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Expedition Sediments: Mud's Journey through the Watershed.
Subjects: Earth Science / Environmental Science Grades: 9-12

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EXPEDITION SEDIMENTS: MUD'S JOURNEY THROUGH THE WATERSHED

Jesse Turner
Virginia Institute of Marine Science

Grade Level
9th Grade

Subject area
Earth Science

The VA SEA project was made possible through initial funding from the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center. VA SEA is currently supported by the Chesapeake Bay National Estuarine Research Reserve, Virginia Sea Grant, and the Virginia Institute of Marine Science Marine Advisory Program.



Activity Title: Expedition sediments: mud's journey through the watershed

Focus: Estuarine sediment transport for grains of estuarine mud and sand, with a focus on processes surrounding a highly populated estuary such as the Chesapeake Bay.

Grade Levels / Subject: 9th grade Earth Science

VA Science Standard(s) addressed:

- ES.1. (c) scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted
- ES.8. (d) through (f) The student will investigate and understand how freshwater resources are influenced by geologic processes and the activities of humans... d) identification of sources of fresh water including rivers, springs, and aquifers, with reference to the hydrologic cycle; e) dependence on freshwater resources and the effects of human usage on water quality; and f) identification of the major watershed systems in Virginia, including the Chesapeake Bay and its tributaries.
- ES.10. (a) through (c) The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include a) physical and chemical changes related to tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations; b) importance of environmental and geologic implications; c) systems interactions.

Learning Objectives

- Students will explain and illustrate how sediments are transported through an estuary and its watershed.
- Students will graph and compare sediment residence times in different locations.
- Students will compare the timescales of different sediment transport processes.

Total length of time required for the lesson: 1 hour

Key words / Vocabulary

Bank erosion – erosion of a sand cliff or steep bank of land into a body of water, especially during storms with large waves.

Beach nourishment – adding sand back onto a beach to rebuild the beach out toward the ocean, usually after a large storm or hurricane.

Dredge – to remove sand or mud from the bottom of a lake, river, or inlet, such as to deepen a channel.

Ebb tide – water moving out of an estuary toward the ocean or water level falling as the tide draws water away from land.

Estuary – body of water between a fresh river and an ocean that has a mixture of water coming from both the river and the ocean.

Erosion – the breaking down of rocks, minerals, and organic matter on land into tiny fragments due to the force of wind and water over time

Flood tide – water coming into an estuary or water level rising as the tide pushes water toward land.

Marsh – low-lying area filled with marsh grasses that gets periodically flooded at high tide.

Marsh replenishment – adding sediments back onto a marsh surface to help expand the marsh or raise its elevation, usually from dredge spoils.

Reservoir – Man-made lake created by building a dam in a river. Water fills in the area behind the dam after it is built to make a lake.

Resuspension – movement of a grain of sand or mud that was sitting on the bottom back up into the water. This happens when there is enough friction on the bottom (like stirring with a spoon).

Sediments –underwater fragments of rocks, minerals, and organic matter broken down into small pieces by natural forces. Includes clay, silt, sand, mud, and gravel

Turbidity – how well light penetrates through water. Turbid water appears murky or unclear because of the tiny particles suspended in the water.

Channel – the deep part of a river or estuary, often in the center of the waterway.

Deposition – movement of a grain of sand from the water down onto the seafloor as they settle out and drop down.

Residence time – the measure of how much time material spends in one place. For sediments, residence time is the amount of years a grain of sediment stays in one body of water (Voepel et al. 2013).

Sediment transport – the movement of sediments in bodies of water, due to gravity and due to the movement of the water in which the sediments are suspended.

Renewable resource – a material that has a dollar value and can be replaced naturally over time, such as wood from trees or solar energy from the sun.

Background Information

My name is Jessie Turner and I am a marine science graduate student at the Virginia Institute of Marine Science (VIMS). I study water clarity in the Chesapeake Bay. One of my projects is trying to find out how the amount of sediments coming from rivers and bank erosion changes how clear the water is in the Bay. I need to know where the sediments came from, how fast they settle to the bottom, and how long they stay in each part of the Chesapeake Bay before they get resuspended and moved somewhere else. I also help collect sediment samples for lots of other projects.



Mud and sand that settle to the bottom of a body of water have both positive and negative effects on the environment. Sediments are a natural part of the environment, serving as habitat for animals and plants living on the bottom of lakes, rivers, estuaries, and the ocean. From a human point of view, sediments are also a renewable resource. Mud and sand can be dredged from one location and relocated to build marshes and wetlands or to nourish beaches. However, in some places, sediments can be harmful to aquatic ecosystems. When erosion caused by human construction or agriculture increases the amount of sediments from land going into rivers and estuaries, the excess sediment can have negative impacts on water quality. Excess sediments can limit light for plants and make the water appear cloudy (CBP, 2018).

Many physical processes drive sediment transport, moving mud and sand around by way of erosion and water flow. This game focuses on sediment transport in estuaries and their surrounding watersheds. Processes the students will see on their sediment “journey” include:

- a) Sediments get resuspended and transported by water flow or currents into another water body. This is the main process of sediment transport, either resuspension by wind-driven waves, by tidal currents, or by large storms and hurricanes. Hurricanes resuspend more sediments than other storms because there are larger waves and higher water levels, with more energy to stir sediments up off the bottom.
- b) Sediments collect on the bottom or the “bed” of a given body of water as sand and mud settle out of the water column.
- c) Sediments get deposited on land, into a marsh, or onto a beach.
- d) Reservoirs fill in as sediments collect behind a dam. When rivers flow into reservoirs behind man-made dams, sediments slowly deposit behind the dam over time. As the dam reservoir gets full of sediment, the water in the reservoir gets shallower. Then, sediments are slowly scoured out and transported over the dam into the downstream river during times of high flow (Cercio and Noel, 2016).
- e) Dredging takes sediments up out of bays, estuaries, and rivers to maintain channels for navigation by boats. Dredged sediments or “dredge spoils” are sometimes sprayed onto marshes for marsh replenishment, pumped up onto beaches for beach nourishment, simply moved to the side of the channel where they were dredged, or placed on land in infill sites.

The timing of the sediment cycling in a watershed is much slower, operating on longer time scale than the water cycle that students may already be familiar with. While water is a liquid and moves quickly through its different phases, sediments are very small solids with different properties than water. It takes more force to resuspend sediments, so they can stay in place much longer than

water. For example, one sediment grain typically stays in the mud of the York River estuary for 50-200 years. In the deep parts of Chesapeake Bay, one sediment grain will stay up to 500 years (Dellapenna et al., 1998).

