ELA Common Core Content Standards:

Estimated duration: 1.5 hours
Additional time will be needed for monitoring activity.

NGSS Earth and Space Science CCCS Standards:
MS-ESS1-1, MSESS1-2 Earth's Place in the Universe;
Science and Engineering Practices
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 parts of the Klamath River Basin, e.g. lips, estuary, tributaries, Lake Ewauna Reservoir, headwaters at Upper Klamath Lake, etc.

Goal: Students will explain and illustrate how sediments are transported through a watershed. Students will graph and compare sediment residence times in different locations. Students will compare the timescales of different sediment transport processes.

Theme/Big Ideas:	Sediment moves in different ways through a watershed
Big Questions:	How are the choices we make in managing our landscape related to our watershed?
Vocabulary:	Aquifer, Estuary, Bay, Headwaters, Source, Stream, River, Ocean, Groundwater, Mouth, Tributary, Reservoir, Bay, Sea

Materials:

- **Sediments in the Klamath River Basin**, (included: text, vocabulary "cheat sheet")
- **Klamath Basin Sediment Game** (included: game instructions, table, graphing exercise and game follow-up questions)
- **Klamath Basin Sediment Game: Master** (included)
- **Vocabulary "Cheat Sheet"**, (included)
- **Sediment Transport Dice**, (blueprints included)
- **Klamath River Basin Labels**, (included)

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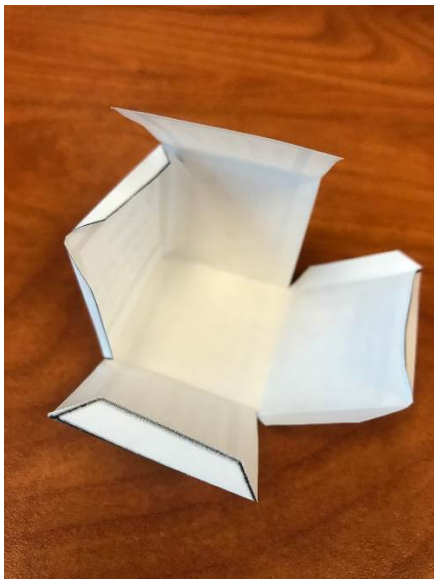
Addendum: Measuring for Turbidity (included)
Addendum: Water Pollution Graphing (included)
Optional: colored pencils/crayons (not included)

Preparation: Print out the eight game dice and assemble, cutting out the entire shape, fold, and use tape or glue, like so:



Print out the photographs of the eight game stations and have tape ready.
Print out the **River Basin Sediments** text with vocabulary, and game charts for each student.

Plan eight stations, easy for students to move around in, around the classroom for the game.

Prepare the stations with dice and station cards. Students will need a table to chart their course, and you'll want someplace easily visible to tape or pin the station location photo.

Background: Many physical processes drive sediment transport, moving mud and sand around by way of erosion and water flow. This game that makes up the main part of this lesson focuses on sediment transport in the Klamath River Basin. Processes the students will see on their sediment "journey" include:

- 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.
- Sediments collect on the bottom or the "bed" of a given body of water as sand and mud settle out of the water column.
- Sediments get deposited on land or onto a shore/beach.

- 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 (U.S. Geological Survey, 2020). This topic has loomed large in the political discourse focused on the question of dam removal in the past several decades.

- Dredging takes sediments up out of estuaries, reservoirs and rivers for a number of reasons: e.g., keeping the estuary from disappearing. Dredged sediments or "dredge spoils" are sometimes moved to the side of the channel where they were dredged, or placed on land in infill sites.

Sediment cycling in a river basin takes much longer than the water cycle with which students may already be familiar. 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 may stay in the mud of the Klamath River estuary for 50 - 200 years.

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 **Klamath Basin Sediment Game: Master** for all possible sediment journey pathways that a student may take during the game.

Discussion: Ask students the following (covered in **G4-6 LB The Klamath River Basin**):

- What is a watershed?

