UNIVERSITY OF COLORADO AT BOULDER – SCIENCE DISCOVERY

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A unique professional development and science enrichment opportunity for teachers and students grades 5-8

2011-2012 Workshops

EARTH SYSTEMS SCIENCE:

EXPLORING CHANGE IN THE CRITICAL ZONE

Science Discovery
UNIVERSITY OF COLORADO BOULDER

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Authors, Editors and Contributors:
Eric Carpenter
Dr. Stacey Forsyth
Kristi Dahl
Laura Cecil
Melissa Foster
Rachel Gabor

Scientific Advisors:
Dr. Suzanne Anderson
Melissa Foster
Rachel Gabor

Earth Systems Science: Exploring Change in the Critical Zone is a collaboration between the Boulder Creek Critical Zone Observatory Program, The Institute for Arctic and Alpine Research and the University of Colorado Boulder – CU Science Discovery Program. This material is based upon work supported by the National Science Foundation under Grant No. 0724960. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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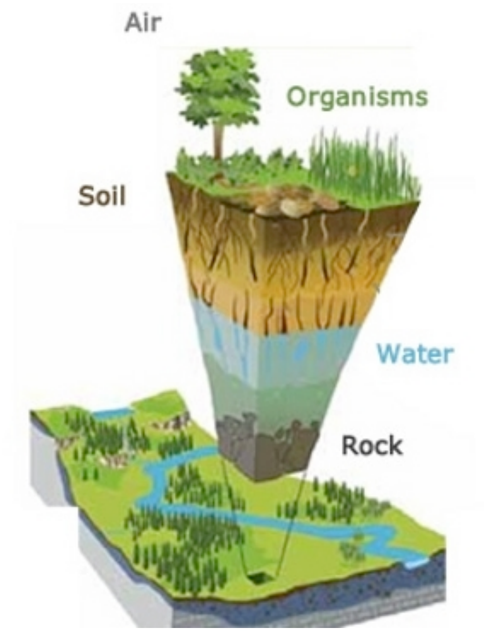
EARTH SYSTEMS SCIENCE:

EXPLORING CHANGE IN THE CRITICAL ZONE

The Critical Zone is Earth's porous near-surface layer, from the tops of the trees down to the deepest groundwater. It is a living, breathing, constantly evolving boundary layer where rock, soil, water, air, and living organisms interact. The Critical Zone is home to complex interactions that control the availability of life-sustaining resources like food and water.



Scientific research in the Critical Zone focuses on understanding how the system operates, how it evolves, and how it will respond to future changes in land-use and climate. Research in the Boulder Creek Watershed, part of the National Science Foundation's Critical Zone Observatory Program, strives to understand how the area's geology, hydrology, ecology and climate interact to provide and control the availability of water resource in three key areas represented by the learning modules described below.

Foundations for Flow:
In this module, learners and teachers will build a Colorado watershed from the bedrock up and wear it down with constructive and destructive forces over time. Using snow, ice, and summer rains they will create glaciers, streams and rivers to grind the mountains down to the landforms that we see today. They will see how events in our geological past, including the formation of sedimentary rock layers, mountain building, uplift and erosion, combine to form the foundations of the watershed.

Fire and Water:
Using computer mapping and hands-on experiments, participants will explore the relationships between ecosystems, wildfires, soils and water. They will predict fire intensity and see how wildfires impact soils, erosion and water quality. They will conduct experiments to help understand how different soils impact water flow and storage, how forest fires change soil and surface structures, and how these factors combine to impact both water quality and water availability in the watershed.

Ice, Snow and H_2O:
This chilly module focuses on how weather, climate, snow and ice impact the Earth System Interactions that supply year-round water to Colorado, with only the occasional flood or landslide. Participants will create and conduct experiments with glacial ice, and use snow, data, measurements and math to understand the relationship between glaciers, snowpack and our water supply.

For more information of the Boulder Creek Critical Zone Observatory Program visit the program website at: http://czo.colorado.edu

Foundations for Flow

Module Overview:
The distribution of surface and ground water is controlled by the structural geology of the Earth's watersheds. Research in the Boulder Creek Critical Zone Observatory strives to understand how geologic processes shaped the land, and therefore the watersheds, over time. The current topography, rock layers, and the size and shape of the drainage basins can be understood using geologic evidence, research tools, and Earth Systems Science.