In this game, one turn represents about 100 years. So, a grain of sand can stay in the ocean for more than 300 years, but only stays in a freshwater stream for less than 100 years. However, the game is not to scale. To keep a focus on the connectivity between systems, the game had to be scaled differently, otherwise some grains would be “stuck” at the Ocean station or the Land station for the entire game. See the Teacher key for all possible sediment journey pathways that a student may take during the game.

Handouts: (attached)

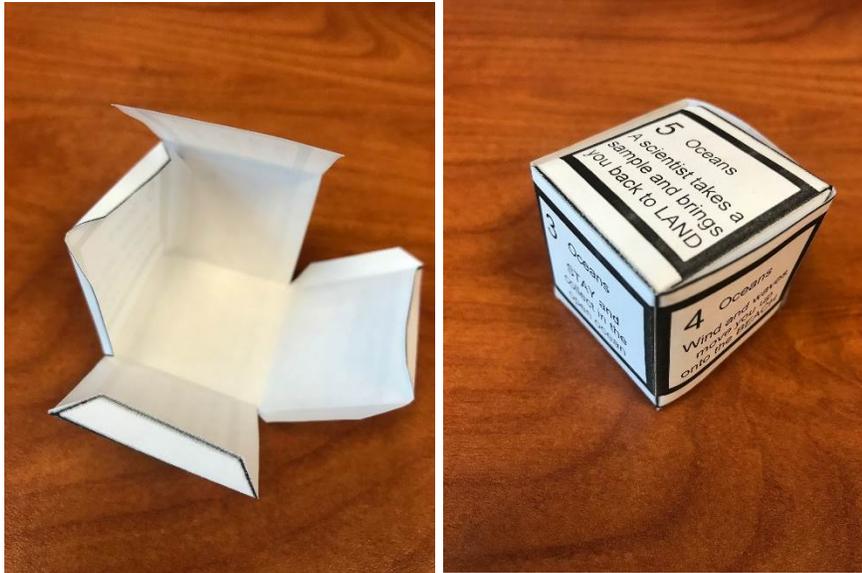
- Game instructions (also on slides)
- Student worksheet – includes table, graphing exercise, and questions.
- Answer key for worksheet
- Teacher key

Materials / Supplies

- Sediment Transport Dice (attached)
- Sediment Location Labels (attached)
- Slides with image for free-write, video links, and student game instructions (attached)
- Projector and computer including Microsoft PowerPoint
- Internet access to watch videos using projector
- *Optional:* colored pencils/crayons and/or beads and string

Classroom Setup

- Print, cut out, and assemble Sediment Transport Dice (see pictures below)
- Print Sediment Location Labels
- Print student Game Instructions (one page per station, or more if desired)
- Connect projector to display slides and videos
- Plan eight stations around the classroom to be the stations for the game. Classroom setup should be easy for moving around. NOTE: If this is a large class, consider printing extra copies of the Dice for Ocean and Bay locations, and staging more tables/desks at these stations to help when many students arrive at those locations!
- Prepare the stations with dice, station cards, and (if desired) coloring utensils and beads. Stations can either be tables, groups of desks, or areas at the side of the room such as a corner where a piece of paper can be taped on a wall above one desk or table.



Dice assembly: Cut out the entire shape, fold, and use tape or glue.

Procedure

Free-write—5 minutes

- Put up the slide and start off with 5 minutes of free-writing: “Describe what you see in this picture. What do you think is going on here?”

Introduction – 10 minutes

- Introduce sediments. Use the contents of the Background Information section above if needed. Explain to students how sediments can be seen as “good” vs. “bad” for ecosystems and for people. For example, sediments are a renewable resource for marshes and beaches, but they can be detrimental to water quality when there is too much erosion.

Optional: Watch three short videos:

- Bay 101: Sediment, Chesapeake Bay Program <https://vimeo.com/110608386>
- Marsh Replenishment: <https://www.youtube.com/watch?v=AlgYACJfSQ&feature=youtu.be>
- Beach Nourishment: <https://www.youtube.com/watch?v=-7w6jY6LnpM>

- Ask students “Where do we find sediments?” or “Where do we find mud? Sand?” As students give correct answers, put the respective station labels up around the room where each station will be.

d) Explain the game to students. They will be travelling around the watershed as individual grains of sand. Each student is one grain of sand. Explain that they need to keep track of where they go on the worksheet with the table.

Optional: explain how students should color in their tables and/or make a bracelet using the different colors at each station as they go, if you are using those extra items.

Use a random system to break students up into their starting stations. They should be evenly spread out around the room.

Game– 20 minutes

e) Display the “Game Instructions” slide on the projector. Start the game: do one very slow practice turn so that students understand how to roll the die and go to the next station according to what the numbered cards tell them. For example, if they roll a “3” at the ocean station, they remain in the ocean. Ring the bell or let them hear the sound that signals the end of a turn.

f) Play the game. Use a bell/sound for each turn. Play for about 15 minutes, or until students have fully or almost fully filled in their tables (15-20 stops). Stop a few turns into the game to check that no one is lost.

g) At the end station of the game, ask students to write their final station on the last “start” column of the table (see answer key).

Results – 5 minutes

h) Ask students to return to their original seats to 1) count up their totals and 2) fill out the graph. Draw an example graph on the board if necessary.

i) Start a place for students to tally up all of their results, either on the board or on a poster or separate piece of paper. The whole class results should have a total number of times that students visited each of the 8 stations. One way to do this is to have students come up one group at a time to add their results with the tally system. Another way to do this is to have them come up one by one after they finish their graphs. (While they are filling out the graph and pooling results on the board is a good time to start taking down the game).

Note: if some students make their graphs faster than others, have them color them in, then skip down to questions 7 and 8 (last page of the worksheet) and start writing about their sediment journey and drawing a diagram or picture of their journey.

Discussion – 5 minutes

j) Discuss the whole-class results with students. Draw the whole-class results on the board in a bar graph or write the total numbers where students can see them. Ask, “Where did the sediments (you) stay the longest?” (should be the ocean, the bay, and the marsh or possibly the reservoir and the estuary). “Where did the sediments (you) stay for the shortest amount of time?” (should be the stream or the beach).

Student in-class work – 10 minutes

k) Ask students to fill out questions 3 – 6 below their graphs on the worksheet.

l) For the rest of class, have students answer questions 7 and 8: writing a story about their journey and drawing a diagram of their journey.

Conclusion – 5 minutes

m) Before students leave the classroom, wrap up the lesson. Ask “What did we learn from the game?” or “What do you think was the big-picture point of this game?” If students provide answers that make sense, write their answers on the board. Explain and list on the board the following bullet points, whether students provide these answers or not:

- All of the systems are connected: sediments travel through all of these places
- Sediments stay for longer in some places than others
- Humans alter the natural transport of sediments by:
 - building dams/reservoirs
 - dredging
-

Assessment

The worksheet for this lesson plan is designed to assess students’ ability to explain the journey of a sediment grain and compare the different storage locations and processes.