Answer: It's a land area that channels water, such as rainfall and snowmelt, to creeks, streams, lakes, and rivers, and eventually to outflow points such as reservoirs and oceans.

- What's the difference between a watershed and a river basin?

Answer: In a river basin, all the water drains to a large river. The term watershed is used to describe a smaller area of land that drains to lake, wetland, or tributary of a large river, like a smaller river or smaller stream. There are many smaller watersheds within a river basin.

- Does all water flow directly to the sea?

Answer: When rain falls on dry ground, it can soak into, or infiltrate, the ground. This groundwater remains in the soil, where it will eventually seep into the nearest stream.

Note: Some water infiltrates much deeper into underground reservoirs called aquifers.

Preparation for Activity: Ask students if they remember the answer to the question, "Why would fertilizer end up in the river?" (Whatever happens to surface or groundwater in one part of the river basin will find its way to other parts. The bits of fertilizer that haven't been used by plants will flush into groundwater systems, sometimes helped by rain or snow, which eventually find their way into creeks and rivers.)

Tell them that these bits of fertilizer can be called sediments. Explain that sediment is solid material that is moved and deposited in a new location. Sediment can consist of rocks and minerals, like grains of sand or pebbles. They can also be a big as a boulder.

The remains of plants and animals can be sediments, as well as minerals and chemicals, like those you would find in fertilizers.

Sediment moves from one place to another through the process of erosion. Our water system, that is the rain, snow and the bodies of water found in our river basin, plays a major role in moving these solid materials from one place to another.

Read Aloud: Pass out the **Sediments in the Klamath River Basin** and have students read the text aloud.

Explain to students how sediments can be seen as "good" vs. "bad" for ecosystems and for people. For example, sediments can be a renewable resource for marshes, but they can be detrimental to water quality when there is too much erosion.

Next, have them read the **Vocabulary "Cheat Sheet."** You might turn this into a game, asking for volunteers to try to define the words to their fellow students. Have students watch to see if the student tries to use the "cheat sheet."

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.

Preparation for Activity: Pass out the **Klamath Basin Sediment Game** instructions, table, chart graph and follow-up questions.

Have students read the instructions quietly to themselves, first. Then explain the game to students. They will be travelling around the river basin 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.

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

Activity: 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 a bell or make some kind of sound that signals the end of a turn.

Play for about 15-20 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. 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).

Activity: Students return to their seats and 1) count up their totals and 2) fill out the graph.

Draw an example graph on the board, and then start a chart in which to count up all of their results. You can also do this on a 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: 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 you stay the longest? (ocean, mouth/lips, estuary or reservoir)
- Where did you stay for the shortest amount of time?" (river or beach)

Activity: Have students to finish up their worksheets. If desired, provide crayons or other art utensils for the drawing of their journey through the river basin.

Discussion: As a follow-up to game, ask students the following questions:

- What did we learn from the game?

Answers: 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; using sediment for research purposes; dredging

- Do you think the way that sediment is transported will change once all four dams are removed?
- How do you think dam removal will affect water quality on the Klamath River?

Answer: Following the removal of four dams along the Klamath River, more naturally dynamic flow conditions may result in novel water quality, sediment transport, and geomorphic conditions leading to temporary or longer-term ecological impacts.

Point out that we can't be really sure how the river might change after the dams are gone, and that is the reason we are going to contribute data that will measure water quality change in upcoming field trips.

Fun Facts: The use of vacuum or suction dredge equipment, otherwise known as suction dredging, is unlawful in California rivers, streams, and lakes, and any such activity is subject to enforcement and prosecution as a criminal misdemeanor. (See generally Fish & G. Code, §§ 5653, 5653.1, 12000, subd. (a).)

Assessment: The worksheet for this lesson plan is designed to assess students' ability to explain how sediment moves through the basin and compare the different storage locations and processes.