The materials and activities in this module help learners explore the geology and geological history of the Colorado Front Range and are easily adaptable to any region. The introductory PowerPoint and rock sample-based activities focus on: defining watersheds; using Google Earth-based maps to explore a local watershed; and geological events like uplift, erosion, and the deposition of sediments. The core activities in this module center around a stream-table or outdoor space, involve some time for preparation, and leave room for local adaptation. Learners will first simulate the uplift and erosion of sedimentary layers by a repeated series of glaciations using a base material, snow, crushed ice, spray bottles and a hairdryer. The next activity simulates stream erosion, and the eventual deposition and modification of sediment layers on the floodplain.

The wrap-up focuses on reinforcing key concepts in Colorado's geologic history and general watershed structure, while facilitating the evaluation of the stream table model's ability to recreate characteristic features associated with glacial and stream-based erosion and deposition. The "Extensions" section provides additional activities for the stream table, as well as resources and ideas for learner directed research, citizen science, and science fair projects.

Colorado Academic Standards:
Standard 3: Earth Systems Science:

- Prepared Graduates: Evaluate evidence that Earth's geosphere, atmosphere, hydrosphere, and biosphere interact as a complex system
  - Grade 5-Concept 2: Earth's surface changes constantly through a variety of processes and forces
  - Grade 6-Concept 1: Complex interrelationships exist between Earth's structure and natural processes that over time are both constructive and destructive
  - Grade 8-Concept 2: Earth has a variety of climates defined by average temperature, precipitation, humidity, air pressure, and wind that have changed over time in a particular location

- Prepared Graduates: Describe and interpret how Earth's geologic history and place in space are relevant to our understanding of the processes that have shaped our planet
  - Grade7-Concept 2: Geologic time, history, and changing life forms are indicated by fossils and successive sedimentation, folding, faulting, and uplifting of layers of sedimentary rock

Learning Goals:

Learners will be able to:

- Describe and evaluate the impact of various geologic events and processes on the current structure of the Boulder Creek Watershed
- Differentiate between constructive and destructive geologic forces impacting the Boulder Creek Watershed
- Describe the role of glacial and stream erosion in shaping the structure and hydrology in the Boulder Creek Watershed
- Describe major events in Colorado's climate over time and how they impacted the Boulder Creek Watershed

Key Concepts:

- The Earth's surface changes constantly through a variety of processes and forces
- Complex interrelationships exist between the Earth's structure and natural processes over time that are both constructive and destructive
- Glacial and stream erosion, as well as deposition, have characteristic features identifiable in the environment
- Colorado's climate has changed over time, impacting both living and nonliving systems

Guiding Questions:

- How has Colorado's geology changed over time?
- What geologic events created the Boulder Creek watershed and its features?
- What constructive forces were involved in those changes?
- What destructive forces were involved in those changes?
- How has Colorado's geologic history influenced the structures and materials we find here?
- How have changes in climate and weather impacted the Boulder Creek Watershed?

Activity 1: Introduction and Rock Sample Identification

Overview:
The introduction uses a PowerPoint presentation featuring scientifically guided, artist's renditions of Colorado's geologic history to explain the role of large-scale tectonic and climactic events in the formation of the current geological features. The slides use current Colorado maps and images to establish sense of place, and then show a series of map-based pictures of Colorado over a two hundred million year period highlighting major events that coincide with significant rock layers found in the Boulder Creek Watershed. Each team will then be provided rocks samples linked to the major events described in the presentation. Learners are then asked to identify the rock samples based on descriptions of the events that formed them including: sand-dune formation, stream erosion, coastal deposition and the uplift of granitic basement rock. The assessment section asks learners to describe one key event and how the features of the rock sample relate to the processes or events that led to its formation.