See the answer key for examples of graphs and answers to the questions.

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Image Sources:

Liberty Dam Reservoir. Created April 21, 2015. By Bohemian Baltimore - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=48376635>

Dangerous River Plume. Photographed August 3, 2015. Andrew McDonnell, University of Alaska Fairbanks, Personal permission. amcdonnell@alaska.edu

Situk River. Created April 26, 2017. Jessica Turner, Virginia Institute of Marine Science. jsturner@vims.edu

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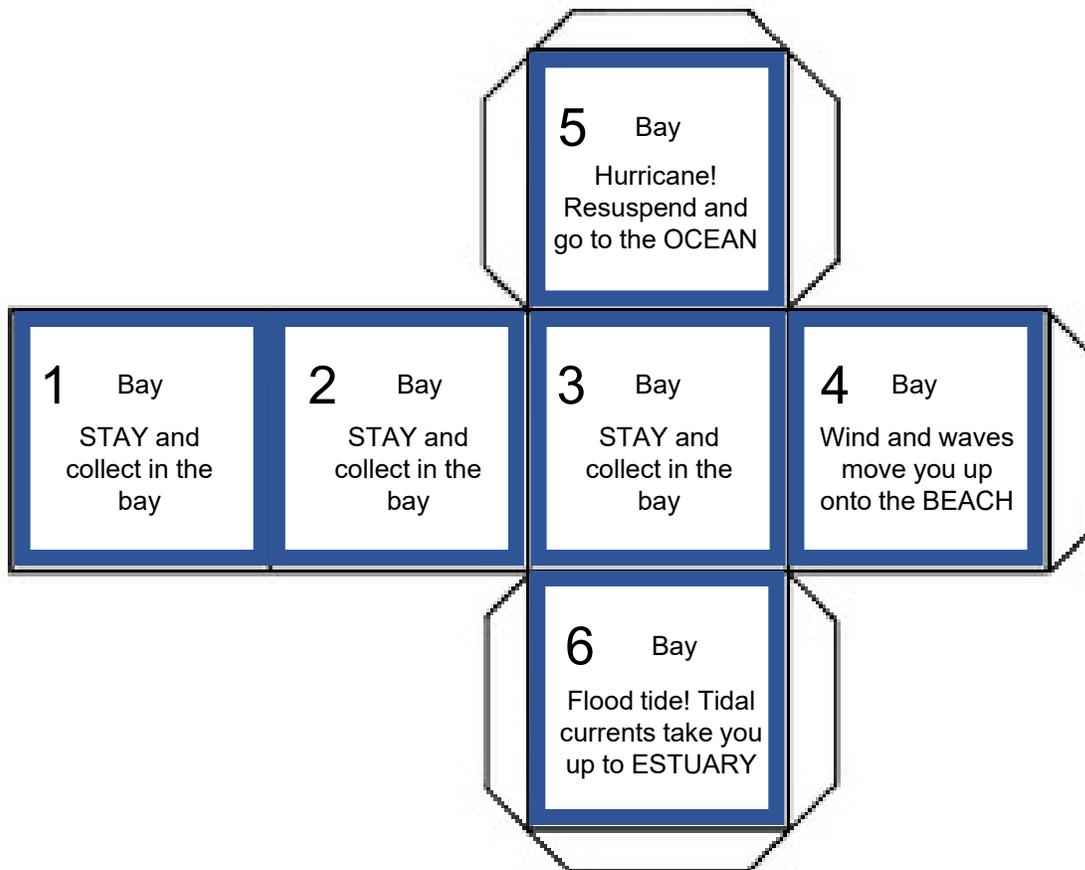