Activity: Relevant to this lesson, but can be done separately, are two a water quality monitoring activities for students included in the Water Quality lesson series. For an in-classroom graphing activity, choose **Addendum: Water Pollution Graphing**. For an outdoor activity, choose **Addendum: Measuring for Turbidity**.

References:

California Department of Fish and Wildlife (2023): Suction Dredge Permits. Retrieved 8/02/2023

Cenedese, Claudia, et al. (2023). Ocean. Britannica, Geography & Travel. Retrieved 6/30/2023

cK12 (2023). Streams and Rivers. Retrieved 8/02/2023

National Geographic, Education. Resource Articles for Grades 5 – 8. Information regarding definitions of river basin retrieved from mid-May to mid-August.

Turner, Jessie (2019): Expedition Sediments: Mud's Journey through the Watershed. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.25773/1PAH-7023

U.S. Geological Survey, 2020. Sediment Mobility and River Corridor Assessment for a 140-Kilometer Segment of the Main-Stem Klamath River Below Iron Gate Dam, California. Retrieved 6/30/2023

U.S. Geological Survey, 2022. Iron Gate Dam and Hatchery, Klamath Dam Removal Studies, retrieved 6/6/2023. Note: Outdated includes some good information and lovely photographs.

Water Education Foundation. Surface Water vs. Groundwater. Retrieved 7/03/2023

Klamath Basin Sediment Game: Master - all possible dice rolls for teacher reference.

	1.	2.	3.	4.	5.	6.	Main Processes
Land	Stay & collect	Stay & collect	Flow w/rain into Creek	Flow w/rain into River	Rain/wind, bank erosion into Estuary	Rainstorm and slide into River	Many processes cause erosion that carries sediment from land to other locations.
Creek	Flow down to River	Dislodged and back to River	Dredged and dumped on Land	Trapped by debris & Stay	Culvert cleaned, dump on Land	Stay & collect	Creeks carry sediments to other locations downstream.
Reservoir	Scientists dump onto Land	Resuspend, flow down into River	Stay & collect	Flow into irrigation water, then Land	Stay & collect	Dredged out and dumped on Land	Collection of sediments from upstream. Only dramatic processes can remove sediments in reservoir to other locations.
River	Stay & collect	Flow into the Lake Ewauna Reservoir	Flow until you get to the Mouth/ Lips	Flow with the water into the Estuary	Flood, rise and seep into Land	Storm, resuspend down to Ocean	Rivers collect sediment from upstream and downstream, but most of it lands near the ocean.
Estuary	Stay & collect	Stay & collect	Resuspend and go down to Mouth/ Lips	Dredged from channel, sprayed onto Land	Storm! 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.
Mouth/Lips	Stay & collect	Stay & collect	Wind, waves take you back up the Estuary	Wind, waves wash up onto Beach	Hurricane, resuspend down to Ocean	Flood tide currents move up to Estuary	Mouth/Lips collect sediments from upstream. 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 Mouth/ Lips	Wind, waves move to Estuary	Beach collects and loses sediments from Estuary, Mouth/Lips, 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 Estuary	Ocean seafloor collects sediments from all sources. Wind, waves, currents, and storms, move sediments toward ocean from other locations.

Klamath River Mouth, or "Lips," the Pacific Ocean. Photo credit: Jennifer Silveira/USFWS. License for use: Public Domain

Background Information

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. Sediment plays a vital role in salmon species' natural reproductive cycle. Sediments can also be a renewable resource: for example, mud and sand could be dredged from one location and relocated to help re-build marshes and wetlands that have declined as a result of the 1906 Klamath Project. However, in some places, sediments can be harmful to aquatic (and wetland) ecosystems. When erosion caused by human construction or agriculture increases the number 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 (U.S. Geological Survey, 2020). One way to monitor for water quality is to take water samples and measure turbidity, which is caused by particles suspended or dissolved in water that scatter light making the water appear cloudy or murky. These particles can include sediment - especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms.

