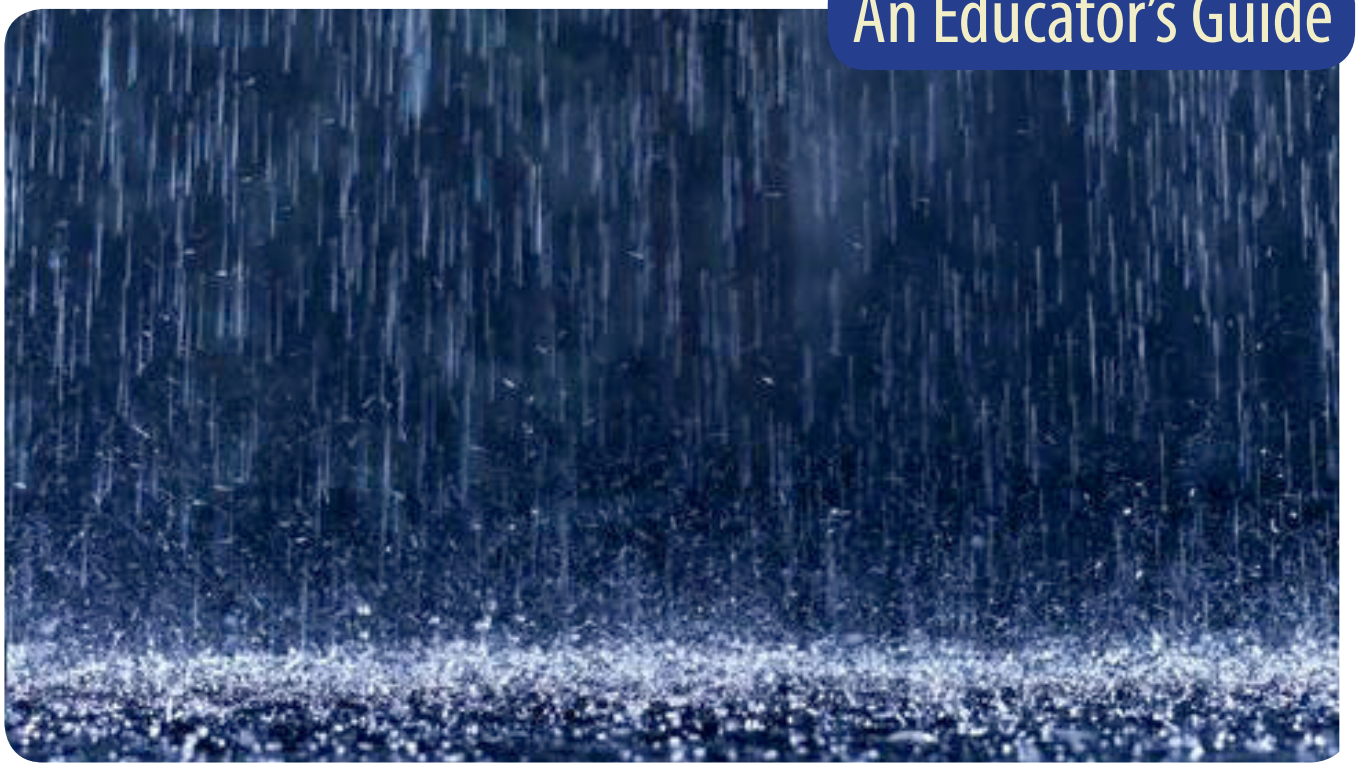
An Educator's Guide



Water Spotters

Rain, Weather and Change
A curriculum to explore Colorado's water cycle and weather.

INSIDE

- Essential Questions
- Strategies for Teaching
- Engaging Activities
- Activities to Extend Learning
- Correlation to Standards

CIRES Education & Outreach

cires.colorado.edu/education/outreach/waterspotters/

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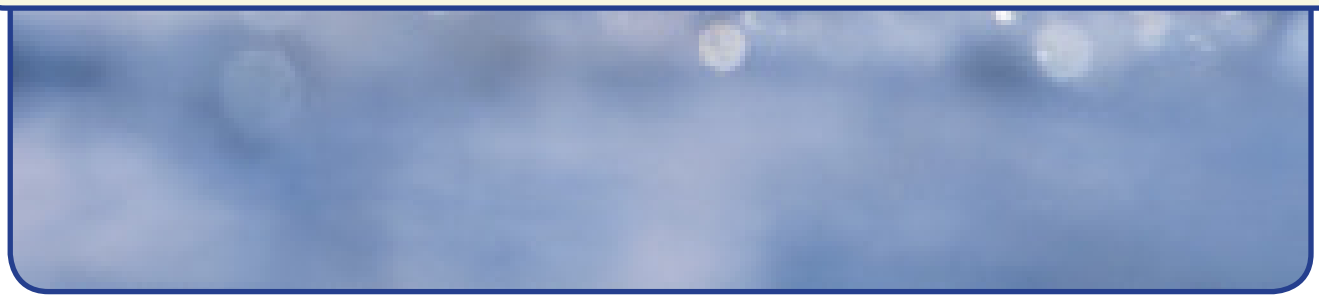

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Water Spotters Overview

Water Spotters is a curriculum that can be implemented in a variety of settings, depending on the format of your program. Water Spotters introduces students ages 11-15 to the water cycle through citizen science. The curriculum is organized into four modules that are further divided into two activities. Each module includes a concept introduction activity and is followed by a more in depth activity. Each activity includes a teacher's guide and a student handout with directions for students. Key Concepts provide supporting information for the teacher on new concepts introduced in modules 1-4.