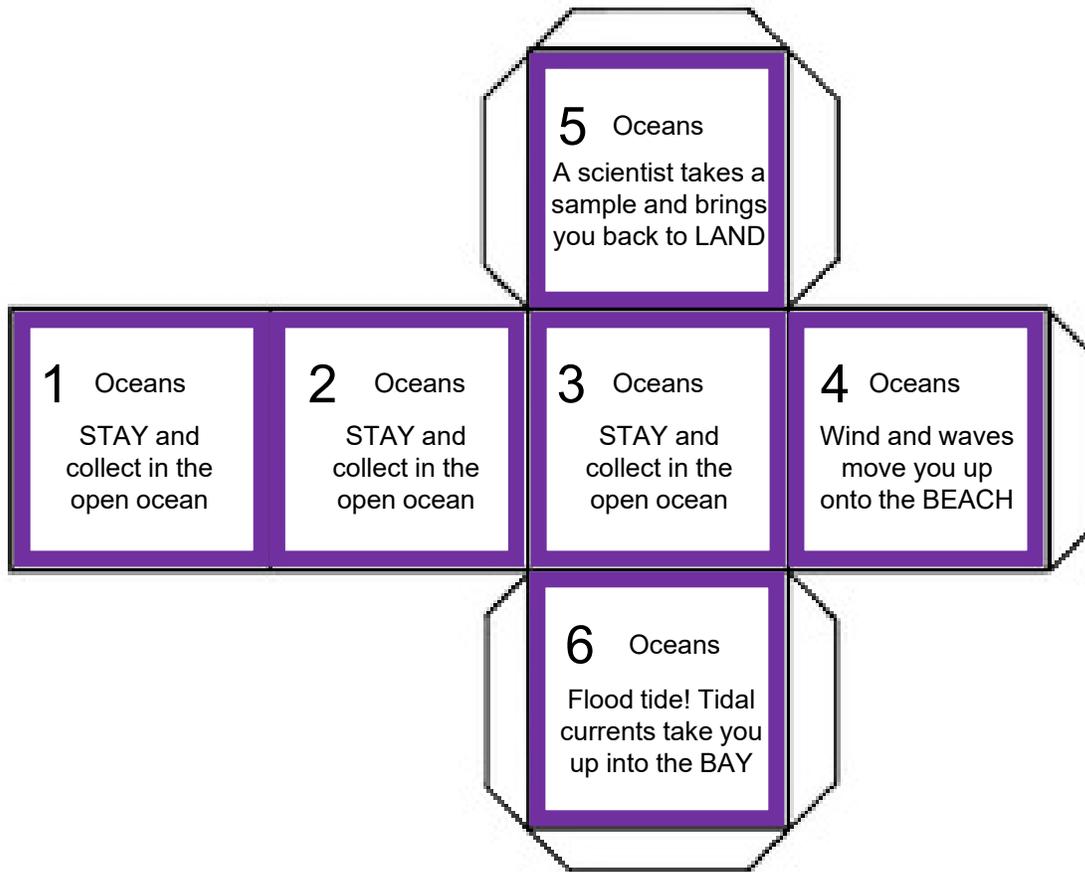
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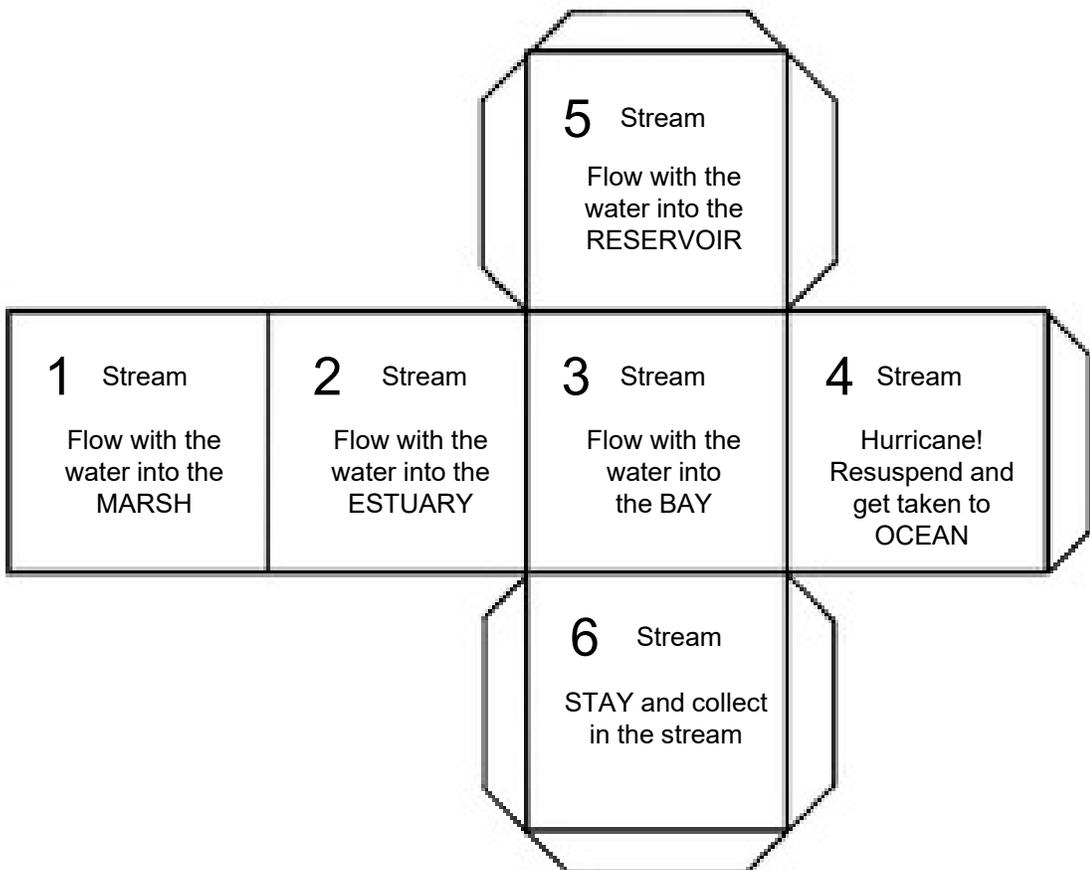
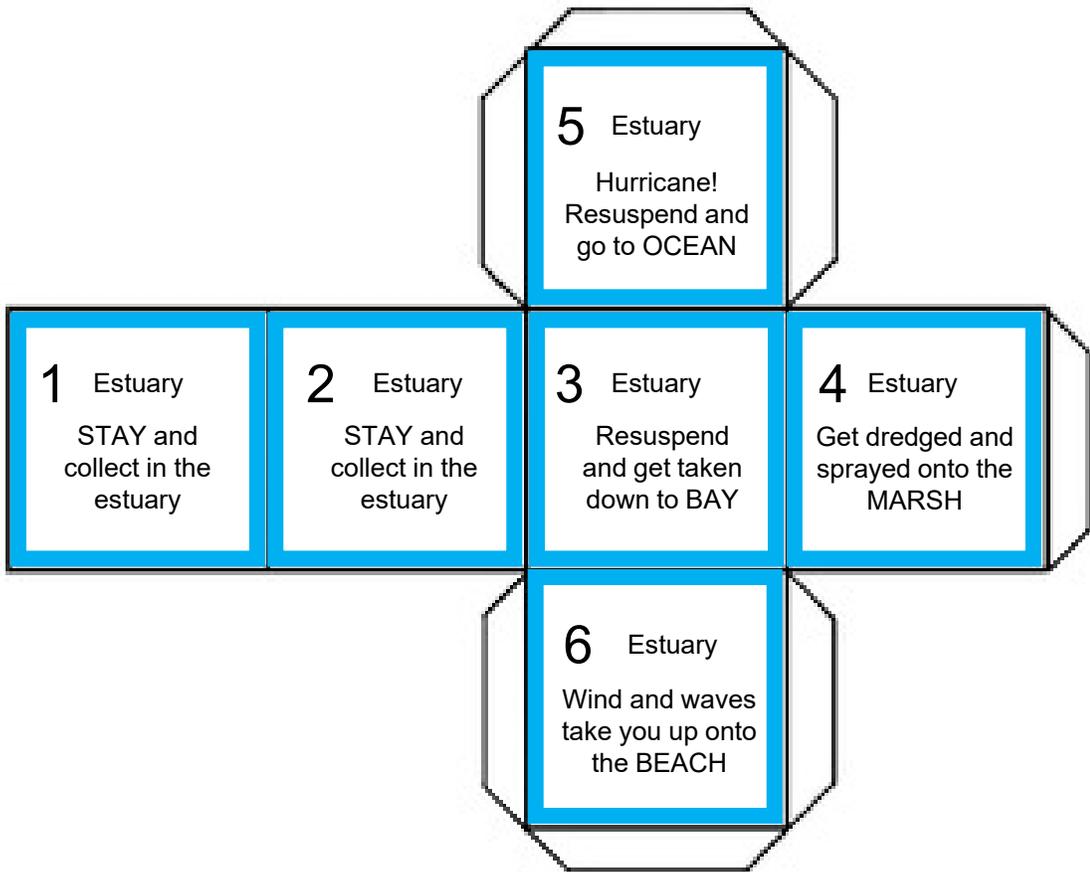
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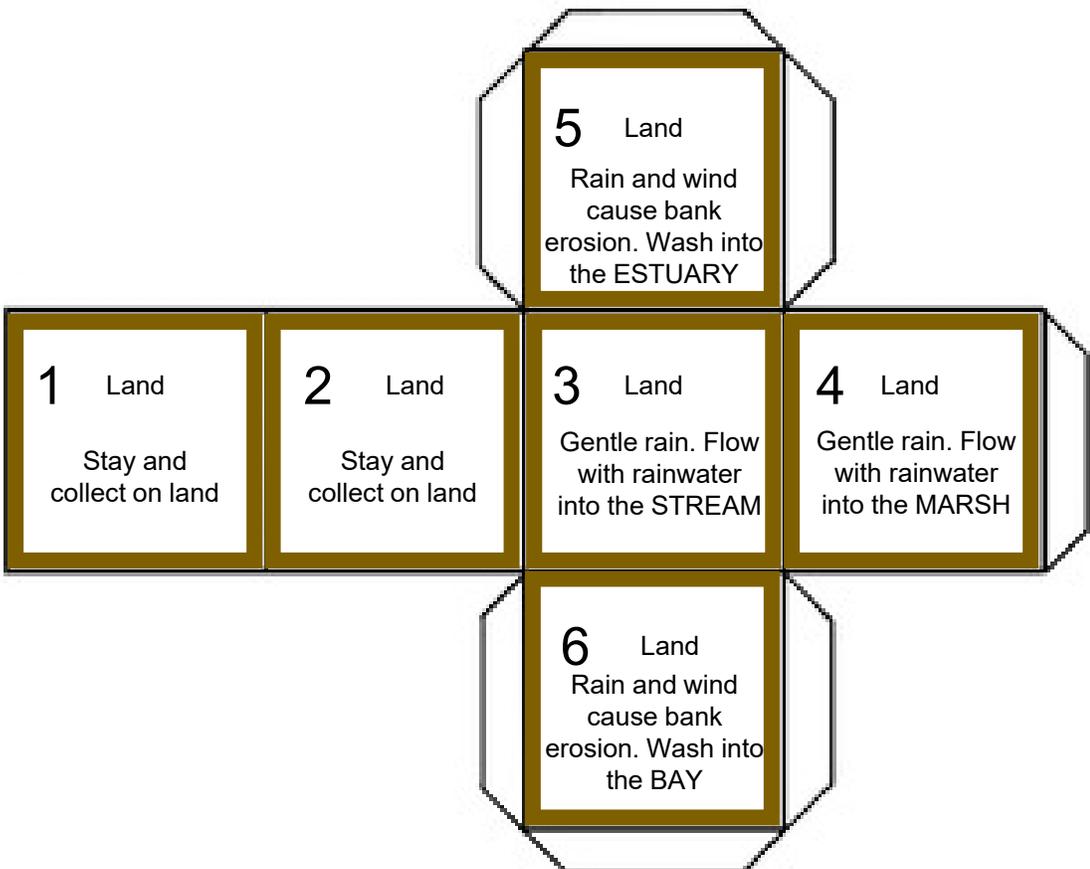
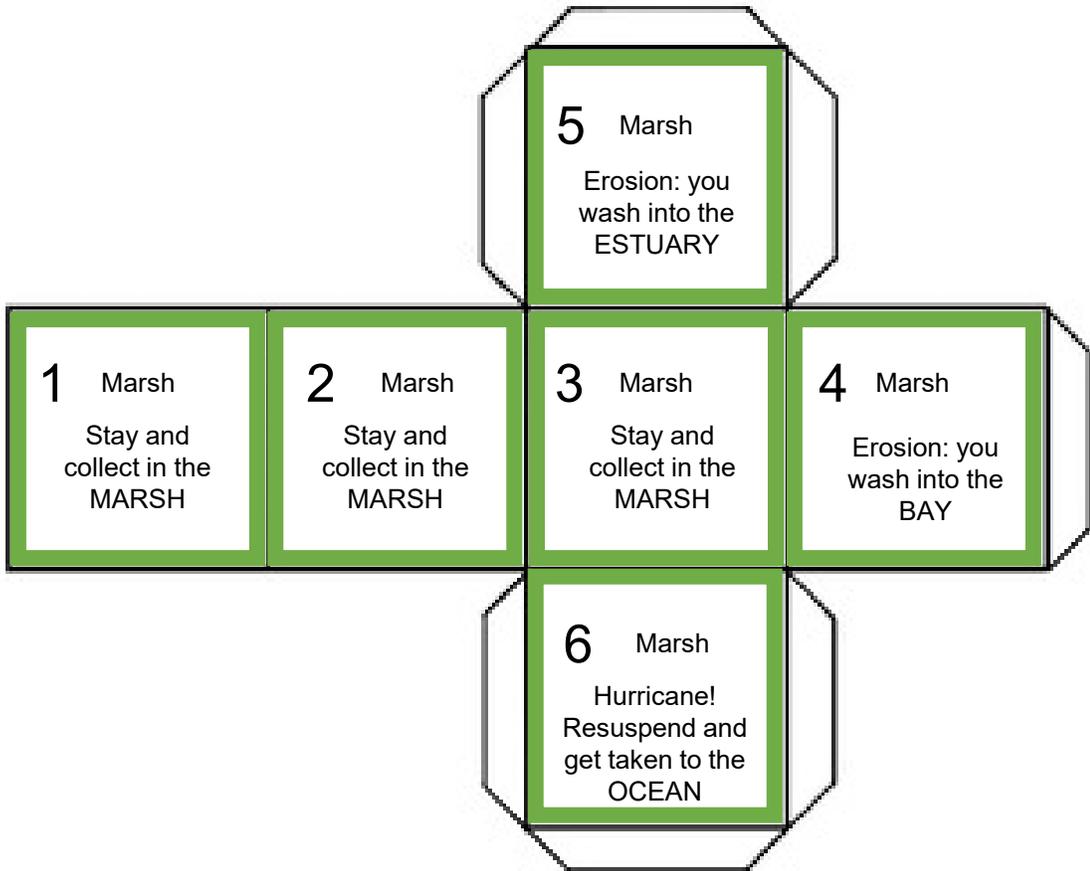