Time Needed: 10-15 Minutes

Learning Objectives:
Learners will:
- Relate changes to map-based images of Colorado over a large geologic time scale to major events in our geologic history
- Describe relationships between existing geologic features and the processes and forces that created them
- Will match rock samples to descriptions of the geologic processes/events that formed them

Learner Engagement:
- Establishing sense of place using maps from local to regional scale
- Relating learner experiences in the mountains, with local rivers or creeks, or with remarkable local geologic features to major geologic events in the past.

Guiding Questions:
- How has Colorado's geology changed over time?
- What geologic events created the Boulder Creek watershed and its features?
- What constructive forces were involved in those changes?
- What destructive forces were involved in those changes?

Common Misconceptions:
- The Earth's surface features have been stable for long periods of time

Prerequisite Knowledge and Skills:
- A basic understanding of plate tectonics and plate motions
- A basic understanding of the rock cycle, erosion, and deposition

Materials for the Teacher:
- PowerPoint presentation, notes and background materials
- Large rock samples for demonstration
- Computer, screen, projector or smart board

Materials for the Class:
- A set of 4 rocks samples for each team

Safety and Logistics:
Depending on the class, materials available and options included, facilitators should ensure there are enough rock samples, particularly conglomerates, for each learner to handle and take home small pieces (i.e. pebbles from the conglomerates). If tools like rock hammers, pliers or other implements are used, safety glasses and additional safety protocols should be incorporated.

Set Up:
1. Preview the presentation, notes and background materials
2. Set-up and check the presentation system and associated files
3. Prepare sets of rock samples and optional tools

Procedures
1. Review the major geologic events related to your rock samples from the PowerPoint presentation and distribute the sets of rock samples.
2. Give the learners time to examine and share the sets of rocks, compare and contrast the visible features, and share highlights amongst the group.
3. Read the description below of the four rocks and have the teams pick, as a group, a sample matching each. If using Front Range samples, they are:
   - One of these rocks is not like the others. It is very hard and made of many small crystals tightly locked together. This is a sample of the uplifted basement rock called granite.
   - This rock sample was made from fine sands, originally in sand dunes that covered this part of Colorado. Which of these is the sandstone?
   - One rock sample started as mud, laid down at the bottom of an ancient sea. Over many, many years it was compressed into a soft, brittle rock called shale.
   - This rock is made from sand and pebbles washed downstream as the Ancestral Rockies were eroded over two hundred million years ago. Which is the Conglomerate?
4. Using the demonstration set, correct and elaborate on the team's selections using the details below:
   - The sample of Granite was part of the massive layer of basement rock pushed up by the tectonic forces. Over millions of years of erosion it was exposed to the elements and though it is very hard, it too was ground down and broken off a much larger layer.
   - There are many types of sandstone in Colorado, depending on the source and size of the materials. They come in greens, blues, yellows, reds and browns and tan.
   - This type of shale was originally mud on the bottom of the ancient seas that covered the Great Plains. In some places it is thousands of feet deep and shales like these can be found under the surface soils from the Rockies to the Mississippi River.
   - As the Ancestral Rockies were eroding, rocks, pebbles and sand were washed down ancient streams and some of the materials were left in streambeds and deltas. The sand and pebbles have been cemented in this rock for over 200 million years! (If you have enough material, encourage the learners to safely break up the conglomerates and keep a pebble that has been trapped in the conglomerate for 200 million years!)

Assessment:
Have one learner from each group relate a characteristic of their rock sample to the observable features, and pose the Guiding Questions to the group in either a written or discussion format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to include igneous, sedimentary, and metamorphic rock samples, incorporate higher level descriptions, as well as more advanced geologic concepts like crystallization, mineral identification, measurements of hardness, streaking, etc. In locations with limited sedimentary layers, like high mountain areas, concepts like igneous intrusion, dike formation, and mineral deposition can be incorporated by using those materials. In areas with limited mountain formations, different shales, sandstones, and mudstones can be incorporated, as well as concepts related to shale and the availability of fossil fuel resources.