The hydrologic cycle is important to many areas of scientific study. It is our goal to offer a few key examples of activities that demonstrate the science around water and weather. These activities give teachers a jumping off point into many hydrologic concepts.

Understanding the Water Cycle

In the first two activities, students are introduced to the water cycle through a shared experience that will inspire their creativity and build on prior knowledge by creating a diorama of the water cycle that they will then revisit throughout the curriculum.

Activity A: Understanding the Water Cycle
Students reflect on what they know about the water cycle with this hands-on activity. It is designed to reinforce their correct concepts, give them an opportunity to rethink misconceptions and build their knowledge throughout the course of the curriculum by revisiting their dioramas and adding information as their knowledge increases.

Activity B: The Water Spotter Protocol
Students learn some methods to study water. This activity includes a video overview of the Water Spotters project, the water sample collection process and an overview by Dr. Noone of what water isotopes are and how he uses water isotopes to track precipitation.

Exploring Watersheds and Water Budgets

In the first module, students are introduced to the water cycle. Now students will learn how the water cycle and watersheds are related. Students will also learn about the concept of a water budget and how to calculate a local water budget. We also revisit our water cycle dioramas to incorporate watershed concepts.

Activity A: Exploring watersheds and water budgets
Students explore the concept of a watershed. This hands-on activity allows students to revisit their dioramas to reinforce water cycle and watershed processes, a key concept throughout the Water Spotters curriculum. Plus this also begins to introduce the idea of an area water budget.

Activity B: Creating a school yard water budget
Students learn that there is a balance between water coming into the region from precipitation and water leaving the region through evaporation.

Understanding Weather

The Water Spotters weather stations will be integral to these activities and students learn about tracking weather and the factors that influence weather.

Activity A: Tracking Weather
Students will use both the school weather station and the Internet to collect and record weather measurements for your city as well as two other cities over a two-week period (minimum). These measurements should not take longer than 5-10 minutes daily, so you can also complete the first *Factors that influence Temperature* activities / lessons during the same time period after the students have gathered and recorded the daily weather data each day.

Activity B: Weather Factors
Students will compare weather data for locations at different elevations to discover the effect that elevation has on temperature.

Activity C: Weather Factors
How do land and water interactions contribute in determining the temperature of a region? Students will compare weather data between inland and coastal cities to determine how land and water differences affect temperature. Students will complete a short lab comparing the heating rates of soil and water. Students will then apply their results to develop an understanding of how local geography influences the temperature of a region.

Understanding Water Chemistry

The final two activities introduce students to water chemistry through a familiar experience, the water cycle, with the new concept of isotopes in water. We also revisit our water cycle dioramas to incorporate what we learned about isotopes in water and the way they move through the water cycle.

Activity A: Atoms, Elements and Isotopes
Students revisit and review knowledge of atoms and elements. These hands-on activities reinforce their knowledge and create a firm foundation to introduce the concept of isotopes. With a variety of activities that scaffold knowledge, students are then prepared for the final activity which models water isotopes through the water cycle.

Activity B: Journey through the Water Cycle
Students learn the difference between heavy and light water molecules and how they differ as they travel through the water cycle. This session builds the ability to analyze existing knowledge of the water cycle and construct new knowledge about the isotopes of water.

Project Resources

CIRES Education Outreach Water Spotters Website
http://cires.colorado.edu/education/outreach/waterspotters/

Dr. David Noone's Website
http://climate.colorado.edu/

Module 1: Water Cycle Foundation

Activity A – Making a Water Cycle Diorama

Overview

In this activity students' Concept diagrams/ dioramas can be shaped over time. Since all the Water Spotter activities are designed to build on each other you might consider using this introductory activity to allow students to reflect on their water cycle conceptions and ask probing questions without too much instruction. Review the students' created water cycle dioramas before beginning the next activity to identify any major misconceptions or gaps in knowledge that may need more scaffolding. You will revisit the concept dioramas throughout the unit of study.

Objectives

Students will:

- Understand basic knowledge of the water cycle.
- Learn strategies for building knowledge of the water cycle.
- Create a water cycle diorama for unit study.

Time

45 minutes - After a brief introduction to the activity, allow 20 - 30 minutes for students to create their dioramas. Then in the final class time debrief with the students. NOTE: As students work at different paces be prepared to flex according to the pace of your students.

Materials

- Card Stock
- Construction paper
- Glue and scissors
- Colored pencils or markers

Teacher Preparation

- Prepare the materials needed for students to create their dioramas.
- *Optional*: prepare a large sheet of bulletin board paper to create a concept map or a 2D diorama model to debrief and compile the class's ideas about the water cycle.
- *Optional*: If you choose to use The Water Cycle Rap video in the debriefing, have all the technology set up to do so.

Vocabulary

Accumulation - the process in which water pools in large bodies (like oceans, seas and lakes).

Condensation - the process in which water vapor (a gas) in the air turns into liquid water. Condensing water forms clouds in the sky. Water drops that form on the outside of a glass of icy water are condensed water.