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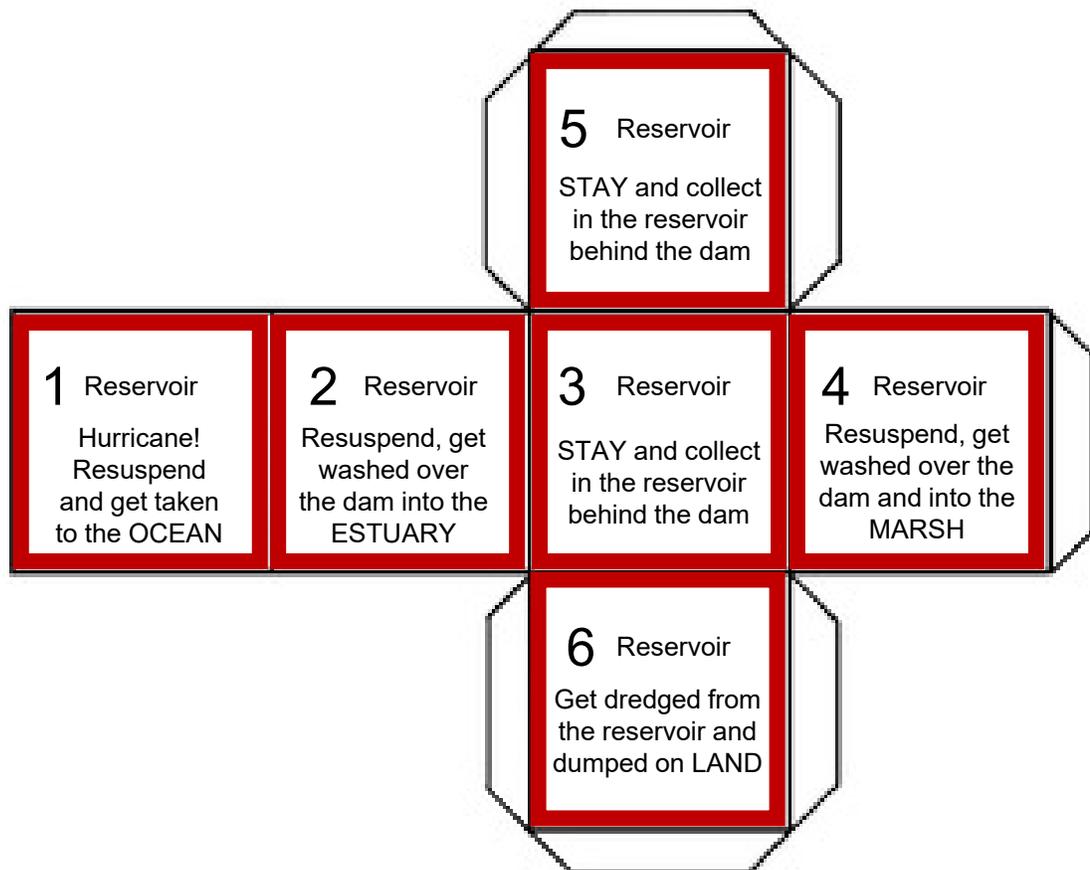
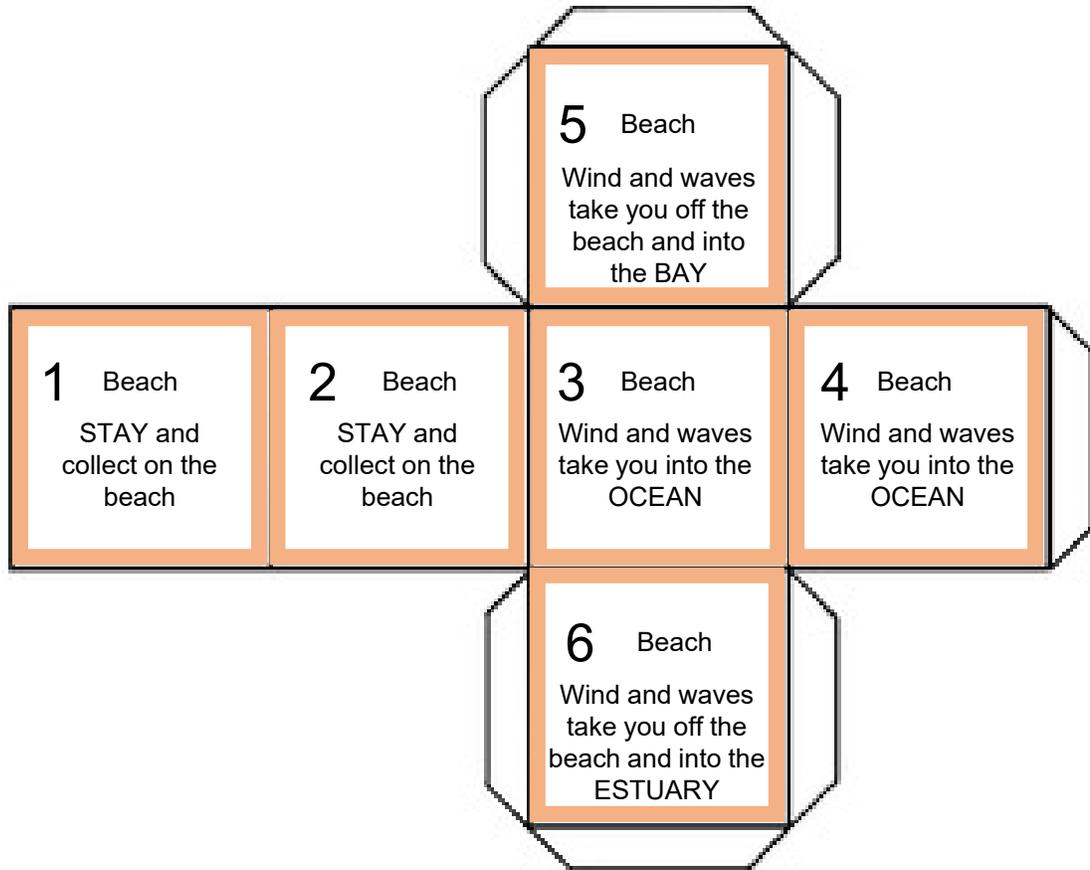
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Western Maine (Land). Photographed June 15, 2013. Jessica Turner, Virginia Institute of Marine Science. jsturner@vims.edu