Vocabulary "Cheat Sheet"

Source: A river's source, or headwaters, is the place where a river begins and can come from different points, including glaciers, underground springs, or lakes. (National Geographic Society)

Headwaters: Headwaters are the source of a stream or river. They are located at the furthest point from where the water body empties or merges with another. Two-thirds of California's surface water supply originates in mountain regions. (Water Education Foundation)

Stream: A moving body of water of any size is a stream. (Ck-12. org, Streams and Rivers)

River: A river is a large stream that flows downhill in a channel (ibid)

Groundwater: Groundwater is rain or snowmelt that seeps down through the soil until it reaches rock material that is saturated with water. It is stored in the spaces between rock particles (no, there are no underground rivers or lakes).(Water Education Foundation)

Fun Fact: Typically, groundwater is naturally clean and safe to drink. Because the soil on top acts as a filter, groundwater is usually free of micro-organisms that may cause disease.

Aquifer: An aquifer is a body of porous rock or sediment saturated with groundwater. Groundwater enters an aquifer as precipitation seeps through the soil. It can move through the aquifer and resurface through springs and wells. (National Geographic)

Reservoir: A reservoir is an artificial lake where water is stored. Most reservoirs are formed by constructing dams across rivers. A reservoir can also be formed from a natural lake whose outlet has been dammed to control the water level. The dam controls the amount of water that flows out of the reservoir. (National Geographic)

Fun Fact: More than 40 percent of the inflow to Lake Shasta — the state's largest reservoir — comes from springs in the northern Sierra Nevada and southern Cascade Mountain ranges.

Estuary: Estuaries and their surrounding wetlands are bodies of water usually found where rivers meet the sea. Estuaries are home to unique plant and animal communities that have adapted to brackish water—a mixture of fresh water draining from the land and salty seawater. (National Oceanic and Atmospheric Administration). Words used synonymously: inlet, sound

Fun Fact: Some people say that difference between an *estuary* and a *bay* is that an estuary has an connection to one or more flowing rivers: a bay doesn't, necessarily. Although the Klamath River doesn't have a "bay" at the end of, here's a good definition in case you were wondering:

Bay: A broad inlet of the sea where the land curves inward. A bay is a body of water partially surrounded by land. (National Geographic Society)

Beach: A beach is a narrow, gently sloping strip of land that lies along the edge of an ocean, lake, or river. (Beaches are usually made of sand, tiny grains of rocks and minerals that have been worn down by constant pounding by wind and waves. (National Geographic Society)

Fun Fact: River 'beaches' are more properly called 'river banks' and 'sand bars,' but most people would agree that they are certainly also 'beaches'.

Ocean: An ocean is a continuous body of salt water that is contained in an enormous basin on Earth's surface. The major oceans and their marginal seas cover nearly 71 percent of Earth's surface, with an average depth of 3,688 metres (12,100 feet). (Encyclopedia Britannica)

And in case you were wondering, as the author of this lesson was, what the difference between an *ocean* and a *sea* was, I looked it up for you! (Hey!. I can *hear* you groaning)

Sea: A sea is defined as a portion of the ocean that is partly surrounded by land. Given that definition, there are about 50 seas around the world. But that number includes water bodies not always thought of as seas, such as the Gulf of Mexico. (National Geographic)

Klamath Basin Sediment Game Instructions:

You, like every student, will be travelling around the river basin as an individual grain of sand.

The worksheet table will help you keep track of where you go . First, write down where you start. When it's your turn, roll the dice and find out where your next station is. When you arrive at a new station:

- Write down where you have arrived in the "Location ended" 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:

	Location started	Location ended	Transport process (What happened?)
1.	Mouth/Lips	Estuary	Wind and waves took me back up the river
2.	Estuary		

Fun Fact: Actually, the word "dice" is plural. I only used that here in the instructions because a lot of people don't know that. Since you're only rolling one at a time in this game, the proper word to use is actually "die." Not the nicest name, I know. But when you roll the die, you're rolling only one and not the usual two that you most often play with. When you roll the dice, you better be rolling at least two of them, right?