Evaporation - the process in which liquid water becomes water vapor (a gas). Water vaporizes from the surfaces of oceans and lakes, from the surface of the land, and from melts in snow fields.

Precipitation - the process in which water (in the form of rain, snow, sleet, or hail) falls from clouds in the sky.

Subsurface Runoff - rain, snow melt, or other water that flows in underground streams, drains, or sewers.

Surface Runoff - rain, snow melt, or other water that flows in surface streams, rivers, or canals.

Transpiration - the process in which some water within plants evaporates into the atmosphere. Water is first absorbed by the plant's roots, then later exits by evaporating through pores in the plant.

Procedure

Part 1: Introduction

Most middle school students will be familiar with the water cycle. You may begin the lesson with a brief activity to introduce them to this concept. Alternatively, you can help the students understand the water cycle with greater sophistication. Do not coach students to draw lines that indicate the flow of the process; this is instead a good opportunity to evaluate your students' depth of knowledge and understanding.

Part 2: Facilitating and Debriefing

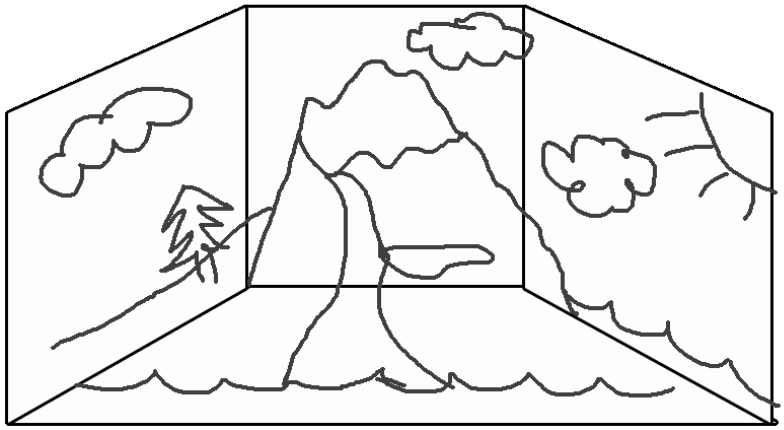
Tell the students that they are now going to have approximately 20 minutes to create their dioramas. You may wish to go over the student worksheet with your class or have them proceed with reading the directions on their own. You might mention to the students that they will use this diorama again in future activities as reference and to add labels and comments as you progress through the unit.

There are several ways to approach the debriefing process with your students. Regardless of which format you decide, make sure you cover the core concepts and vocabulary of the water cycle.

- Go around the room and ask each student pair to share briefly the key features of the water cycle and the interactions
- Show the video *The Water Cycle Rap* http://www.youtube.com/watch?v=i3NeMVBcXXU Have the students listen for the processes of the water cycle and add or change their labels
- Science for Ohio has a great Water Cycle resource. Click on "Ready to Print" then select Student Information Pages http://www.cas.muohio.edu/scienceforohio/Water1/index.html

Resources

USGS Water Cycle Diagram
http://ga.water.usgs.gov/edu/watercycle.html
CoCoRaHS Water Cycle Video
https://www.youtube.com/watch?v=ZzY5-NZSzVw&feature=player_embedded#!



NAME: _____ **DATE: _____**

What do you know about the water cycle?

Water is always being recycled through our environment. We say water has a cycle it moves through so it really does not have a beginning or an end. Work with a partner to create a diorama of the water cycle. Label as many of the processes as you can.

Water Spotters background: The water cycle is a closed system. That is the amount of water that exists today, existed billions of years ago as well. It may be in different states at different times but the amount is constant.
The Water Spotters activities will explore different aspects of the water cycle, and help you to understand how we study this special resource.

Goal:
When you complete this activity and compare your diorama with your classmates, you and your teacher will have a good idea of your prior knowledge of the water cycle.

Materials

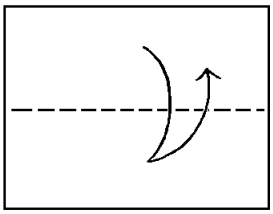
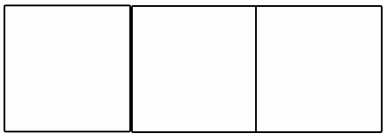
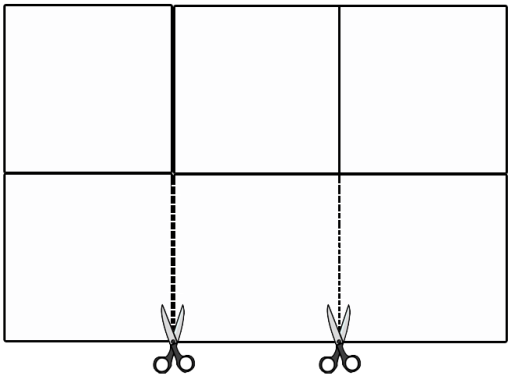
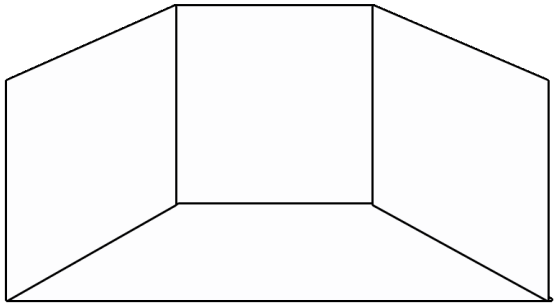
Card stock	Construction paper	Markers
Scissors	Glue	Colored Pencils

Procedure

1. Read through the directions for how to make a diorama on the next page. Be sure to ask for clarification if you are unsure about any step in the process.

2. You will be asked to explain your diorama. So discuss with your partner the key features you include so you both understand the water cycle you have created.

3. You will add to your diorama throughout this unit. Consider leaving a little space to add labels and comments later.

How to Make your Diorama	
1. Take a piece of card stock and fold it in half.	2. Then fold your paper into thirds.
	
3. Next, open up the sheet of paper to reveal the folds. Cut two lines half way up as shown in the picture. (dotted lines)	4. Now you are ready to fold up your diorama and make your model of the water cycle. When you are finished – glue the bottom flaps.
	

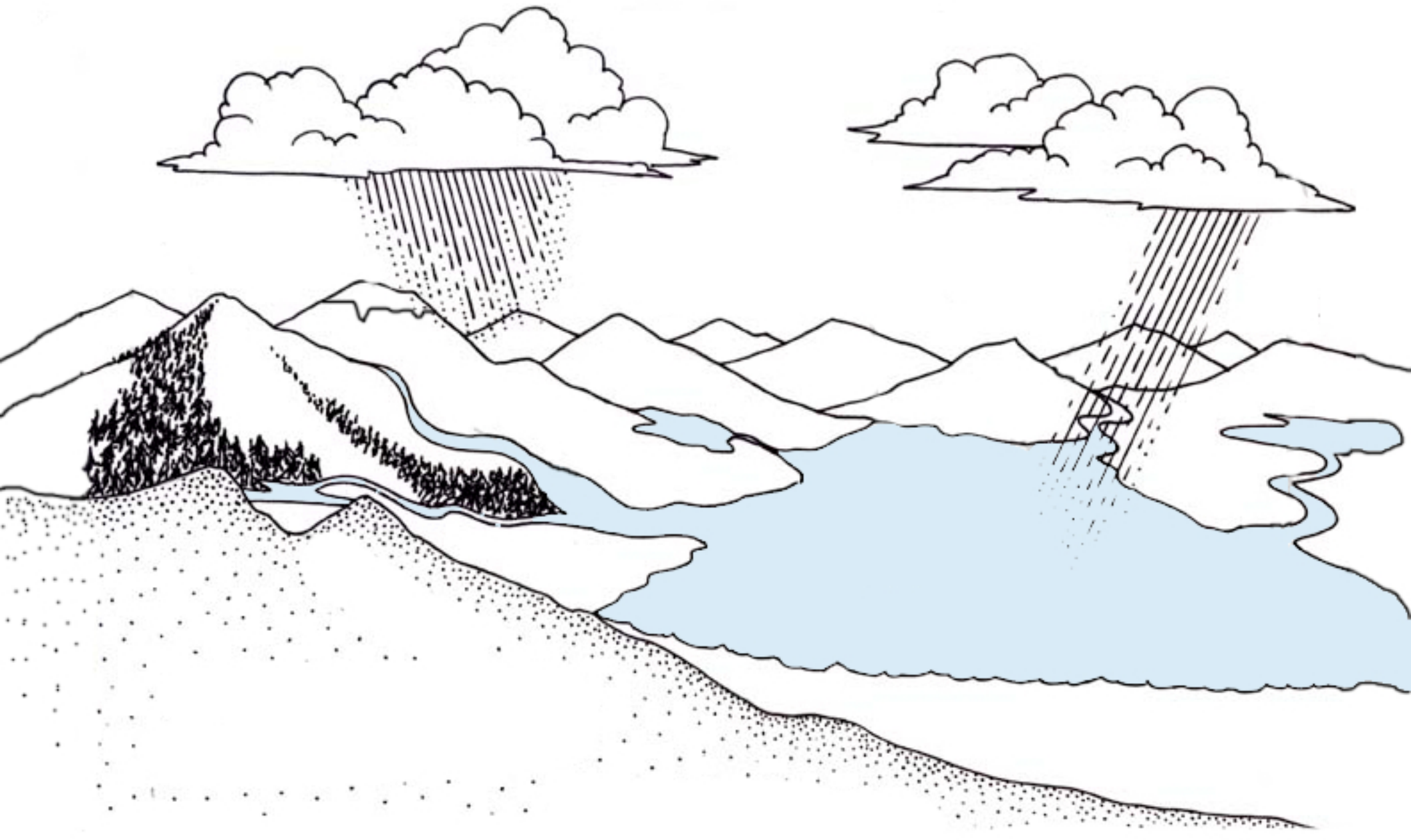
HINT: Create your diorama while it is flat – then glue up the flaps!

Reflection questions (preparing to present):

1. What are the key features of your diorama?

2. Explain the water cycle flow depicted on your diorama.

3. Consider if you have any questions about the water cycle after you have made your diorama. What questions about the water cycle do you have?



Module 4: Water Chemistry

Activity B: Water Isotope Journey

Overview

The movement of water and energy through the earth's system shapes our weather and climate. We use a conceptual model called the water cycle to describe the important reservoirs that store water on the planet and to demonstrate how these reservoirs are interconnected. Since water is a limited resource, water on Earth today was also present when the dinosaurs roamed the planet. During those millions of years, however, water may have changed form many times as it has journeyed through the water cycle.

This activity helps students explore some of the major pathways that link reservoirs in the water cycle. It also shows students that an average water molecule will spend more time in reservoirs with long residence times than reservoirs with short residence times. The first portion of the lesson is based on "The Incredible Journey," developed by Museum of the Earth. The second half of the lesson examines how 'heavy' water, which contains naturally-occurring heavy isotopes of either oxygen or hydrogen, experiences evaporation and condensation differently than 'light' water ($H_2{}^{16}O$). While light water preferentially evaporates, heavy water preferentially condenses. Because these processes are sensitive to temperature and relative humidity, they can be useful indicators of climatic conditions. As a result, scientists use isotopic measurements to link water cycle processes to climate and to study climate change.

Objectives

Students will learn that:

- In the water cycle, molecules move amongst different reservoirs (e.g. ocean, atmosphere, lakes, biomass).
- Different reservoirs exhibit distinct residence times. A residence time is the amount of time an **average** molecule is likely to spend in that reservoir before moving onto another (e.g. days in the atmosphere, weeks in plants and soil, months in rivers, tens of years in lakes, nearly one hundred years in glaciers, and thousands of years in groundwater and the ocean).
- Water molecules must change phase to move from some reservoirs to others. Phase changes are involved when ocean, lake, river, or soil water evaporates, plants transpire, snow or ice sublimates, and vapor condenses and precipitates.
- Because heavy and light water molecules are affected differently by condensation and evaporation processes, they move through the water cycle differently. Heavy molecules are more likely to stay in liquid components of the water cycle. As a result, atmospheric vapor is isotopically lighter than the ocean.

Vocabulary

Condensation - the process in which water vapor changes into liquid water.

Deuterium - A heavy isotope of hydrogen, composed of one proton, one electron, and one neutron. The molecular mass of deuterium is two.

Evaporation – The process by which liquid water changes into vapor.

Heavy water – A water molecule composed of at least one heavy isotope of either hydrogen or oxygen (e.g. HDO, $H_2{}^{18}O$).

Hydrogen - The first element of the periodic table. A hydrogen atom is composed of one proton and one electron, giving it a molecular mass of one.

Isotope - Atoms of the same element that have the same numbers of protons and electrons but different numbers of neutrons.

Light water - A normal water molecule composed of two normal hydrogens and one normal oxygen (e.g. H_2O).

Reservoir – A space in which water is accumulated and stored, such as a lake, a glacier, or the atmosphere.

Residence time – The amount of time an average molecule is likely to spend in a reservoir before moving onto another.

Sublimation – The process by which snow and ice change directly into water vapor without first melting to liquid.

Transpiration – The passage of water vapor through plants to the atmosphere.

Activity 1: The Water Cycle Game

Background

The movement of water from oceans to atmosphere, from land to sea is described by the water cycle. This activity shows students six possible reservoirs in the water cycle (ocean, atmosphere, ice and glaciers, soil and surface waters, plants (biomass), and groundwater) and how they are connected through processes such as evaporation, transpiration, and precipitation. While this activity highlights some of the major components and links in the water cycle, it does not provide an exhaustive list. Students will move through the water cycle by rolling dice.

This activity also teaches students about water residence times in the various water cycle reservoirs. For example, on average, a water molecule spends thousands of years in the ocean but only days in the atmosphere. Students will encounter a higher probability of staying at the ocean station for repeated rolls of the dice than at the atmosphere station. Please note that the probabilities given are not exact; they are meant to emphasize relative differences in residence times.

Materials for 6 student stations

6 reservoir signs (see attachment)
6 number cubes (dice)
6 printouts of rolling directions
6 containers of colored beads (use one color for each station)
String for each student to make one bracelet
A **Water Cycle Processes Worksheet** for each student
A **Residence Times Worksheet** for each student

Teacher set up before activity

1. Select 6 locations around the room to serve as 6 reservoir stations.

2. Print out the Water Cycle Processes reservoir signs and hang one at each station.
3. Place a container of beads at each station. (Each reservoir should be assigned a distinct color.)
4. Place a set of Water Cycle Processes rolling directions and several dice at each station.
5. Print out a **Water Cycle Processes** and **Residence Times** worksheet for each student.

Pre-activity discussion
Ask students to refer to their water cycle dioramas from Module 1. What are some of the major reservoirs they drew? Ask students to name the processes by which water molecules move from one reservoir to another. Be sure that students are familiar with transpiration and sublimation. You may want to write these key process names on the board: evaporation, condensation, precipitation, transpiration, sublimation, melting, surface transport (includes soil runoff and streamflow), percolation.

Q: In which reservoir is most of the Earth's water stored?

Q: In which reservoir is most of the Earth's freshwater stored?

Reference: http://ga.water.usgs.gov/edu/watercyclesummary.html#global

The amount of time an average water molecule will spend in any one reservoir before moving onto another determines the reservoir's residence time. Earth's largest reservoir, the ocean, has a very large residence time, yet groundwater may have an even longer residence time despite its smaller reservoir size. Ask students to think about what factors besides size might influence a reservoir's residence time.

Reference:
http://www.windows2universe.org/earth/Water/water_cycle_climate_change.html

Activity directions
1. Students will travel through the water cycle as normal water molecules. Pass out a worksheet and pre-cut string to all students and distribute them evenly amongst the six reservoirs to begin their water cycle journey.

2. Students will move through the water cycle by rolling dice. The rolling directions at each reservoir tell students whether they should stay at the same station or move on to another. (More than one die at each station should prevent long wait times).

3. Students will collect one bead every time they roll a die, even if their roll indicates they should stay at the same station. The bracelets they string will

record their journey through the water cycle, and the beads will indicate the amount of time spent in each reservoir. Students will also record the reservoirs they visit on their worksheets.

4. Students should continue to roll dice and move about the room until they have filled in the first column of the worksheet and collected and strung a bead for each reservoir visited.

Post-activity discussion
Part 1. Students should complete the second column of their **Water Cycle Processes** worksheets by naming the processes by which their water molecule moved from one reservoir to another.

Q: According to your journey through the water cycle, which reservoirs contributed water to the atmosphere? Are there other possible sources of water to the atmosphere that you did not encounter?

Q: Name three processes by which water moves to the atmospheric reservoir.

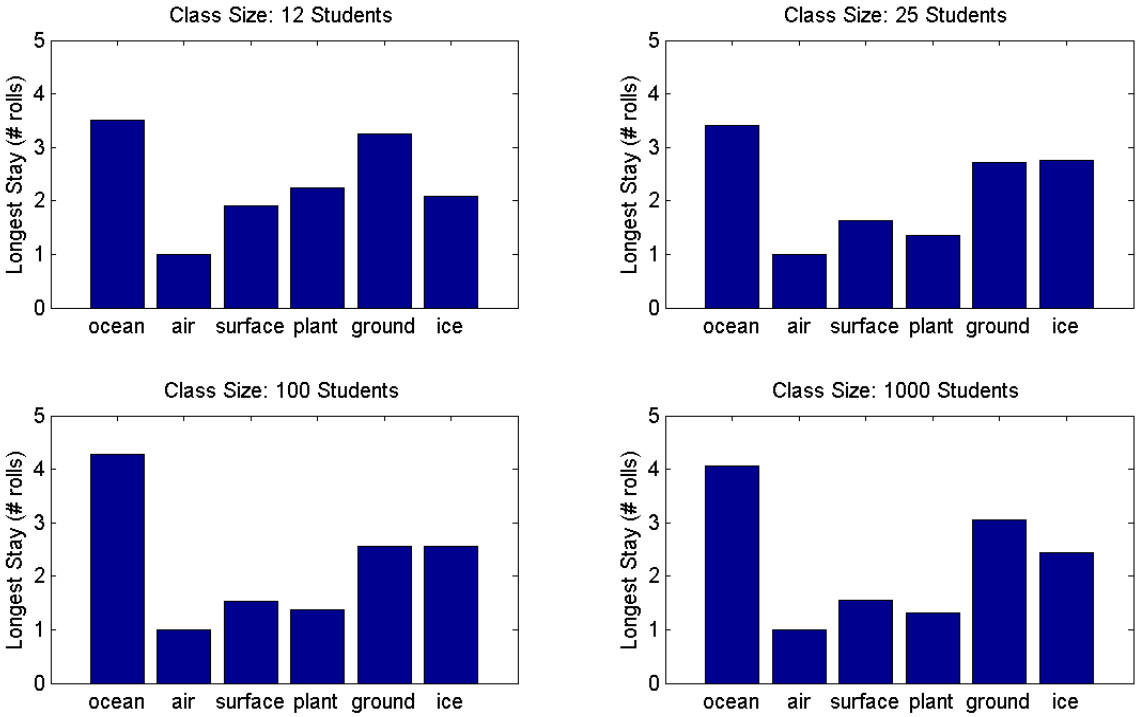
Part 2. Students should complete the **Residence Times Worksheet** and calculate their longest stay in each reservoir. An easy way to do this is to count the longest chain of any one color of beads. For example, if a student rolled ocean-ocean-ocean-atmosphere-ocean, their longest stay in ocean is 3 rolls.

Part 3. As a class, calculate the average longest stay for each reservoir. Make a bar chart of the results.

Q: How do the class-average results compare qualitatively with the residence times listed on the **Residence Times Worksheet**?

Q: Which is more representative of the average molecule's journey: the collective class results or an individual student's results? Why?

The larger your class, the more representative your average longest stays should be of the reservoir residence times on planet Earth. Examples below show average longest stays for class sizes ranging from 12 to 1000 students.



Activity 2: Heavy and Light Water

Background

In the second half of the lesson, students learn that isotopically heavy and light water molecules experience different probabilities of evaporating and condensing (as a result, water vapor in the air is nearly always isotopically lighter than ocean water and surface freshwater). These probabilities will be determined by rolling dice. They are not meant to reflect real-world probabilities but to emphasize differences between heavy and light molecules for the sake of the lesson.

Differences in the probabilities of evaporating and condensing between heavy and light water change with environmental conditions such as temperature and humidity. Consequently, by tracking the relative amounts of heavy and light water, say, in a sample from a lake or an ice core from a glacier, scientists can infer changes in regional and even global climate.

Materials

1 die per pair of students
Light Water Worksheets for half of the class
Heavy Water Worksheets for the other half

Pre-activity discussion

In an earlier lesson, your class learned about atomic structure and isotopes.

Q: What is the difference between an atom and its isotope?
When either hydrogen or oxygen contain extra neutrons, they have more mass and are therefore called heavy isotopes. Similarly, water molecules containing either a heavy hydrogen or oxygen are called heavy water.

Refer to the **Water Cycle Processes Worksheet**.

Q: Of the three processes you named that contribute water to the atmosphere, do you expect any of these to transport light water preferentially over heavy water? If so, which ones? Can you guess why?

Activity directions
1. Students should work in pairs. Provide each pair a single die, one **Light Water Worksheet** and one **Heavy Water Worksheet**. Assign one student to be the light water molecule and the other to be the heavy water molecule.

2. Pairs will roll their die 25 times to determine whether they evaporate, condense, precipitate, or re-evaporate in a mini-water cycle between the ocean and atmosphere. One student will follow the rolling directions on the **Light Water Worksheet**, while the other follows the directions on the **Heavy Water Worksheet**. Only one person should roll the die but both students should track their molecules. Students should complete their worksheets.

Post-activity discussion (stay in pairs but discuss as a class)

Q: What do the rolling directions represent for each type of water molecule?

Q: Comparing the light and heavy water rolling directions, which water molecule (light or heavy) is likely to spend more time in the ocean? Did you find this to be the case during your journey? Which partner circled ocean the most number of times?

Q: Which water molecule is likely to spend more time in the atmosphere? Did you find this to be the case? Which partner circled air the most number of times?

Q: Based on the class's collective answers to the questions above, which of the three reservoirs do you expect is isotopically heaviest? (A: Ocean) Which is isotopically lightest? (A: Air)

Each pair should compare the number of arrows from cloud to air and cloud to ocean.

Q: Of the two molecules, which was more likely to rain out into the ocean and which was more likely to re-evaporate from cloud to vapor? (A: Heavy and Light, respectively).

Q: Since heavy water is more likely to rain out of the atmosphere, do you expect the air to be isotopically heavier or lighter the farther you travel from the ocean? (A: Lighter since precipitation will occur but the air mass will not be replenished by fresh ocean water evaporation).

Q: Since precipitation forms from vapor, do you expect rain that falls in Denver to be isotopically heavier or lighter than rain that falls in San Francisco, on the California coast? (A: Lighter).

As an extension, you can explain to students that differences in the probabilities of evaporating and condensing between heavy and light water molecules become larger when temperatures are colder. As a result, Denver's atmospheric vapor and rainwater both become lighter as temperatures drop.

Additional Resources

The Incredible Journey curriculum
www.in.gov/dnr/nrec/files/pwdice.pdf

The Hydrologic Cycle, PhysicalGeography.net:
http://www.physicalgeography.net/fundamentals/8b.html

Water Cycle Tables, Rain and Evaporation, Windows to the Universe:
http://www.windows2universe.org/earth/Water/water_cycle_climate_change.html

Summary of the Water Cycle, USGS:
http://ga.water.usgs.gov/edu/watercyclesummary.html#runoff

Information about the Hydrogen Atom:
http://www.chemicalelements.com/elements/h.html

Isotopes in Water: http://wwwrcamnl.wr.usgs.gov/isoig/res/funda.html

MESA
WATER SPOTTERS

OCEAN

If you roll…	go to reservoir…
1	ocean
2	ocean
3	ocean
4	ocean
5	atmosphere
6	atmosphere

MESA
WATER SPOTTERS

ATMOSPHERE

If you roll…	go to reservoir…
1	ice/glacier
2	ice/glacier
3	ice/glacier
4	soil/surface
5	soil/surface
6	ocean

MESA
WATER SPOTTERS

SOIL AND SURFACE WATERS

If you roll…	go to reservoir…
1	ocean
2	soil/surface
3	plant
4	groundwater
5	groundwater
6	atmosphere

MESA
WATER SPOTTERS

PLANT

If you roll…	go to reservoir…
1	plant
2	plant
3	plant
4	atmosphere
5	atmosphere
6	atmosphere

MESA
WATER SPOTTERS

ICE AND GLACIER

If you roll…	go to reservoir…
1	ice/glacier
2	ice/glacier
3	ice/glacier
4	soil/surface
5	soil/surface
6	atmosphere

MESA
WATER SPOTTERS

GROUNDWATER

If you roll…	go to reservoir…
1	groundwater
2	groundwater
3	groundwater
4	groundwater
5	soil/surface
6	ocean

Water Cycle Processes Worksheet

Name_____ **Date**_____

Instructions: You are a water molecule about to embark on a water cycle journey. Write the name of the reservoir you start in on line #1. You will move from reservoir to reservoir by rolling dice. Record each reservoir you visit **every time** you roll the dice, even if you are instructed to stay at the same reservoir for repeated rolls. Continue to roll until you have filled in the left column of your worksheet. After you have completed your water cycle journey, your teacher will ask you to fill in the right column of your worksheet by naming the processes by which you moved from one reservoir to another. An example is shown below.

Example

Reservoir	Process
1. ocean	A. start
2. ocean	B. storage
3. atmosphere	C. evaporation
4. glacier	D. precipitation (snow)

Your Journey

Reservoir	Process
1. _____	A. start
2. _____	B. _____
3. _____	C. _____
4. _____	D. _____
5. _____	E. _____
6. _____	F. _____

Reservoir

7. _____
8. _____
9. _____
10. _____
11. _____
12. _____
13. _____
14. _____
15. _____
16. _____
17. _____
18. _____
19. _____
20. _____
21. _____
22. _____
23. _____
24. _____
25. _____

Process

G. _____
H. _____
I. _____
J. _____
K. _____
L. _____
M. _____
N. _____
O. _____
P. _____
Q. _____
R. _____
S. _____
T. _____
U. _____
V. _____
W. _____
X. _____
Y. _____

Residence Times Worksheet

Name_____ **Date**_____

Instructions: You have just completed your journey through the water cycle. Calculate your longest stay in each reservoir. An easy way to do this is to count the longest chain of any one color of beads on your water cycle bracelet. You can also look at your Water Cycle Processes Worksheet and count the number of **consecutive** times you visited each reservoir. For example, if you visited ocean, ocean, ocean, atmosphere, ocean, and then ocean, your longest stay in ocean is 3 and your longest stay in atmosphere is 1.

Longest Stay

Ocean	_____	**Soil/Surface**	_____
Atmosphere	_____	**Plant**	_____
Ice/Glacier	_____	**Groundwater**	_____

Questions

1. Did you travel to all six of the reservoirs?

2. Rank the six reservoirs according to the longest amount of time you spent in each one.

3. At which reservoir was your longest stay?

4. At which reservoir was your shortest stay?

Here are typical residence times of water on planet Earth:

Reservoir	**Average Residence Time**
Ocean	~3,000 years
Groundwater	100s to 1000s of years (depending on depth)
Ice/Glacier	10s of years
Soil/Surface	months (soil, rivers); 10s of years (lakes)
Plant (biomass)	weeks
Atmosphere	days

5. Was your journey typical of an average water molecule? Make an argument for or against.

Light Water Worksheet

Name_____ **Date**_____

Instructions: You are a light water molecule (H_2O) about to cycle amongst the ocean (liquid), the atmosphere (vapor), and clouds (liquid). You will evaporate, condense, re-evaporate, or precipitate as you move from one reservoir to another. Your journey will be determined by rolling a die with your partner and following the directions below. Your goal is to keep track of your journey by drawing arrows and circling reservoirs. See the other side of the worksheet for an example.

Rolling Directions (only one person should roll)

If you roll…	If you are at OCEAN…	If you are at AIR…	If you are at CLOUD…
1	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
2	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
3	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
4	Draw an arrow ocean→air	Circle air	Draw an arrow cloud→air
5	Draw an arrow ocean→air	Circle air	Draw an arrow cloud→air
6	Circle ocean	Circle air	Draw an arrow cloud→air

Your Journey

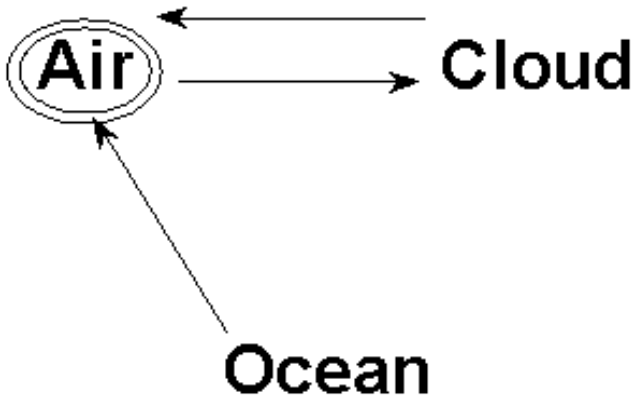
Start in the ocean!

Air Cloud

Ocean

Example:

You start in the ocean. You and your partner roll 2, then 4, then 6, then 2, then 5. You draw an arrow from ocean to air, then circle air, then circle air, then draw an arrow from air to cloud, then draw an arrow from cloud to air. You have just evaporated, stayed in the air for two turns, condensed to form cloud, and re-evaporated into vapor.



Heavy Water Worksheet

Name_____ **Date**_____

Instructions: You are a heavy water molecule (HDO or $H_2{}^{18}O$) about to cycle amongst the ocean (liquid), the atmosphere (vapor), and clouds (liquid). You will evaporate, condense, re-evaporate, or precipitate as you move from one reservoir to another. Your journey will be determined by rolling a die with your partner and following the directions below. Your goal is to keep track of your journey by drawing arrows and circling reservoirs. See the other side of the worksheet for an example.

Rolling Directions (only one person should roll)

If you roll…	If you are at OCEAN…	If you are at AIR…	If you are at CLOUD…
1	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
2	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
3	Draw an arrow ocean→air	Draw an arrow air→cloud	Draw an arrow cloud→ocean
4	Circle ocean	Draw an arrow air→cloud	Draw an arrow cloud→ocean
5	Circle ocean	Draw an arrow air→cloud	Draw an arrow cloud→ocean
6	Circle ocean	Circle air	Draw an arrow cloud→air

Your Journey

Start in the ocean!

Air Cloud

Ocean

Example:

You start in the ocean. You and your partner roll 2, then 4, then 6, then 2, then 5. You draw an arrow from ocean to air, then draw an arrow from air to cloud, then draw an arrow from cloud to air, then draw an arrow from air to cloud, then draw an arrow from cloud to ocean. You have just evaporated, condensed to form cloud, re-evaporated into vapor, condensed again to form cloud, and precipitated into the ocean.