Ocean



Ilha Grande (Open Ocean). Created January 2, 2009. By Anderson Mancini
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Bay



Chesapeake Bay Bridge. Created August 16, 2008. By JoshuaDavisPhotography.com CC BY-SA 2.0, https://commons.wikimedia.org/wiki/File:Chesapeake_Bay_Bridge_3.jpg

Estuary



Exe Estuary. Created May 18, 2007. By steverenouk - IMG_0664, CC BY-SA 2.0,
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Stream



Situk River. Created April 26, 2017. Jessica Turner, Virginia Institute of Marine Science.
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Marsh



Salt Marsh, Tynningame. Created March 3, 2007. By Dr Duncan Pepper, CC BY-SA 2.0,
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Land



Western Maine (Land). Photographed June 15, 2013. Jessica Turner, Virginia Institute of Marine Science. jsturner@vims.edu

Beach



Sand dunes at Naikoon Provincial Park. Created May 12, 2011. By Karen Neoh, CC BY 2.0,
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Reservoir



Liberty Dam Reservoir. Created April 21, 2015. By Bohemian Baltimore - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=48376635>

Expedition Sediments

Teacher Key

Game options: all possible dice rolls for teacher reference.

Station	1	2	3	4	5	6	Dominant processes
Land	Stay & collect	Stay & collect	Flow w/rain into Stream	Flow w/rain into Marsh	Rain/wind, bank erosion into Estuary	Rain/wind, bank erosion into Bay	Many processes cause erosion that carries sediment from land to other locations.
Stream	Flow down to Marsh	Flow down to Estuary	Flow down into Bay	Hurricane, resuspend down to Ocean	Flow into Reservoir	Stay & collect	Streams carry sediments to other locations downstream.
Reservoir	Hurricane, resuspend down to Ocean	Resuspend, flow down into Estuary	Stay & collect	Resuspend, flow down into Marsh	Stay & collect	Dredged out and dumped on Land	Collection of sediments from upstream. Only dramatic processes can remove sediments in reservoir to other locations.
Marsh	Stay & collect	Stay & collect	Stay & collect	Erosion, wash into Bay	Erosion, wash into Estuary	Hurricane, resuspend down to Ocean	Marshes collect sediment from upstream and downstream, but erosion can redistribute sediments.
Estuary	Stay & collect	Stay & collect	Resuspend and go down to Bay	Dredged from channel, sprayed into Marsh	Hurricane, resuspend down to Ocean	Wind, waves carry to Beach	Estuaries collect sediments from upstream and downstream. Wind, waves, and storms move sediments in and out.
Bay	Stay & collect	Stay & collect	Stay & collect	Wind, waves wash up onto Beach	Hurricane, resuspend down to Ocean	Flood tide currents move up to Estuary	Bay collects sediments from upstream and downstream. Wind, waves, and storms move sediments in and out.
Beach	Stay & collect	Stay & collect	Wind, waves move to Ocean	Wind, waves move to Ocean	Wind, waves move to Bay	Wind, waves move to Estuary	Beach collects and loses sediments from Estuary, Bay, and Ocean due to wind, waves, and storms.
Ocean	Stay & collect	Stay & collect	Stay & collect	Wind, waves move up to Beach	Scientist samples onto Land	Flood tide currents move up into Bay	Ocean seafloor collects sediments from all sources. Wind, waves, currents, and storms, move sediments toward ocean from other locations.

Game Instructions:

You will be travelling around the watershed as an individual grain of sand.

Each student is one grain of sand. Keep track of where you go on the worksheet with the table.

Each turn, when you arrive at a new station:

- Write down where you have arrived in the 2nd column of the current row and in the first column of the next row down.
- Write down how you got there – what was your sediment transport process?

Roll the dice to see where you will go next.

Example:

Time	Location started	Location ended	Transport process (What happened?)
1	Ocean	Beach	Wind/waves washed me up
2	Beach		

Game Instructions:

You will be travelling around the watershed as an individual grain of sand.

Each student is one grain of sand. Keep track of where you go on the worksheet with the table.

Each turn, when you arrive at a new station:

- Write down where you have arrived in the 2nd column of the current row and in the first column of the next row down.
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Roll the dice to see where you will go next.

Example:

Time	Location started	Location ended	Transport process (What happened?)
1	Ocean	Beach	Wind/waves washed me up
2	Beach		

Name: Answer Key / Example

Time	Location started	Location ended	Transport process (What happened?)
1	Beach	ocean	Wind and waves
2	ocean	ocean	stay and collect
3	ocean	Bay	tide
4	Bay	ocean	Hurricane
5	ocean	ocean	stay and collect
6	ocean	Land	sampled by scientist
7	Land	Land	stay and collect
8	Land	Stream	rain
9	Stream	Reservoir	Flow with water
10	Reservoir	Reservoir	stay and collect
11	Reservoir	Land	dredging
12	Land		
13			
14			
15			
16			
17			
18			

1. How many times did you visit each location? (Only count one column)

Estuary 0

Bay 1

Ocean 4

Stream 1

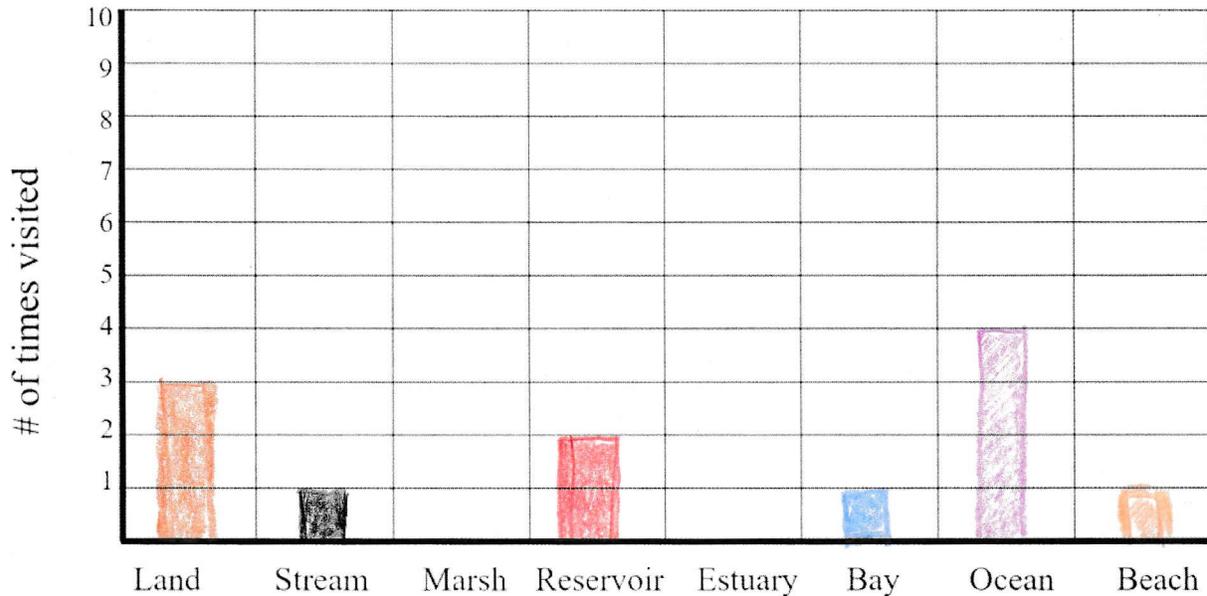
Marsh 0

Land 3

Beach 1

Reservoir 2

2. Make a bar graph of the amount of time you spent in each location:



Combine your results with the results from the whole class...

3. Where does sediment stay the longest?

The Ocean
(could be the Bay, Marsh, etc.)

4. Why do you think it stays there for longer than other places?

The ocean is very big and deep, so it can store more mud and sand, and it's hard to resuspend sediments to move them out.

5. Where does sediment stay for the shortest amount of time?

The Stream
(could be the Beach, Estuary, etc.)

