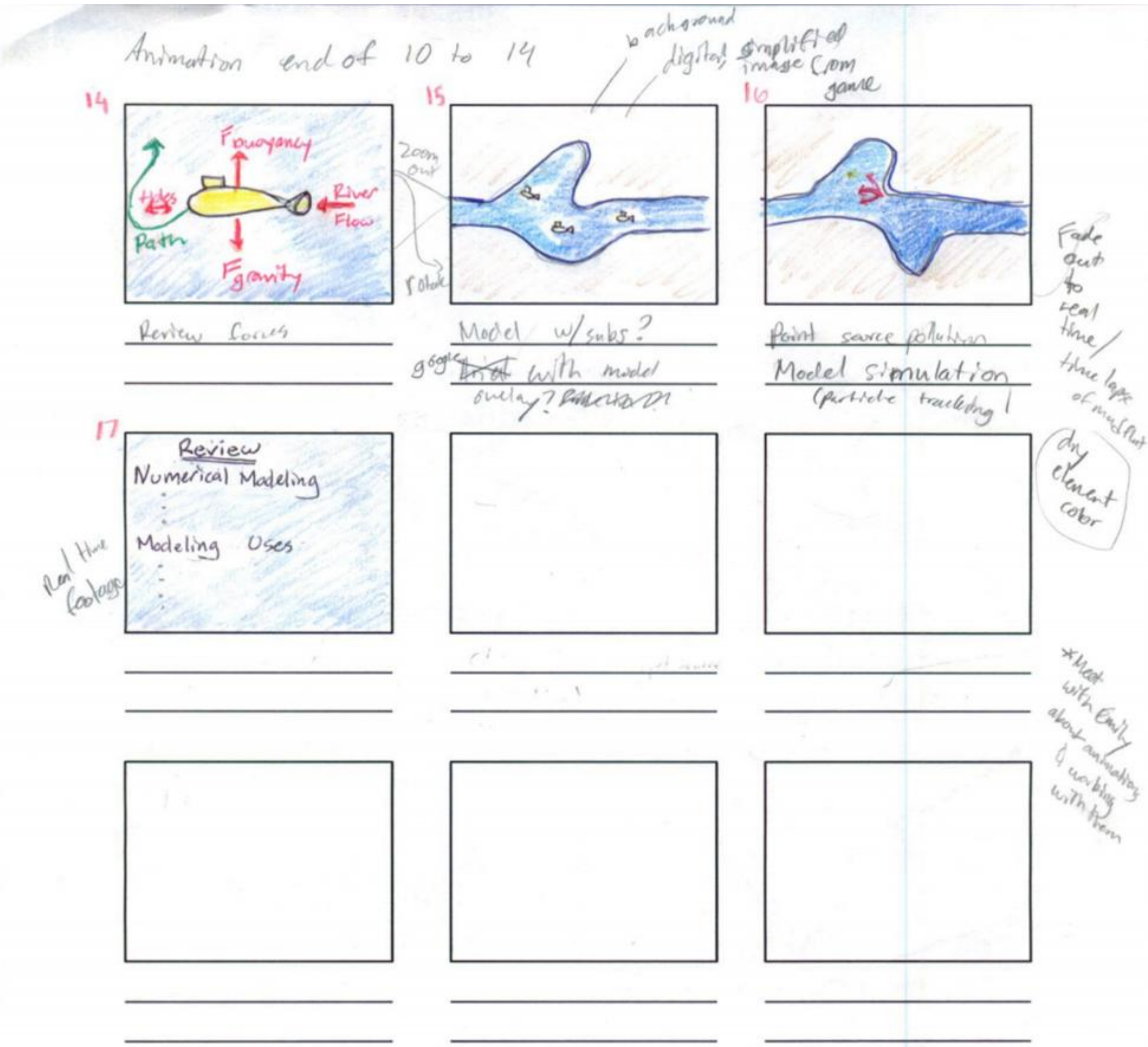
Brought to you by OSU CEOAS

Main contributors: Marina Cameron, Emily Lemagie, and Dr. James Lerczak

Appendix IV: Storyboard

Below is the storyboard developed for the video. It provided a rough sketch of the visual progression of the video during development, filming and post-production. A combination of the script and storyboard was used in order to communicate intention of what would eventually be produced.


EPA / NOAA public domain
What is an Estuary?
Narrow Channel
Mouth
Wide mudflats
salt water
fresh water
Learning Outcomes
Time lapse / footage
in real time
Aerial view estuary
with titles
or google images (look into copyright)
Screen RGB (20 colors)
Salt Water Wedge
Fresh water
Salt water
Tides
Mixing
River
Emily will do saltwater & fresh water mixing
vector graphics from Emily
.eps file
.kml file (read in google earth)
Plan view - Tides
- River
Model & overlay images
Profile - Buoyancy forces
Model
Real time video for
model introduction
SMS Aquarius
Set up meeting with Emily for her to show you
zoom in
Real time video
Emily working on model
Running model/
model inputs
use image from game
zoom in
tilt to side view
Model then
animate then tilt
tides
fresh
Estuary Floor
needs to be exaggerated by animation
Show tilting
River Flow
River flow
Tide
Buoyancy flow


Animation end of 10 to 14
background
digital simplified image from game
14
15
16
Fbuoyancy
Tides
Path
River Flow
Fgravity
Zoom out
rotate
Review forces
Model w/subs?
google with model overlay?
Point source pollution
Model simulation
(particle tracking)
Fade out to real time/ time lapse of mudflat
dry element color
17
Review
Numerical Modeling
Modeling Uses
real time footage
*Meet with Emily about animating & working with them