Activity 2: Granitic Uplift and Glacial Erosion

Overview:
In this activity learners will place an approximately one inch thick layer of simulated Fountain Formation sedimentary rock on a slope and erode it with repeated glaciations. Using snow or crushed/shaved ice, teams will deposit layers of snow on the slopes and compress it to simulate the compaction of snow layers over time. The results will be contrasted with the learners understanding of the difference between snowpack, snowfields and glaciers, before repeating the process a number of times. In the second part of the activity learners will be asked to focus the snow in one central area and compress the snow to simulate glacial erosion. The class will be shown examples of the characteristic features of glacial erosion and asked to identify any of those features present in their model while the simulations are repeated. Finally, learners will be given a tear-drop shaped 'sanding block' to add additional forces to their glacial erosion models and to differentiate between the features associated with stream an glacial erosion. The wrap-up uses sample images, diagrams of common glacial features, and asks learners to evaluate their model's ability to simulate glacial erosion.

Time Needed: 20-30 Minutes

Learning Objectives:
Learners will:
- Simulate and describe the impacts of glacial erosion over time using a model
- Identify characteristic features of glacial erosion in their model landscape
- Describe the role of glaciers in shaping the Boulder Creek Watershed

Learner Engagement:
- Have the learners describe the of the role of ice and snow in Colorado's water supply

Guiding Questions:
- What geologic events created the Boulder Creek Watershed and its features?
- What destructive forces were involved in those changes?
- How have changes in climate and weather impacted the Boulder Creek Watershed?

Common Misconceptions:
- The impact of glaciers is limited only to high elevation areas
- Glacial ice, not the materials they move, are the scouring agents in glacial erosion

Prerequisite Knowledge and Skills:
- A basic understanding of geologic time
- A basic understanding of changes in weather and climate over time

Materials for the Teacher:
- Computer, screen, projector or smart board
- PowerPoint presentation, notes and background materials
- A set of colored felt, play foam or other flexible materials cumulatively 6-10 cm thick
- Towels, rags or paper towels for spot clean-up during the activity
- Plastic wrap, a mixing bowl and 2-6 cm deep cookie sheets or baking pans
- Play sand, plaster and food coloring

Materials for the Class:

- A set of stream tables with drains and base materials, or sloped outdoor space
- A hard base material to simulate the role of basement rock and mountains
- A layer of sedimentary rock for each team, prepared in advance
- 2000-3000 ml of snow, shaved or crushed ice per team
- Two spray bottles, two 500 ml beakers and a small watering can filled with warm water
- An extension cord, fused power strip, and hairdryer for each station
- A tear-dropped shaped sanding block, ice cubes, or other methods to simulate glacial and stream erosion
- Brooms, dustpans, small mops, rags, hand or paper towels

Safety and Logistics:

This activity, like all stream table activities has the potential to be quite messy and learners will need ample supervision to ensure proper sharing of roles and to keep things organized. Extreme care should be taken to ensure the hairdryer and its power supply is kept well away from water, misguided sprays, or spills. It is strongly recommended that the hairdryers are handled by adults only. Finally, with water, snow and ice in play, slipping and falling hazards should avoided by supplying the learners with adequate cleaning tools and supervision.

Set Up:

1. Prepare a set of sedimentary rock layers for each team at least 12 hours in advance by:
    - Lining the bottom of a cookie sheet or baking pan with plastic wrap and leaving enough around the edges to allow the materials to be lifted out.
    - Following the direction on the container, mix enough plaster to cover the bottom of the pan with 1-2 cm of plaster. Pour the mix on top of the plastic wrap base.
    - As the plaster sets up, use your fingers to add variation (troughs and depressions) to the plaster. This will help the sand/plaster mix stay in the proper place
    - Give the plaster enough time to fully set up, usually 30-45 minutes.
    - Dust the top of the dry plaster with a very small amount (10 ml) of dry plaster
    - Mix 2000 ml of play sand, 250 ml of water, 150 ml of plaster, and 40 drops of red food coloring in a large mixing bowl. Depending on the type of sand used and the humidity, the amount of plaster can be varied from 100 to 200 ml through experimentation. The resulting materials should be durable, soft enough to scratch with your fingernail, and 'melts' when warm water is added. The food coloring can also be modified, in both amount and color, to match local materials. For more sedimentary material options, options see the Set-Up section in the next activity.
    - Immediately spread the mixture in the pan, press down firmly and let dry.
2. Prepare the space for the potentially messy activities by removing any valuable materials and protecting surfaces from water/sand by covering them with plastic or other material.
3. Prepare the stream tables by cutting 1 cm holes for drain, placing a bucket or large beaker below it, and lining the bottom with 3-5 cm of sand or gravel.
4. Create sloped areas of the model (approximately 45 degrees) and hard surfaces by using large flat rocks, thin layers of concrete over sloped sand, or some other materials.
5. Prepare a set of materials for each group by filling the water containers (spray bottle, beakers and/or watering cans) with warm water and providing them with the tear-drop shaped sanding block (http://dura-block.com/durablockline.html). The block can be substituted with ice cubes or any material that will create U and V-shaped valleys.

Procedures

1. Begin by showing the class the glaciers section of the PowerPoint Presentation and the optional National Geographic YouTube video showing the geologic processes associated with the Laurentian Orogeny and mountain building.
2. Demonstrate the folding and uplift of sedimentary layers by the granitic basement rocks using the play-foam or felt layers.
3. Inform learners that the blocks of sedimentary rocks created for the activity represent the uplifted layers of sedimentary rock from the Fountain Formation (grainy red sandstones), and have the learners place them on the sloped section of the model.
4. Have the teams delegate a learner for each of the critical tasks. These tasks can be rotated throughout the activity:
    - A team member in charge of getting snow and water
    - Two people in charge of spreading and compressing the snow on the model
    - Two people responsible for adding water to the model when asked.
5. Have the delegates use the spray bottles to apply a liberal amount of water to the sedimentary rocks using the spray bottle (approximately 6 ‘pumps’ per side)
6. Have the delegates retrieve approximately 100 ml of snow from the cooler or container and sprinkle it evenly across the sedimentary rock layer
7. Inform the learners that this represents a winter’s worth of snow left on the mountains.
8. Repeat the spraying (Step 5), and then have an adult heat the models with the hairdryer for approximately 60 seconds.
9. Inform the learners that the resulting distribution of snow represents ‘snowfields’ or snow left on the slopes throughout the year. Provide them with definitions of snowfields and glaciers, and then show them the corresponding slides from the PowerPoint Presentation.
10. Repeat steps 5, 6 and 8, having the learners note and describe to their teacher any signs of erosion or changes to the landscape as a result of their efforts.
11. Have the learners compress or compact the snow with their hands, pushing down firmly, but not hard enough to crack or crush the sedimentary layers below.
12. Repeat the process of adding snow, compressing, spraying, heating and noting changes to the landscape a number of times.
13. Explain to the learners that this simulation could represent one winter, or multiple winters in a series of ‘cold’ years or glacial periods. Inform the class that they will now work to form a glacier by adding snow on top of a central snowfield.
14. Have the learner responsible for retrieving the snow make two ‘snowballs’ from approximately 100 ml of snow each.
15. Instruct the teams to gently press the snowballs down the slope, flattening them out and using them to erode the surface. Repeat the spraying and heating steps, focused primarily on the area with the snowball glaciers.
16. Show the class the corresponding slides showing glaciers, diagrams of glaciers, and the current and historical glacial extents in the Boulder Creek Watershed.
17. Have the learners make snowballs of approximately 50 ml of snow, adding them to the central glacier, and repeat the compression, spraying and heating. Repeat this process a number of times until the bulk of the teams have significant erosion and characteristic features of glacial erosion.
18. Show the class the corresponding slides showing the Front Range mountains, common features of glacial erosion, and have them identify any features they recognize in their models (U-shaped valleys, cirques, moraines, glacial lakes, etc.)
19. Tell the class we need to ‘speed up the process’ by using the tear-drop shaped sanding block to scour the mountains and make U-shaped glacial valleys.

20. Rub the block on your arm to reinforce the concept that the ice does not scour the terrain, but the weight causes the materials beneath it to do the scouring. Have the learners repeat the process of adding small snowballs, spraying and heating, while adding and accentuating the existing U-shaped valleys with the sanding block.
21. Wrap-up by having the learners identify features of glacial erosion, evaluate the models ability to simulate glacial erosion, and give them the opportunity to use the snow, spraying, heating, and block to experiment with the creation of these features in their model.

Assessment:
Show the class the final slides associated with this activity, explore the Google Earth map of the Boulder Creek watershed, and have the learners identify features in the mapped landscape that can be attributed to glacial erosion and deposition. Conclude by posing the Guiding Questions to the group in either a written or discussion format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to many locations by changing the shape or angle of the mountains, incorporating complex valley features, or changing the color or consistency of the sedimentary materials. This activity can be restructured as a guided inquiry for higher level learners by giving them the tools and materials, showing them the glacial structures desired, and letting them experiment and document the methods or processes needed to recreate them.

Activity 3: Stream Erosion and Watershed Structure

Overview:
This activity focuses on the uplifted sedimentary layers common across Colorado and the stream-based erosion and deposition that shapes canyons and floodplains. The activity uses sedimentary layers similar to those in the previous activity, but diverse enough to represent a wide variety of base materials. The process begins by adding layers of sediments to the base of the mountains, directly beneath the areas scoured by glaciers, thereby completing the model terrain. Next, teams add water from both beakers and watering cans to the model, noting the types of erosional and depositional features created by the process. Finally, participants are asked to compare and contrast the features in their models to images and diagrams from the PowerPoint presentation and complete a final evaluation of their model's resemblance to the Boulder Creek Watershed.

Time Needed: 20-25 Minutes

Learning Objectives:

Learners will:

- Simulate and describe the impacts of stream-based erosion and deposition over time using a model
- Identify characteristic features of stream erosion and deposition in their model landscape
- Describe the role of stream erosion in shaping the Boulder Creek Watershed

Learner Engagement:

- Establishing sense of place using maps and images
- Having learners describe the topographical features associated with streams and rivers they have observed

Guiding Questions:

- What geologic events created the Boulder Creek watershed and its features?
- What constructive forces were involved in those changes?
- What destructive forces were involved in those changes?

Common Misconceptions:

- Geologic features remain static over long periods of time

Prerequisite Knowledge and Skills:

- A basic understanding of stream structure and flow patterns

Materials for the Teacher:

- Computer, screen, projector or smart board
- PowerPoint presentation, notes and background materials
- Plastic wrap, a mixing bowl and 1" deep cookie sheets or baking pans
- Natural clay, play sand, ground charcoal or other nearly black material, fine or screened sand, small gravel or pebbles, tube sand, plaster and food coloring.
- Buckets for waste rock an excess materials
- A bucket for soiled rags and other waste

Materials for the Class:

- A set of stream tables with drains and base materials or sloped outdoor spaces
- A hard base material to simulate the role of basement rock and mountains
- Multiple (4-8) layers of sedimentary rock for each team, prepared in advance
- Two spray bottles, two 500 ml beakers and small watering can filled with warm water
- Brooms, dustpans, small mops, rags, hand or paper towels

Safety and Logistics:

This activity, like all stream table activities has the potential to be quite messy and learners will need ample supervision to ensure proper sharing of roles and to keep things organized. An option to move this activity to a sand-box or other outdoor space could help minimize any potential issues. Finally, with water in play, slipping and fall hazards should be avoided by supplying the learners with adequate cleaning tools (towels, mops, etc.).

Set Up:

1. Prepare a set of sedimentary rock layers for each team at least 12 hours in advance. Once the mixtures have begun to set-up, use a toothpick, spatula or plastic knife to divide the trays into enough rectangles to provide each team with 2 pieces. These somewhat fragile materials can be prepared well in advance and stored on trays or in bags.
2. Line the bottom of 4-8 cookie sheets, baking pans or trays with plastic wrap, leaving enough around the edges to allow the materials to be easily lifted out.
3. Mix, spread, and compact the recipes described in the appendix to recreate the sedimentary rocks common in the Colorado Front Range. Be sure to allow adequate time for the materials to dry before use.
4. Prepare the space for the potentially messy activities by removing any valuable materials and protecting surfaces from water damage by covering them with plastic or other materials.
5. Prepare a set of materials for each group by re-filling the water containers (spray bottle, beakers, and/or watering cans) with warm water.