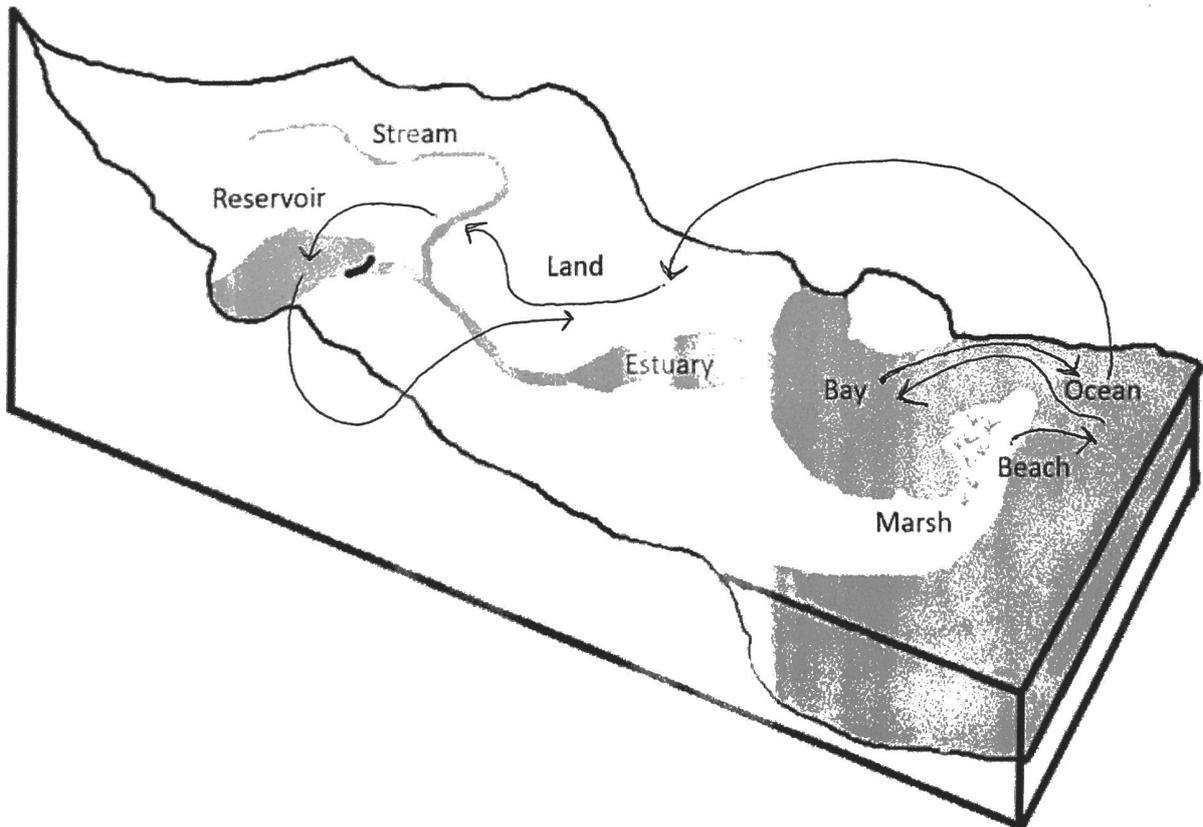
6. Why do you think it doesn't stay there?

Streams are small and shallow and fast-moving. It would be easier to resuspend mud and sand, and the flow would move them away.

7. Write a story about your journey through the watershed as a sediment grain in first-person. What happened to you?

I started on the beach. Then, wind and waves moved me down into the ocean. I stayed in the ocean. Then, a flood tide took me up into the Bay. I got resuspended by a hurricane and washed back into the ocean, where I stayed for another turn. I was taken back on land when a scientist took a sample. I stayed on land. Then, rain washed me into a stream. The flow took me to the reservoir. I stayed in the reservoir. Then I got dredged up onto land.

8. Draw your journey through the watershed with arrows:



Name: _____

Time	Location started	Location ended	Transport process (What happened?)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			

1. How many times did you visit each location? (Only count one column)

Estuary_____

Bay_____

Ocean_____

Stream_____

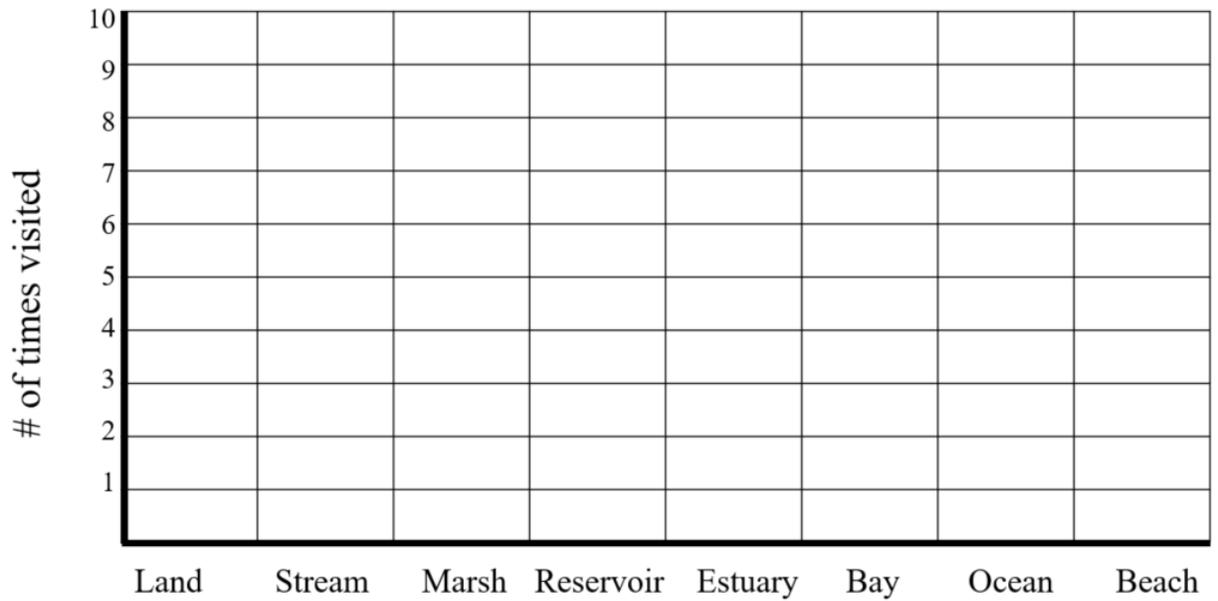
Marsh_____

Land_____

Beach_____

Reservoir_____

2. Make a bar graph of the amount of time you spent in each location:



Combine your results with the results from the whole class...

3. Where does sediment stay the longest?

4. Why do you think it stays there for longer than other places?

5. Where does sediment stay for the shortest amount of time?

6. Why do you think it doesn't stay there?

7. Write a story about your journey through the watershed as a sediment grain in first-person. What happened to you?

8. Draw your journey through the watershed with arrows:

