Title: The Effect of Climate Change on Water

Grade Level: 7th-12th

Topic:	**Climate Change & Our Resources**
Background:	As the concentration of CO_2 in the atmosphere increases and global mean temperatures rise, there are potentially dramatic consequences for water resources management in the Intermountain west. Temperatures in the Western US have increased over the past 50 years (Hamlet and Lettenmaier, 2007). As temperatures rise, snowpack in the Intermountain West is decreasing because the proportion of precipitation falling as snow has decreased in sub- montane regions (Kowles et al, 2006) and snowpack is melting earlier, so the percentage of total precipitation stored in the snowpack is decreasing (Pierce et al., 2008). These changes in the hydrologic cycle mean that the timing of snowmelt-driven streamflow has shifted forward (Stewart et al., 2005), and streamflow during the driest quartile of the year has decreased (Luce and Holden, 2009). Both of these consequences have implications for water resources management in the West (Abatzoglou, 2010). Changes in the timing and magnitude of runoff can lead to flooding as the storage capacity of reservoirs is exceeded. Irrigation-dependent farming, streamflow-dependent recreation like rafting and fishing, hydropower generation and fish habitat could all be impacted by decreased summer flows.
Next Generation Standards:	**LS2A, LS2B, LS2C, LS2D, ESS2A, ESS2C, ESS2D, ESS3A, ESS3C, ESS3D**
Goals:	Understand the impact of changing precipitation type to our water year.
Objectives:	List out the "Enduring Understandings" that students will have after the day? For example • "Students will understand that plants and trees have special parts that allow them to survive in their environment and that these have developed over time in response to pressures from the environment". • Students will be able to point out the adaptations of

	several common plant and tree species in Ponderosa State Park.
Materials:	• Oven rack liner (approx.. 18 inches x 15 inches) or other similar foil tray • Funnel • Containers for collecting and weighing snow and water (large yogurt containers work ⍰well) • Spring scale • 3 large yogurt containers • Heat lamp • Stopwatch
Set up:	**Construct watersheds out of foil trays and funnels**.⍰ Gently fold the foil tray so that it is narrow at the bottom and wide at the top with sloping sides (see picture). Secure the funnel to the bottom of the tray at the narrow end. Place this structure on a cardboard box (or similar structure) so that the whole thing is sloping. This represents a watershed and river drainage. **Prepare your catchment containers**: Make a hole in the top lip of two of the yogurt containers so that they can be hung on the spring scale. Hang the empty container on the spring scale and zero it. Place one container under the spout of the funnel to collect water that comes down through the system. Students will use the second container to collect snow or water. The third container is used as a temporary catchment container (see instructions below). **Depending on your time and intended outcomes, either prepare a graph in advance or have students access and plot data showing historical averages for precipitation and streamflow** in a river basin near you (see example below). You might also include monthly average temperature so students can make inferences about the FORM of precipitation

	in each month. Raw data can be accessed online from the following sources: Precipitation: http://www.wrcc.dri.edu/coopmap/ SNOTEL: http://www.wcc.nrcs.usda.gov/snow/) Streamflow: http://waterdata.usgs.gov/id/nwis/rt Climate summaries: http://www.wrcc.dri.edu/Climsum.html Data is not always easily downloadable in spreadsheet form so you may have to copy values into a spreadsheet that you create. Before you have students try to download data it is very helpful to go through all the steps yourself so that you know where they may have trouble.
Classroom Time:	2 1hour class periods
Introduction (Engage):	Get students engaged by having them think about the things that they like to do that are dependent on water in some form – do they like to ski? Raft? Fish? What other things in their community are dependent on water? [Is there hydropower? Do farmers use water to irrigate crops?]. Ask them to think about the water in their community. Where does it come from? What does the hydrologic cycle look like? Look at a graph of average precipitation and streamflow for the Little Salmon River basin (or the basin you have chosen that is closer to home). **Start by asking students to look** at this graph of average precipitation in a local river basin and ask them to think about the **form** that the precipitation takes. Historically, in this basin we have gotten as much as 80% of our precipitation in the form of snow. You can see that the winter months get the most precipitation and that by summer there is relatively little. Notice there is generally an inverse relationship between precipitation amount and streamflow. When precipitation is at its greatest, in the form of snow, streamflow is at its lowest. When precipitation is at it lowest, streamflow is at its greatest, in the form of snowmelt. How could you bring atmospheric temperature into this discussion as well? **Discuss** climate predictions for the Intermountain west – scientists are predicting that under climate change scenarios more of our precipitation will come as rain instead of snow.

	Tell students that we will be exploring the question "how would a change in the FORM of precipitation affect the shape of the hydrograph?" A hydrograph is a graph that shows seasonal variation in the volume of water flowing in a river or stream. So, in other words, if we get more of our precipitation as rain instead of snow, how will that change the amount of water in our streams throughout the year?
Activity (Explore):	Students will experiment with two different precipitation scenarios – precipitation patterns for the recent historical climate record (past 50 years), and for a warmer climate where more precipitation falls as rain. Instructions for students:1) Using a large yogurt container, collect approximately half a container of snow2) Determine the mass of the snow in your container using a spring scale. Your scale should have been "zeroed" with the container hanging on the scale so you do not need to subtract the weight of the container from the mass you read on the scale.3) Add or remove snow until you have a mass that is approximately equal to the mass indicated in the snowfall data for the first month of our test (October)4) Add the snow to your foil tray "watershed" in a uniform way, covering as much of the tray as possible.5) Wait 3 minutes (use the stopwatch to time the trial). During these 3 minutes you can collect snow for your next "month", start writing out these procedures in your lab notebook and make a hypothesis about how the shape of the hydrograph will change. 6) At the end of 3 minutes, weigh the water that is in the catchment container. This represents streamflow for the month of October. Record this number in the streamflow cell for October on your datasheet and report your number to your teacher. While you are weighing the streamflow for this month, use a separate temporary container to catch any water that continues to flow.

	7) Transfer the water for October into the Reservoir container. Replace the original catchment container under the funnel, and add any water from the temporary container into your weighing container. 8) Repeat steps 1 – 7 for the month of November, December and so on. When you get to a month that has a volume of rainwater you can either weigh out the mass or measure it by volume. 9) When you get to the month of March, turn on your heat lamp to simulate the change in angle of the sun that leads to more solar gain and warming (seasonal change). Test 1: Current climate precipitation pattern After completing your first test, use the data table below to run a second test. This second test has a mix of rain and snow in several of the months so you will be adding both snow and liquid water. Before you start the second test, answer the following question in your lab notebook: How do you think the shape of your hydrograph will change in this test? Test 2: Climate change scenario – same overall precipitation, but more of it is falling as rain instead of snow As students run their experiments and collect their streamflow data, enter their data into an Excel spreadsheet with a graph tied to the data (see attached Excel file for a template).
Explanation	Have students explain the changes they see in the shape of the hydrograph. What do they observe? How has streamflow / discharge been affected by a change in the form of precipitation? (If all goes well, they will have seen an earlier and higher volume runoff and decreased summer streamflow – in other words, the shape of the hydrograph by shifting the peak up and over to the left side of the graph).
Elaboration:	Have students work in their groups to brainstorm the water resources and water uses that their community is dependent on. Possible examples include rivers for fishing, boating, fish habitat, hydropower, irrigation, etc. Divide students into "Expert Groups" to have them focus on four different "sectors": ecology, recreation, hydropower and

agriculture. Have students use internet resources to come up with impacts of earlier runoff and decreased summer streamflow on their sector, in their community. The Climate Impacts Group at the University of Washington http://cses.washington.edu/cig/ has a summary of climate change impacts on various sectors that could be used as a discussion tool. After groups have researched the impacts on their sector, have the expert groups come up with a short presentation to teach the rest of the class about their "sector".

The United States Global Change Research Program has a very useful website that summarizes climate change impacts by region and by sector. It can be found here: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

Some of the impacts that students might find for the Pacific Northwest include:

- Hyrdropower impacts: less water for generating hydropower in the summer months

- Ecological impacts: salmon habitat is impacted as water temperature rises and streamflow decreases

- Irrigation: potential flooding in spring as earlier runoff fills reservoirs to capacity and water needs to be released. Less water available in late summer.

Recreation: changes in the timing of peak recreation season may not coincide with school breaks. Economies that depend on recreation based tourism (rafting, fishing) may find that their peak season happens at a different time of the year and does not last as long.

After each expert group has presented, divide the class into new groups comprised of members of each of the expert groups. Have them brainstorm solutions that balance the needs of each sector. Questions to guide your students include: What tradeoffs could each sector make? How will you decide who gets how much water? What engineering solutions might be used to help communities mitigate or adapt to climate change impacts (think about different ways of storing water, more efficient water infrastructure)? What behavioral solutions could communities use to mitigate or adapt to climate change impacts (think about ways to encourage people to use less

	water, different crops that could be planted, other kinds of recreation). WRAP-UP: Discuss possible actions that students can take to mitigate climate change. Some great resources for helping students come up with ways to address global climate change can be found at http://youngvoicesonclimatechange.com/ You may want to include a discussion of the difference between technological solutions to address climate change versus focusing on changes in human behavior. Which strategy do students think is more effective, and why?
Evaluation:	Have students discuss limitations of the model that they used to test the relationship between form of precipitation and summer streamflow. What was not accounted for? What other tests could they perform? What other questions could they ask?

EXTENSION

There are many possible extensions to these activities. You might have students perform additional experiments based on the new questions that they generate (changing the total amount of precipitation, changing the temperature of the watershed, adding dust or dark particles to explore the albedo affect, making the model more realistic by adding a spongy layer to that would mimic the affect of soil and infiltration).

Extensions for exploring the impact of climate change on the water resources in their community could include setting up interviews with community members whose livelihood is directly dependent on water, or touring existing water resource infrastructure like dams and irrigation canals.

Why are we weighing the snow?

Scientists use the weight of snow to find out how much water is in it. We know that water weighs one gram per cubic centimeter at 1 atmosphere of pressure. If we weigh our container of snow and find that it has a mass of 50 grams, we know that we have 50 cubic centimeters of water! Try it out – measure out 50 cc of water and weigh it. Does it weigh 50 grams?

When scientists want to find out how much water is in the snow, it's not really possible for them to take the mass of the entire snowpack. Instead, they weigh a sample in a known volume so that they can calculate the density of water in the snow.

We can calculate a density of water in snowpack by dividing the mass of our sample by the volume of the sampling container. For example, if our sampling container = 100 cubic centimeters (cc), and we have a mass of 23 grams (g), we divide 23 g / 100 cc and we get a density of 23g/100cc, or 23%.

Density in the snowpack can vary quite a bit, so it's a good idea to either get a core sample that takes snow from all layers of the snowpack, or else take samples from each layer of the snowpack and average them to find the average density.

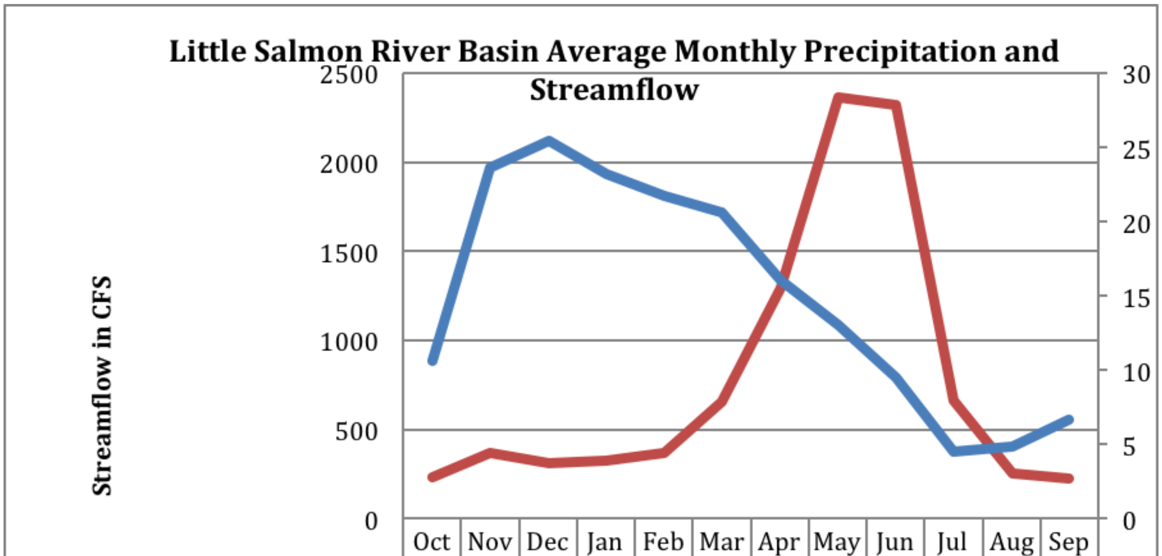
TEST 2	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
SNOW	50 g	90 g	100 g	50 g	50 g	45 g	35 g					
RAIN				50 cc	40 cc	45 cc	35 cc	60 cc	50 cc	20 cc	20 cc	30 cc
TOTAL PRECIP	50 g	90 g	100 g	100 g	90 g	90 g	70 cc	60 cc	50 cc	20 cc	20 cc	30 cc
DISCHARGE												

TEST 1	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
SNOW	50 g	90 g	100 g	100 g	90 g	90 g				
RAIN							70 cc	60 cc	50 cc	20 cc
TOTAL PRECIP	50 cc	90 cc	100 cc	100 cc	90 cc	90 cc	70 cc	60 cc	50 cc	20 cc
DISCHARGE										

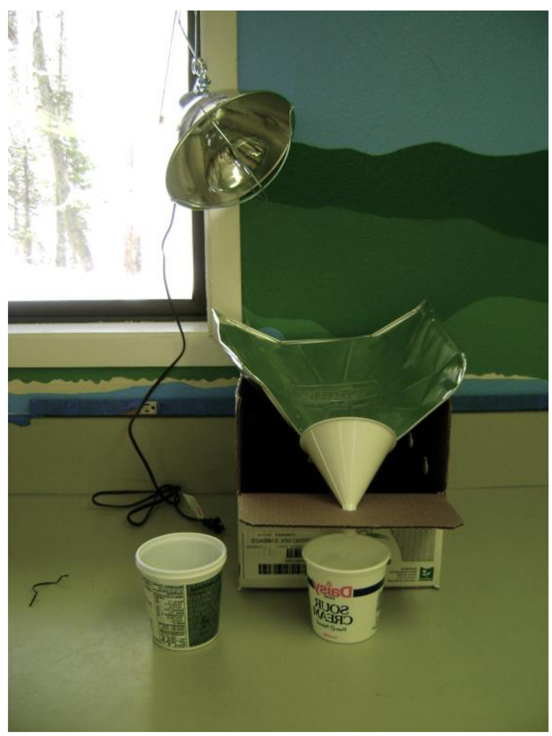
Instructions

1) Using a large yogurt container, collect approximately half a container of snow
2) Determine the mass of the snow in your container using a spring scale
3) Add or remove snow until you have a mass that is approximately equal to the mass indicated in the snowfall data for the first month of our test (October)
4) Add the snow to your foil tray "watershed" in a uniform way, covering as much of the tray as possible.
5) Wait 5 minutes (use the stopwatch to time the trial)
6) At the end of 5 minutes, weigh the water that is in the catchment container. This represents streamflow for the month of October. Record this number in the streamflow cell for October on your datasheet and report your number to your teacher. While you are weighing the streamflow for this month, use a separate temporary container to catch any water that continues to flow.
7) Transfer the water for October into the Reservoir container. Replace the original catchment container under the funnel, and add any water from the temporary container into your weighing container.
8) Repeat steps 1 – 7 for the month of November, December and so on. When you get to a month that has a volume of rain water you can either weigh out the mass or measure it by volume.
9) When you get to the month of March, turn on your heat lamp to simulate the change in angle of the sun that leads to more solar gain and warming (seasonal change).

LITTLE SALMON RIVER	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Average Precipitation in Tributary Basins (in inches)	2.3	4.6	4.9	4.9	4.5	4.4	3.7	3.1	2.4	1.1	1.2	1.5	Bear Basin
	3	7	7.6	6.6	6	5.2	4.2	3.3	2.6	1.2	1.3	2.1	Brundage
	2.8	6	6.2	5.7	5.5	5.7	4.3	3.6	2.3	1.2	1.2	1.6	Squaw Flat
	2.5	6	6.7	6	5.7	5.3	3.8	3	2.2	1	1.1	1.4	West Branch
Sum of Precipitation from Tributary Basins (in inches)	10.6	23.6	25.4	23.2	21.7	20.6	16	13	9.5	4.5	4.8	6.6	4 Trib Basins
AVG STREAMFLOW in the Little Salmon River (in CFS)	230	368	311	319	368	652	1290	2360	2320	660	253	218	Little Salmon River
Average Temperature (in F) in McCall, ID	40	29.5	19.6	19.5	21.2	27.9	36.1	45.7	52.6	62.2	59.7	50.7	



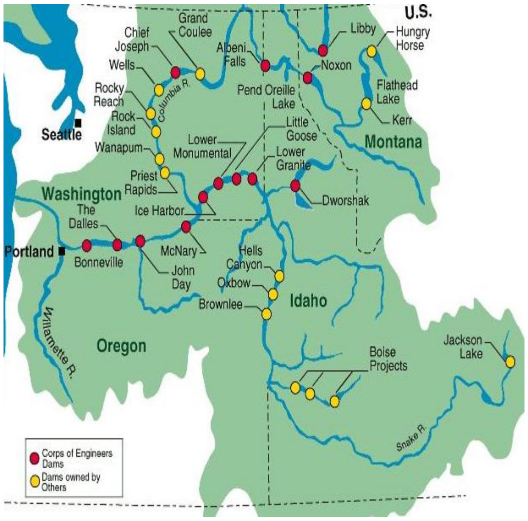
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average Streamflow (in CFS) in the Little Salmon River	230	368	311	319	368	652	1290	2360	2320	660	253	218
Sum of Precipitation (in Inches) from Tributary Basins	10.6	23.6	25.4	23.2	21.7	20.6	16	13	9.5	4.5	4.8	6.6

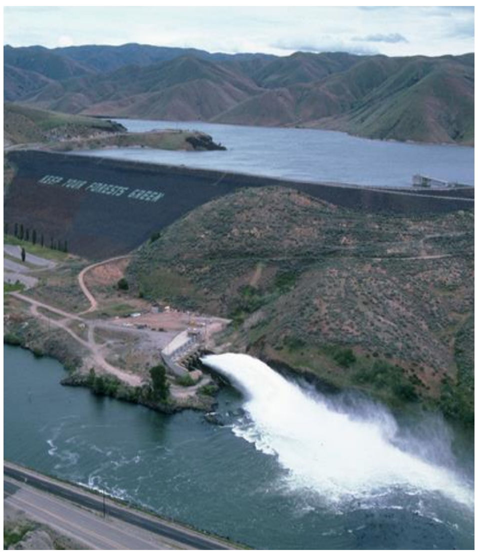


Hydropower

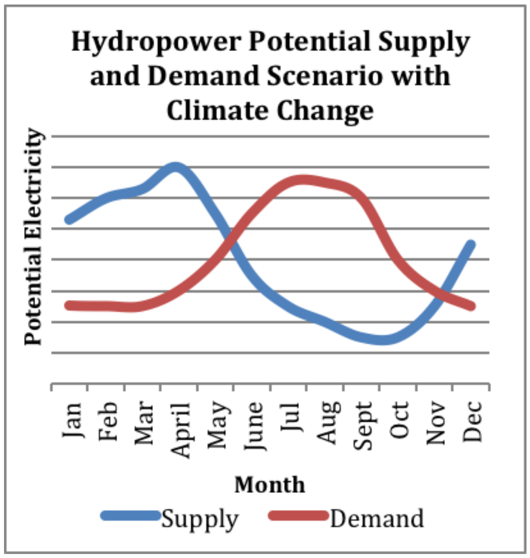
+ Hydropower accounts for roughly 80% of energy generation in Idaho (EIA, 2009). Changes in the yearly hydrograph suggest that climate change will impact Idaho's primary energy source.

Right: Hydropower stations throughout the Columbia River Basin





Lucky Peak Dam on the Boise River



Projected Climate Change Impacts

The timing of peak hydropower supply and demand may not match.

SUPPLY:

- If the hydrograph shows higher winter stream flows, an earlier peak, and lower summer stream flows, we may see increased hydropower production in the winter and spring and a decrease in the summer.

DEMAND:

- Projected year round temperature increase from climate change may increase electricity demand in the summer and decrease that demand in the winter.

CHALLENGES:

- Dams and reservoirs have historically been designed under the assumption that the winter snowpack is a reliable storage basin for precipitation from November to March. With increasing precipitation in the form of rain in the winter, the reservoirs must be prepared for increased storage during the winter to prevent flooding and to capture enough water to meet energy demands in the summer.

+ Planning Principles

1. Recognize that the past may no longer be a reliable guide for the future
2. Integrate climate change projections into all planning processes
3. Monitor regional climate and resources for ongoing change
4. Expect surprises. Design policies and management practices to be flexible and to changing conditions.

What opportunities are there for Idaho hydropower companies to manage the impacts of the changing hydrograph?

Use the planning principles to the left and the discussion starters below to think about adaptive management strategies.

- How can hydropower managers use the hydrograph data that you generated to best plan for earlier spring runoff and higher winter stream flows?
- What possibilities are there for reducing consumer's demand for electricity, especially in the hot summer months?
- Are there ways for hydropower dams to generate and transmit electricity more efficiently from the hydropower dams?
- What other forms of energy can be developed in Idaho that will not be impacted by a changing hydrograph?

Idaho's salmon are uniquely adapted to migrate very long distances from Idaho to the Pacific Ocean and to survive in high altitude alpine lakes. Because of this adaptation, they cannot be easily replaced by other salmon species. Ecological responses to a changing climate are difficult to predict and challenging to manage. Salmon could be particularly sensitive to the changing hydrograph because a salmon's life cycle is the timing and intensity of stream flow and temperature.

Critical salmon spawning habitat on the Pahsimeroi River, Nature Conservancy

Salmon Life Cycle

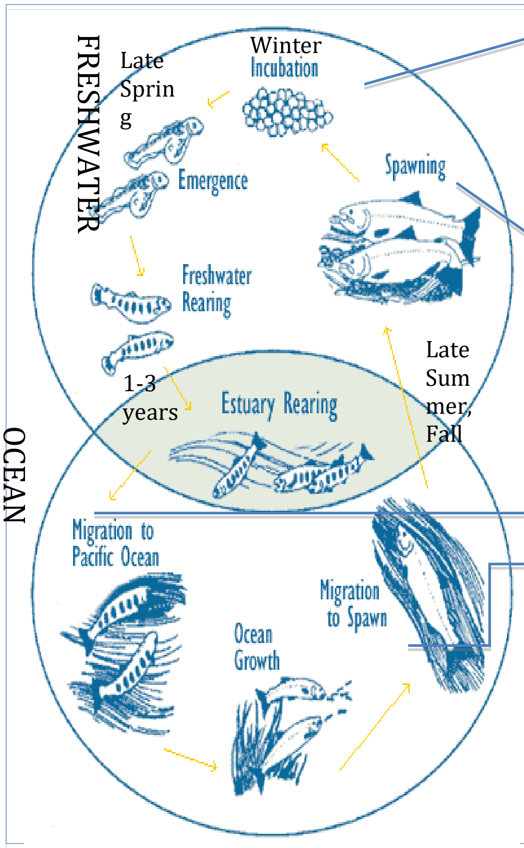


Diagram from Washington Department of Fish and Wildlife.

Projected Climate Change Impacts

- Increased winter and fall flows could influence the success of the salmon redds (nests of eggs) because the increased discharge could scour the stream gravel where the eggs incubate during the winter.
- The salmon spawning migration upstream during the late summer and fall may be limited by reduced summer flows due to the changing hydrograph.
- Similarly, the shift to an earlier spring peak flow could impact the downstream migration of smolts to the ocean.
- With less water in the streams and rivers during the summer and increasing air temperatures, water temperatures will also increase. Salmon are a cold water fish species so if water temperature exceeds a certain threshold, these warm conditions could create a temperature barrier for salmon migration up or downstream.
- Dams can stand as an obstacle or additional sressor to salmon during migration.

Planning Principles

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6. Integrate climate change projections into all planning processes

7. Monitor regional climate and resources for ongoing change

8. Expect surprises. Design policies and management practices to be flexible and to changing conditions.

What opportunities are there to prepare and adapt ecosystem management for a changing climate?

Use the planning principles to the left and the discussion starters below to think about adaptive management strategies.

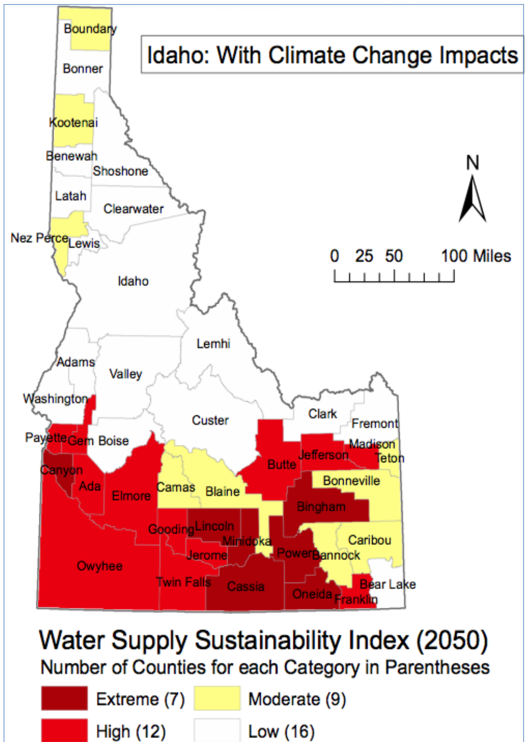
- Additional stressors to the salmon life cycle include excess nutrients and chemicals from agricultural runoff and migration obstacles such as dams. How can we manage hydropower and agricultural systems to reduce these causes of stress?

- Increasing biodiversity in streams and protecting salmon habitats help to reduce the salmon sensitivity to large stream flow changes. How can we manage areas to conserve habitat and keep streams healthy to maintain biodiversity?

- Shade helps to maintain cooler stream temperatures. How can we provide and maintain more shade along the streams during the hot summer months with lower stream flows?

Agriculture

+ Idaho is the second largest irrigating state in the country in terms of water withdrawals for agriculture. Currently, irrigated agriculture in Idaho accounts for 85% of consumptive water use in the state each year (USGS, 2005). A changing hydrograph will shift water availability, posing a challenge for food production to meet the needs an increasing population.



The map above displays the agricultural water supply sustainability risk for each county in Idaho. [1] Crop production in the extreme, high, and moderate "at-risk" counties is extremely important for Idaho's economy. Those counties alone generate over $1.34 billion/year from vegetable, wheat and barley production.[2]

Projected Climate Change Impacts

WATER SUPPLY:

The majority of water withdrawals for irrigation in Idaho come from reservoir storage, and occur in the summertime during peak crop production. If the hydrograph shows higher winter stream flows, an earlier peak runoff, and lower summer stream flows, reservoirs will have to store more water during the winter in order to provide irrigation water in the summer when it is needed. Reservoirs have been designed under the assumption that the majority of winter precipitation would be stored in the form of snowpack over the winter months. Reservoirs may not have the capacity to store winter precipitation and spring runoff until the timing of peak irrigation demand.

WATER DEMAND:

Projected year round temperature increases from climate change may increase evapotranspiration rates from crops in the summer, requiring additional irrigation water to keep the crops productive. With a growing population, the demand for even more food production may increase as well.

Crop Water Needs Table (FAO)
These estimated water needs are expressed in millimeters per growing season for each particular crop. Water use values vary by region.

+ Planning Principles

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11. Monitor regional climate and resources for ongoing change
12. Expect surprises. Design policies and management practices to be flexible and to changing conditions.

What opportunities are there for Idaho farmers to manage the impacts of the changing hydrograph?

Use the planning principles to the left and the discussion starters below to think about adaptive management strategies.

- How can farmers use the hydrograph data that you generated to best plan crop management practices?
- What possibilities are there for reducing agriculture's demand for water, especially in the hot, dry months? Can you think of ways to improve the efficiency of irrigation sprinklers to conserve water?
- Is there anything that we can do as consumers to reduce the demand side?
- How could farmers use the "Crop Water Needs" table to adapt to a changing hydrograph? What other crop information might help farmers to

[1] County Risk Level from "Evaluating Sustainability of Projected Water Demands Under Future Climate Change Scenarios," Tetra Tech Inc. 2010
[2] USDA and US Global Change Research Program, 2009 Retrievedfromhttp://globalchange.gov/publications/reports/scientificassessments/us impacts/climatechangeimpactsbysector/agriculture.

University of Idaho College of Natural Resources