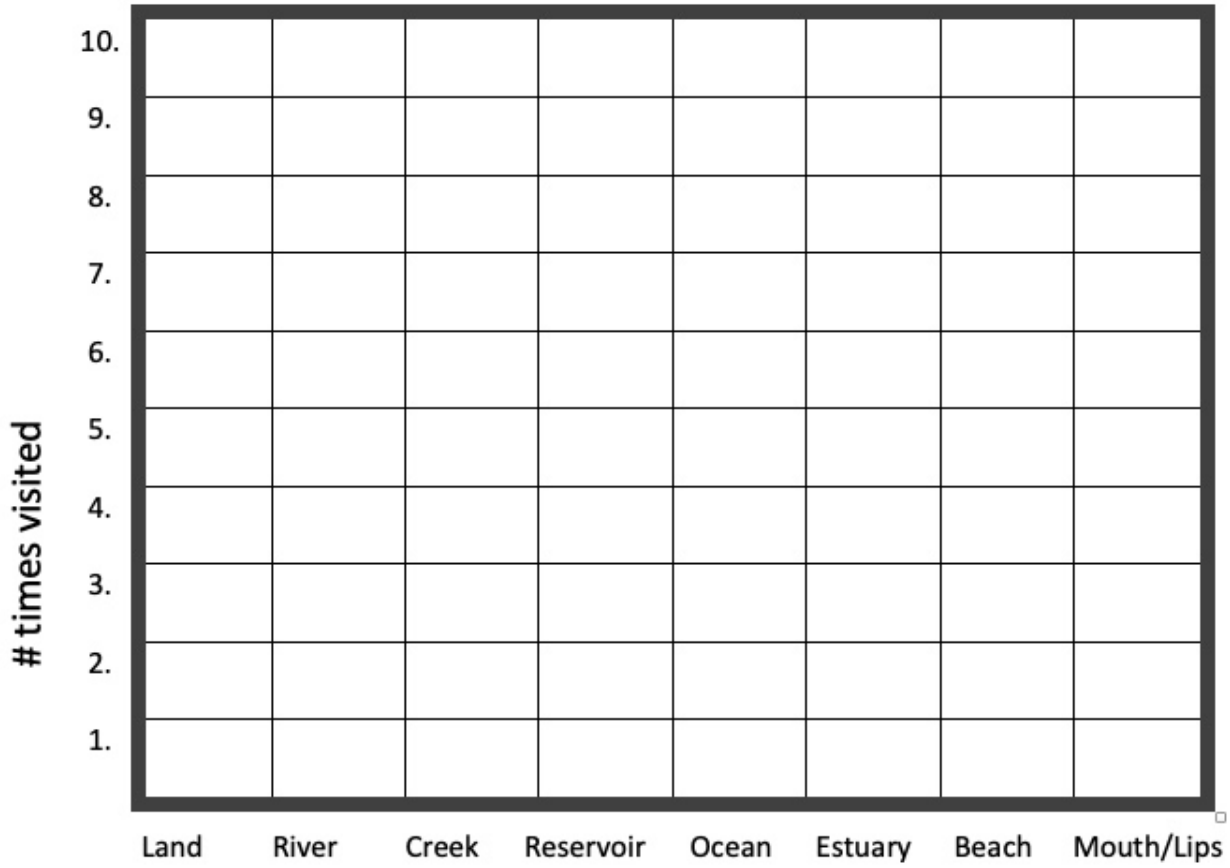
Name _____ Klamath Basin Sediment Game

	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.			
19.			
20.			

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

Estuary_____ Mouth/Lips_____ Ocean_____ Creek_____
River_____ 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. On the basis of the class results:

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 river basin as a sediment grain in first-person. What happened to you?

8. Draw your journey through the watershed with arrows: