INTRODUCTION TO THE CRITICAL ZONE

Overview
The *Critical Zone* supports terrestrial life on Earth. It is the region above and below the Earth surface, extending from the tops of the trees down through the subsurface to the bottom of the groundwater.

The US Critical Zone Observatory network consists of nine field stations, each located in a different climatic and geologic setting. CZO scientists observe and measure many of the same parameters at each site. Building a common set of measurements across a diverse range of environmental conditions allows scientists to examine the underlying factors responsible for ecosystem growth and resilience.

Water is one of the most important factors in any natural system. In this investigation we will look at three sites – each with a different amount of annual rainfall – and explore the behavior of water once it enters the Critical Zone.

Video Link: https://youtu.be/8gW-Vy7zFdU

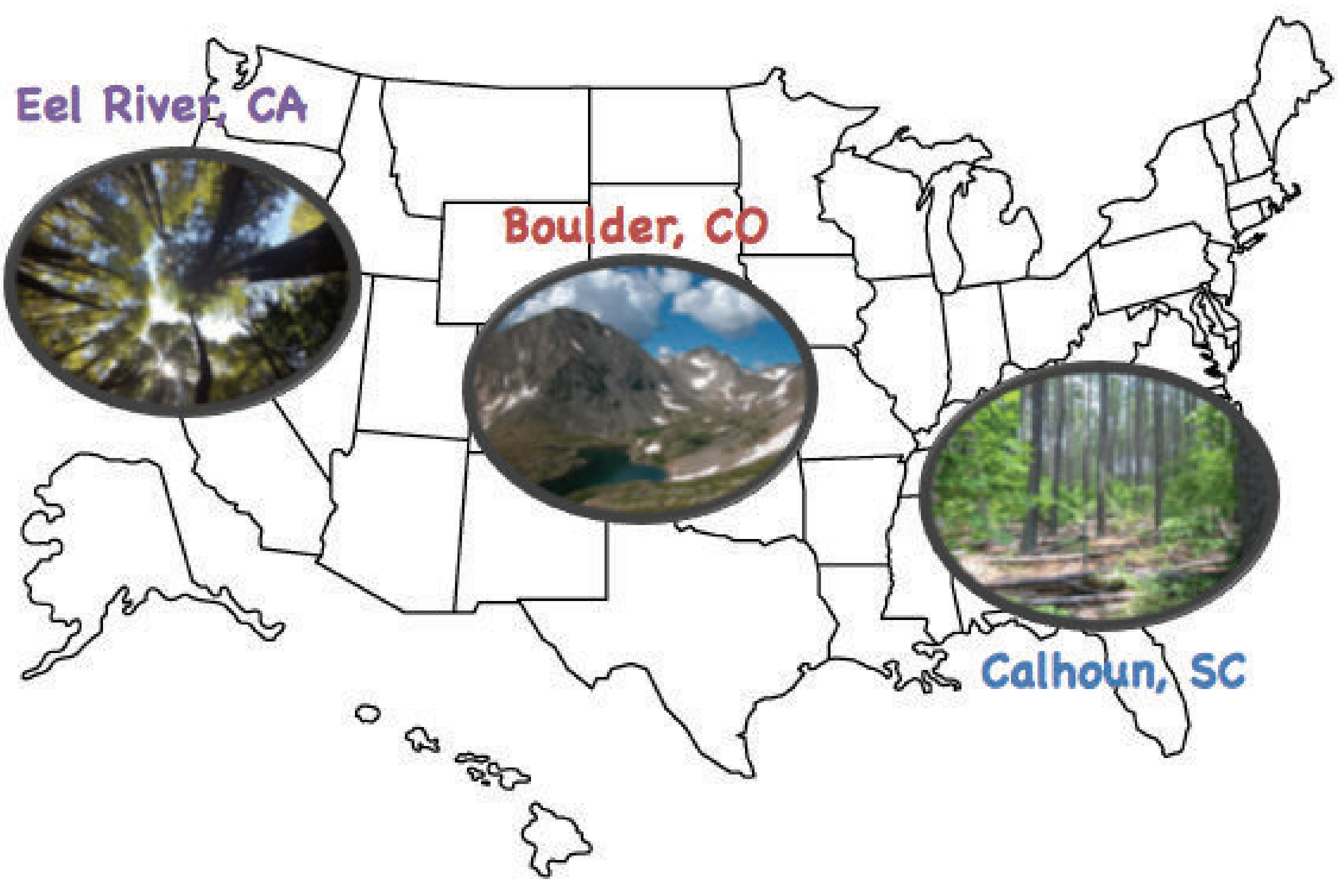


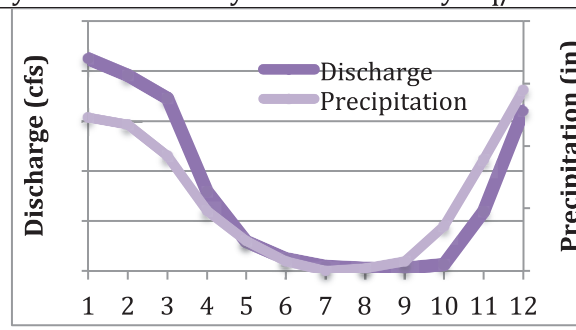
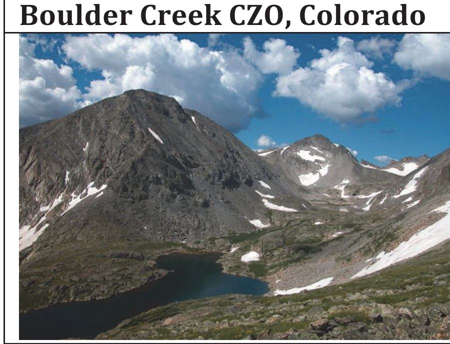
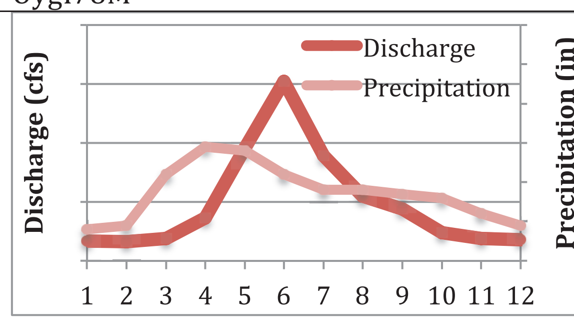
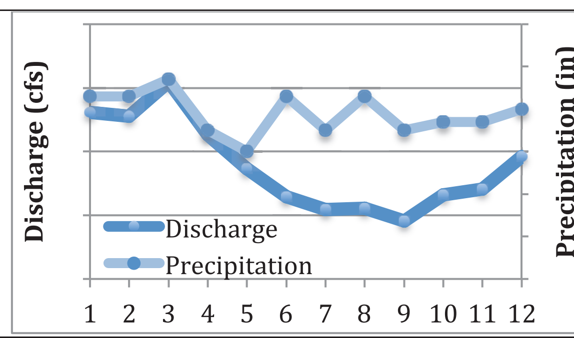
Figure 1: Location of the three Critical Zone Observatories featured in this activity.

Focus Question
What natural processes impact water as it enters and moves through the Critical Zone? Are these processes the same everywhere?

Objectives
Students will use data to examine and draw conclusions about hydrologic pathways in the Critical Zone.

Materials
Data and maps are provided within this document. Students should have internet access to watch short videos and complete a simple data search.

Table 1: Information about selected Critical Zone Observatories

Eel River CZO, California	**Video link ->**	http://criticalzone.org/eel/news/story/chris-wong-eel-river-czo-technician-and-youtube-celebrity-interviewed-by-kq/
	Elevation: 690 feet Watershed area: 248 mi^2 Forest: mixed conifer-deciduous Annual rainfall: 69 inches Max Temperature: 87F Min Temperature: 37F	
Boulder Creek CZO, Colorado	**Video link ->**	https://www.youtube.com/watch?v=0Upy0ygI78M
	Elevation: 5106 feet Watershed area: 307 mi^2 Forest: mixed conifer-deciduous Annual Rainfall: 21 inches Max Temperature: 88F Min Temperature: 21F	
Calhoun Forest CZO, S. Carolina		
	Elevation: 300 feet Watershed area: 759 mi^2 Forest: mixed conifer-deciduous Annual Rainfall: 47 inches Max Temperature: 92F Min Temperature: 28F	

Procedure
Answer the boxed questions on the accompanying answer sheet.
Compare three Critical Zone Observatories:

- Eel River, California
- Boulder Creek, Colorado
- Calhoun Forest, South Carolina

Maps at the back of this handout show the location of the observatories, and the summary chart on the previous page gives information for each, including elevation, annual *precipitation*, average temperature, and forest type. There are video links to two of the sites, Boulder and Eel, so that you can get a better view of the locations and learn a little more about each one. Additionally, the chart includes a graph of the seasonal distribution of rainfall, as well as the seasonal flow in a river that runs through each observatory.

The Critical Zone is where we live. It is where we grow our food, and where we get our water and most of the other resources that we use every day. We will consider the motion of water in time – in each month of the year – and in space, at three sites in the eastern, central, and western US.

- Begin by looking up data for your hometown. On the chart below, fill in the upper row with the name and data for your own site.
- Next, add the data from Table 1 for Eel, Boulder and Calhoun CZOs.

◈ Which CZO is most like your hometown? Explain why.

Teachers

Despite the fact that the Critical Zone is everywhere, the nine CZOs occupy environments that students may not be familiar with. For this reason we begin by asking students to find out about their hometown, so that they will have a baseline for comparison when we explore the CZ Observatories and the data gathered there. Most weather servers will have data for a town's elevation, precipitation and temperature (ex: the National Weather Service (weather.gov) the Weather Underground (wunderground.com) and the Weather Channel (weather.com)). Forest type is a little more difficult to acquire, but looking around outside should give students a good assessment. Many US locations will have mixed forest types, unless the town is at very high latitude or altitude (where conifers dominate) or at very low latitude where there may be few conifers. Towns with a tropical or otherwise warm climate may be dominated by broadleaf evergreen trees and shrubs. When comparing a hometown with the three CZOs selected here, most students will discover that there is no single CZO for which all categories match those for their town. They will need to use their judgment; is it more important that the elevation be comparable or the precipitation? Almost any thoughtful answer is a good one. An additional consideration may be the fact that many hometowns are highly urbanized. In this case it might be difficult to determine the type of landscape that was displaced by development.

Table 2

Site	Elevation	Annual Precip	Max Temp	Min Temp	Forest Type
Eel River CZO					Mixed conifer/ deciduous
Boulder CZO					Mixed conifer/ deciduous
Calhoun CZO					Mixed conifer/ deciduous

Examine Figure 2, the *Hydrologic Cycle*. The Sun heats Earth's surface and causes water to *evaporate*. Liquid water becomes water vapor in the atmosphere. Water vapor eventually *condenses* to liquid rain or solid ice/snow, and returns to the surface as precipitation. Water runs off/under the surface and returns to the ocean. This simple cycle operates with many different variations depending on the ecology and physical conditions within the Critical Zone.

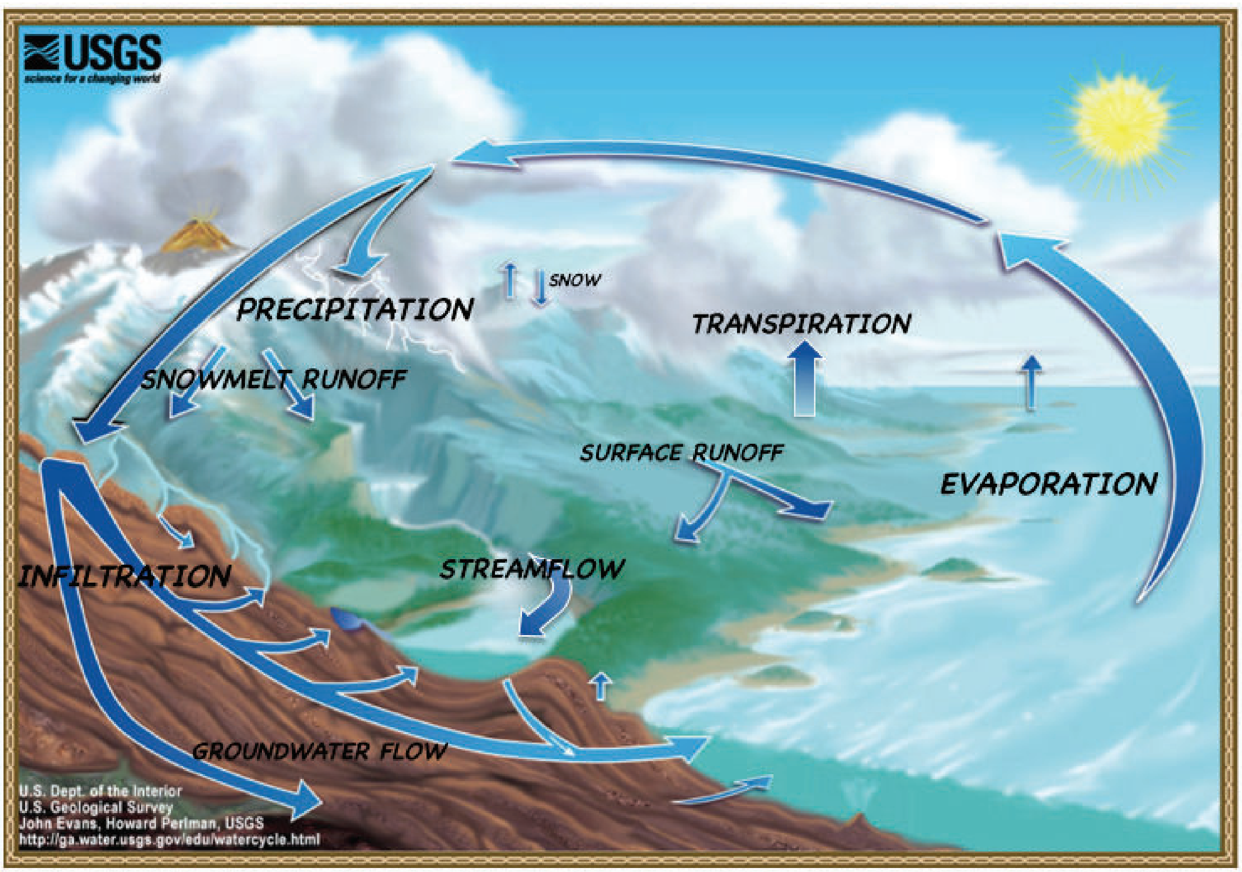


Figure 2: The Hydrologic Cycle

In order to answer the focus questions, "What natural processes impact water as it enters and moves through the Critical Zone? Are these processes the same everywhere?" students will need an understanding of the Hydrologic Cycle. We assume that most courses will cover hydro-cycle basics, while others may go into greater detail. There is a supplemental Info Sheet that accompanies this activity to guide students through some of the key hydro-cycle processes.

The three CZ Observatories chosen for this activity are each dominated by one of three distinct aspects of the hydrologic cycle. The three graphs that compare precipitation and discharge are the fundamental data that illustrate these three processes.

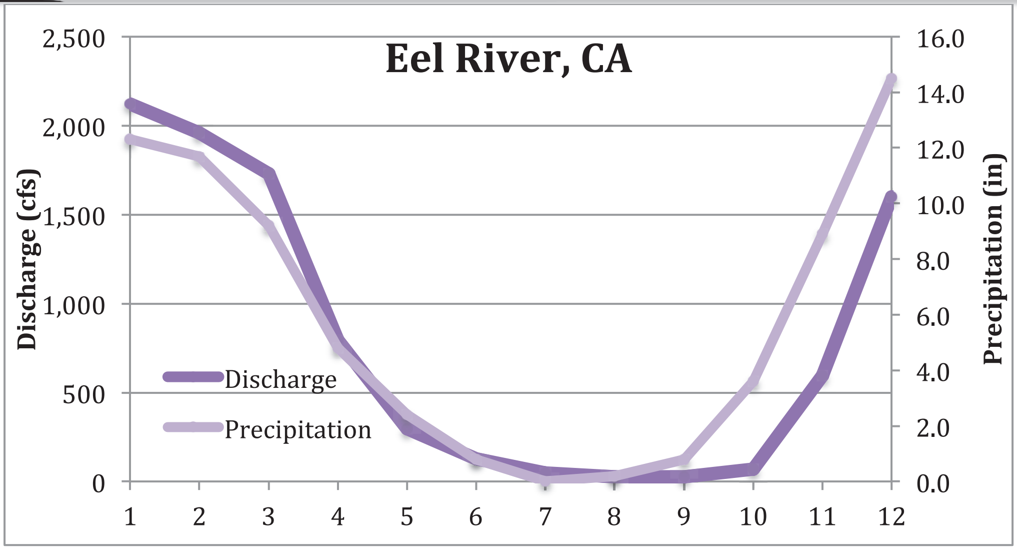
Eel River is located in the coast range mountains of northern California. Eel CZO has the highest low temperature and the lowest high temperature of the three CZOs examined here (the monthly mean low temperature is plotted for each CZO in the lower figure of Map 3). While Boulder Creek and Calhoun Forest both show strong seasonal temperature variations, the seasonal change at Eel River is very muted. Additionally, the mean temperature in the coldest months of the year is never below freezing. Eel River is a place where precipitation always falls as rain, not (or very rarely) snow, and vegetation does not have a dormant winter season. While the temperature at Eel River does not show much variation across the year the precipitation data show a distinct winter wet season and summer dry season. Further, Eel River has the highest annual precipitation of the three sites examined here. So Eel River CZO has a warm, very wet winter, and a warmer, very dry summer. The discharge in the Eel River tracks the precipitation pattern nearly perfectly. From June to September there is almost no rainfall and the river discharge drops accordingly. In October when the rains return the river flow responds, increasing in lock-step with precipitation. At Eel CZO we can clearly see that rainfall drives the response of the river. The response is not immediate – there is a ~1 month delay – which illustrates the average time required for precipitation to move through the watershed to the river channel.

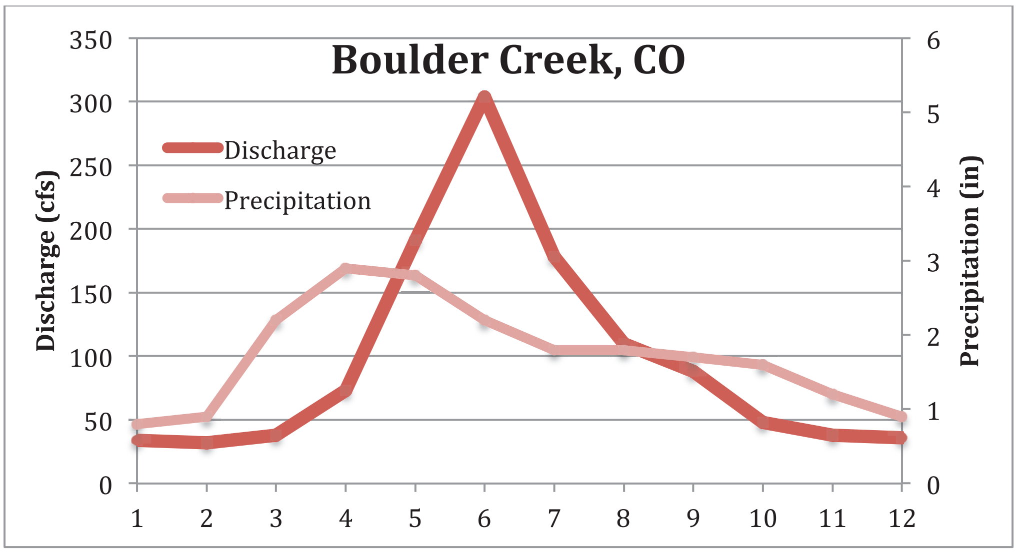
We will begin our exploration of the Critical Zone at the Eel River CZO in California, and then move east to Boulder and Calhoun.

- Examine the Eel River graph in Figure 3. Note which month has the highest rainfall and which month has the highest river discharge, and also the lowest rainfall and discharge.

◆ Do rainfall and river flow make a consistent pattern? Do they rise and fall at the same time or does one process lead the other? Explain, with reference to the Hydrologic Cycle, what you think happens to rainfall in the Eel River watershed.

- Examine the Boulder Creek graph in Figure 3. Do these data make a consistent pattern? Make note of when the highest/lowest rainfall and discharge occurs, and compare these data to the data from Eel River.





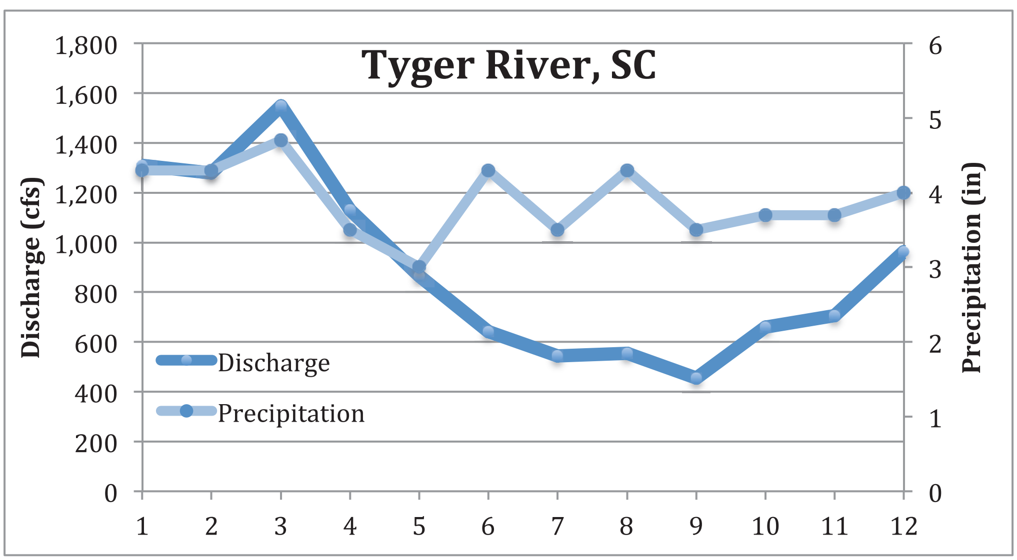


Figure 3: Monthly rainfall and river discharge at three CZOs. River discharge is the dark line in each graph. Discharge is measured in cubic feet per second (cfs) and is plotted on the left-hand axis. Rainfall is the lighter line, measured in inches, and plotted on the right-hand axis.

The hydrographs for Boulder Creek and Calhoun Forest are both quite different from Eel River, and they are different from each other. Whereas precipitation at Eel River ranges from 0 – 15 inches per month from the dry to the wet season, the seasonal variation in precipitation at Boulder varies only a little; from 1 to 3 inches. Nonetheless there is still a large variation in river discharge, and it occurs later in the year (two months after the precipitation maximum). When we examine the other data for Boulder, and the map of its location, we see that Boulder is in the Rocky Mountains at an elevation of 5106 feet above sea level. It is also the coldest of the three sites, with a winter minimum temperature of 21°F. This combination of factors points to the winter snowpack as the driver of river behavior at Boulder. Precipitation at Boulder is low in all months of the year. But with temperatures below freezing at an elevation of 5100 feet, and higher elevations in most of the watershed, the winter precipitation falls as snow. The snowpack stores water until April, when temperatures rise above 32°F. The correlation of rising temperature and rising streamflow is the key observation here. The stream hydrograph for Boulder Creek is a classic snowmelt response, and one that is seen in rivers all across the Rocky Mountain west. It also illustrates the importance of the winter snowpack in providing water to communities in the arid western US.

Finally we examine the water data at Calhoun Forest. This stream hydrograph and the precipitation pattern in the Tyger River basin are unlike those at Eel and Boulder. Calhoun has strong seasonal temperature variation, ranging from a monthly low of 28°F to a high of 92°F. The rainfall is more abundant than Boulder but less than Eel, and the seasonal variation is small, from 3 – 5 inches monthly. The rainfall and river response match each other in the spring months (Mar – May) but by summer they have diverged. Rainfall in summer and fall is about average for the year (4 in/month) but the Tyger River is flowing well below average until the cold months of winter. What is happening here? It almost looks as if there is a "water thief" during the summer and fall. How can it rain without raising the river? For students – and especially for students unfamiliar with temperate forest environments – this is probably the most unusual hydrograph, and the most perplexing process to figure out. This watershed is indeed inhabited by a water thief; it is the forest. Rain that falls on a forested landscape can be intercepted by the tree canopy and returned directly to the atmosphere by evaporation. Rain that reaches the forest floor infiltrates into the subsurface where it encounters the plants' root network. Evaporation pulls water from plant roots up to the canopy where it is transpired to the atmosphere though leaf pores (*stomata*). Thus a forest is a very effective interceptor of precipitation, returning rainfall directly to the atmosphere without moving though the watershed to a river or its tributaries. On a global basis, more than 50% of precipitation in forested watersheds is returned directly to the atmosphere. In the dataset from Calhoun the clue to understanding the role of the forest is the timing of the water deficit. When the forest is dormant in winter and spring the rainfall and river flow are correlated. When trees become active, producing leaves, flowers and other new growth, they pump much more water, leaving less water available to the river.

Eel River, Boulder Creek and the Tyger River at Calhoun Forest each represent a different relationship between precipitation and river discharge. The Eel River is dominated by seasonal rainfall, Boulder Creek responds to melting of the winter snowpack, and the Tyger River competes for water with Calhoun Forest.

- Describe how seasonal river discharge is different at Eel River and Boulder Creek. Consider amount and timing of precipitation, river response, as well as the monthly maximum and minimum temperatures. Explain, with reference to the Hydrologic Cycle, what you think happens to precipitation in the Boulder Creek watershed.

- Now look at data for the Tyger River that flows through Calhoun Forest. Do these data make a consistent pattern? Make note of when the highest/lowest rainfall and discharge occurs, and compare these data to the data from Eel River and Boulder Creek.

- What Critical Zone process is responsible for the behavior of the Eel River? What CZ process is responsible for the behavior of Boulder Creek? Is the Tyger River responding in the same way as either Eel or Boulder? Explain, with reference to the Hydrologic Cycle, what you think happens to precipitation in the Tyger River watershed.

- You have looked at precipitation and river response in three different places. Which was the most surprising to you? Explain why.

Data

The three maps included here show elevation for the continental US measured in feet (Map 1), average annual precipitation in inches (Map 2) and average annual temperature minimum (°F), (Map 3). The minimum temperature was chosen – instead of the annual average – because minimum temperature is a more important control on ecosystems. The locations of the three CZOs are marked on each map, but only labeled on the elevation map (as E, B, C). With the map of minimum temperature is a graph of monthly minimum temperature for the three CZO sites. The three hydrographs include monthly mean river discharge for the river at each CZO (from USGS) and monthly mean precipitation (from NWS). These data are compiled from decades-long observations and are thus not impacted by short-term storm or climate events (e.g. El Nino winters). The source data for each of these graphs is available as a data table, or can be downloaded in spreadsheet form. Student answer sheets are found at the end of this handout, and appended to the student handout.

Vocabulary

Condensation: The change of the physical state of matter from a gas phase into a liquid phase. It is the reverse of evaporation.

Conifer: Evergreen trees and shrubs with long, thin needle-like leaves. They are the dominant plants over huge areas of land, most notably high latitude forests but also in similar cool climates in mountains further south. Boreal conifers have many wintertime adaptations such as downward-drooping limbs that help them shed snow. Many of them seasonally alter their biochemistry to make them more resistant to freezing.

Critical Zone: The region above and below the Earth surface, extending from the tops of the trees down through the subsurface to the bottom of the groundwater; the zone that supports terrestrial life on Earth.

Deciduous vegetation: Deciduous means "to fall off," and is typically used to refer to trees or shrubs that lose their leaves seasonally (most commonly during autumn); also to the shedding of other plant structures such as petals after flowering or fruit when ripe. In tropical regions deciduous plants often lose their leaves during the dry season.

Discharge: The volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second.

Evaporation: The process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields.

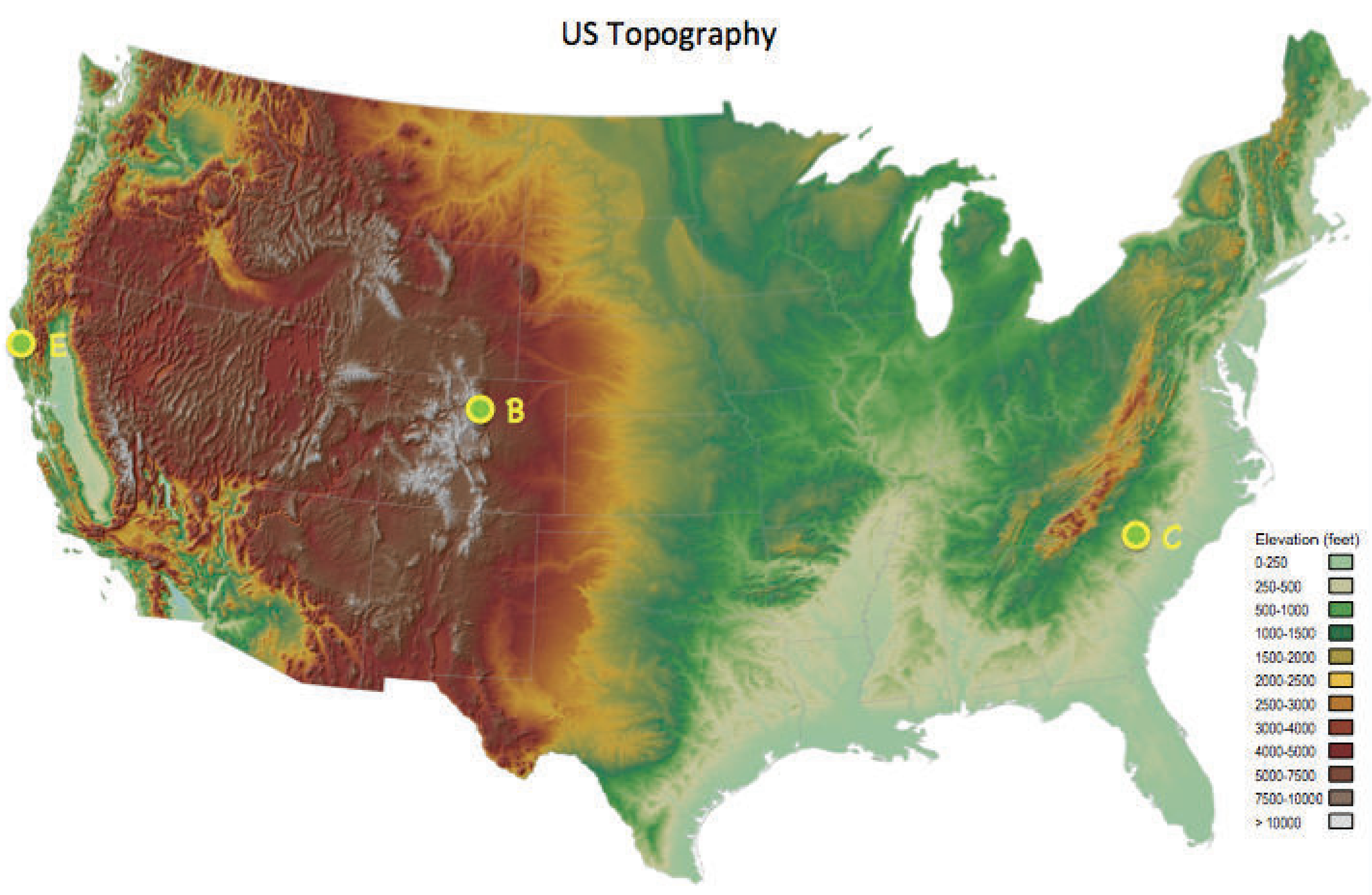
Hydrologic cycle: The cyclic transfer of water vapor from the Earth's surface via evapotranspiration into the atmosphere, from the atmosphere via precipitation back to earth, and through runoff into streams, rivers, and lakes, and ultimately into the oceans.

Infiltration: The flow of water from the land surface into the subsurface.

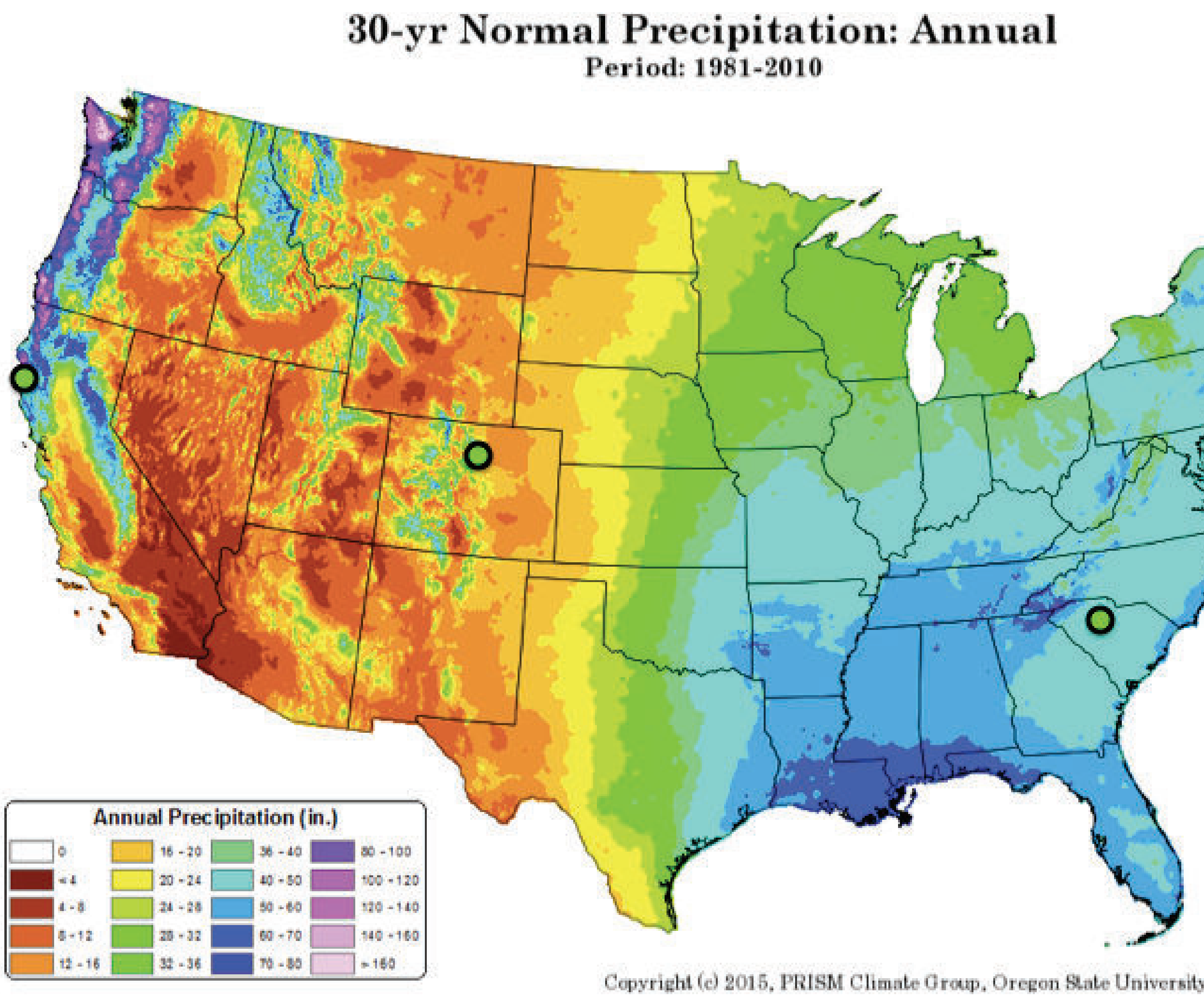
Precipitation: Any product of the condensation of atmospheric water vapor that falls under gravity; rain, snow, hail, sleet, dew, and frost.

Transpiration: The process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

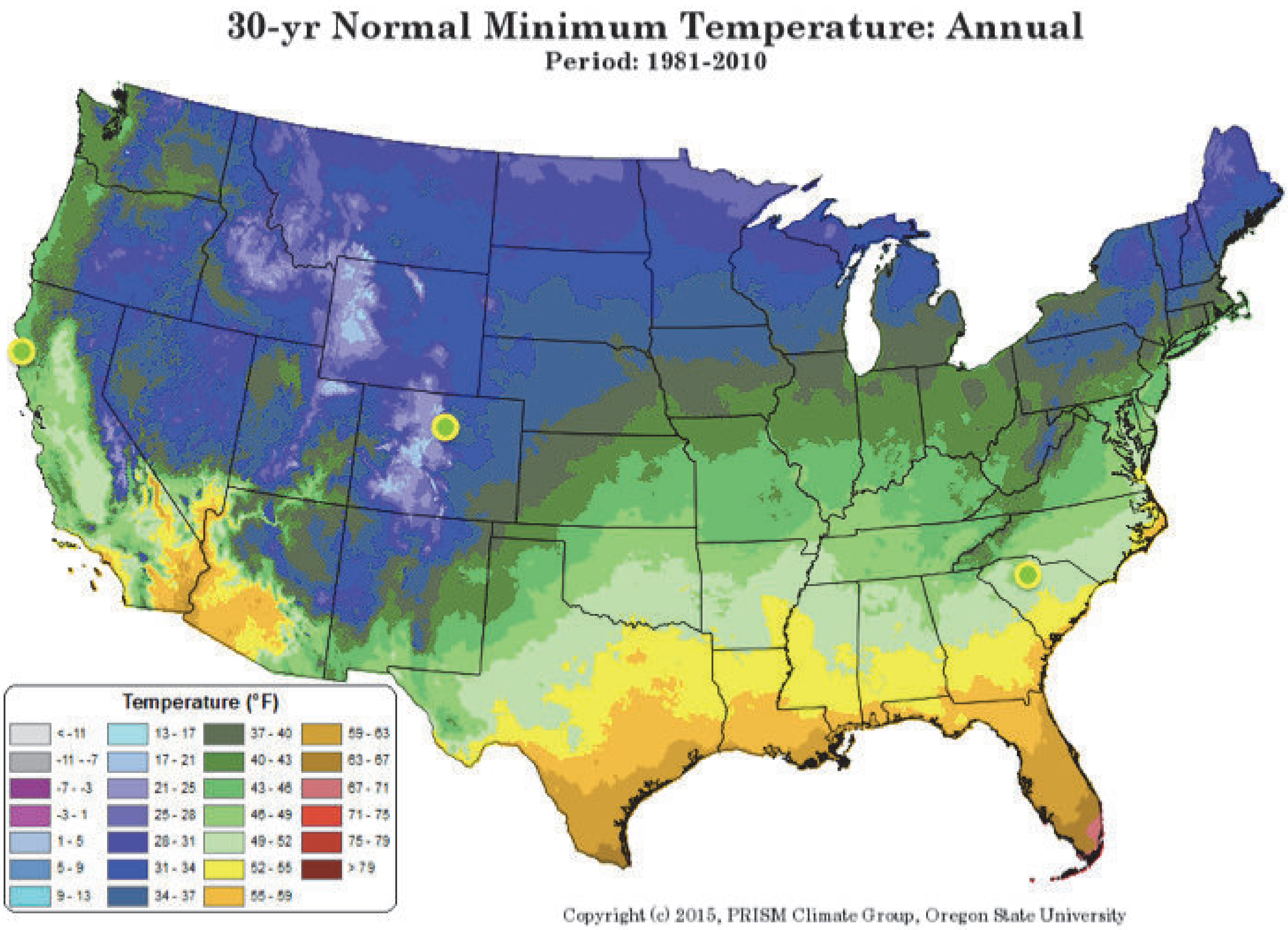
Watershed: The land area that drains water to a particular stream, river, or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large watersheds, like the Mississippi River basin contain thousands of smaller watersheds.



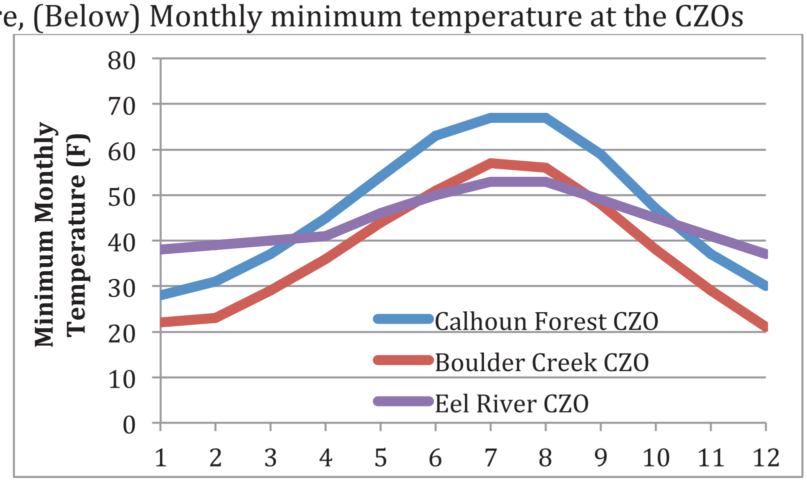
Map 1: Elevation



Map 2: Average annual precipitation



Map 3: (Above) Average minimum temperature, (Below) Monthly minimum temperature at the CZOs



Questions

Fill in Table 2

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Which CZO is most like your hometown? Explain why.

Do rainfall and river flow at Eel River make a consistent pattern? Do they rise and fall at the same time or does one process lead the other? Explain, with reference to the Hydrologic Cycle, what you think happens to rainfall in the Eel River watershed.

Describe how seasonal river discharge is different at Eel River and Boulder Creek. Consider amount and timing of precipitation, river response, as well as the monthly maximum and minimum temperatures. Explain, with reference to the Hydrologic Cycle, what you think happens to precipitation in the Boulder Creek watershed.

What Critical Zone process is responsible for the behavior of the Eel River? What CZ process is responsible for the behavior of Boulder Creek? Is the Tyger River responding in the same way as either Eel or Boulder? Explain, with reference to the Hydrologic Cycle, what you think happens to precipitation in the Tyger River watershed.

You have looked at precipitation and river response in three different places. Which was the most surprising to you? Explain why.

Resources

Boulder Creek CZO You Tube Channel: https://www.youtube.com/watch?v=0UpyOygI78M
Critical Zone Observatory Network, http://criticalzone.org
Koeppen Climate Classes, http://koeppen-geiger.vu-wien.ac.at/pdf/KG_USA_UScounty.pdf
PRISM Climate Group, http://www.prism.oregonstate.edu/normals/
USGS Water Science School, https://water.usgs.gov/edu/