Procedures

1. Begin by distributing the sets of sedimentary layers, and reviewing the series of events that lead to the creation of these layers. If time allows, re-play the succession of slides showing the events, describe the layers and the conditions that formed them, or have the learners describe the characteristics of each layer and hypothesize about the associated processes.
2. Have the groups place the layers at the base of the mountains, leaning uphill at an approximately 75 degree angle, and add one small handful of base materials from the tray on top of the layers to fill in any gaps.
3. Show the class the Google Earth-based map of the area, the slides representing the layers and terrain in profile. Have the teams compare and contrast the general shape of the landscape to the terrain represented in their models.
4. Have the learners evenly pour 250 ml of water over the glacial section of the model, allowing it to run over the new layers, compact the soils and 'recharge the groundwater' to allow for surface erosion to take place.
5. Next have the designated team member pour 5 seconds worth of water from the watering can, with the rest of the group counting, and take note of the erosional and depositional features they are creating. Repeat this step a number of times until the majority of the groups have significant and recognizable features.
6. Show the class the slides representing canyon cutting, valley formation, alluvial fans and terracing. Have the learners search for these features in the models they created.
7. Finally, give the teams an opportunity to experiment with the models in an effort to recreate the features of the erosional and depositional sections of the watershed.

Assessment:
Show the class the final slides associated with the module, explore the Google Earth map of the Boulder Creek watershed, and have the learners identify features in the mapped landscape that can be attributed to glacial and stream erosion, as well as deposition and channel formation over time. Conclude by posing the Guiding Questions to the group in either a written or discussion format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to many locations by changing the recipes for the materials used, both in color and texture, to match local materials. In some high-mountain areas, the layers themselves can be replaced by pushing up the sand or gravel base materials to represent compacted erosional products in the valley bottoms. For areas where the terrain is flatter, the layers can be placed along a gentle slope and overlapped like shingles to represent layers of rock cut through as streams and rivers cross the plains. This activity can also be restructured as a guided inquiry for higher level learners by giving them the tools and materials, showing them the erosional and depositional structures desired, and letting them experiment and document the methods or processes needed to recreate them in the model.

Clean Up and Materials Preparation

Overview:
The focus for the last 10-15 minutes of the module should focus on cleaning up any sand or water, preparing the materials for the next group, and refilling the water containers. Each team will be responsible for:

- Removing the bulk of the sedimentary rock materials from the models, placing them in the waste buckets under the tables, and re-leveling the base material in the bottom of the stream table
- Checking the draining mechanism and bucket for potential problems and improving table drainage by shifting the base materials and pushing water towards the drains
- Wiping down the sanding blocks and other materials used in the models
- Cleaning sand, mud and water off the surfaces and floor
- Refilling the water containers and organizing the table for the next group

Background Information, Resources, and Extensions

Geology Background Information:
To understand the current geology of Boulder creek watershed, and much of Colorado, one must start at the beginning, almost 400 million years ago. In these early times, as North America was forming, Colorado was under the ocean and sedimentary rocks, primarily shales, limestones and sandstones, were deposited on top of the existing granite or basement rocks. Over the next 350 million years many exciting events happened, each leaving a record found in the sediment layers we see today. Tectonic forces caused mountain ranges to be built up, and erosional processes ground them back down to the sea. Inland seas formed, came and went, each leaving behind telltale limestones, mudstones, even beach sand in the form of fine-grained sandstones. During later times Colorado was a dry and giant sand dunes formed across the west as dinosaurs roamed leaving footprints and fossils for us to discover.

As always, the forces of erosion and deposition carried on, until major events 65 million years ago changed everything. The Laurentian Orogeny caused the much of the western United Stated to lift thousands of feet to its current position, and today's Rocky Mountains were born. Pushed up by incomprehensibly strong forces, the basement rocks, primarily granites rose, pushing up thousands of feet of sedimentary rock laid down over millions of years of erosion and deposition. Once formed, the powers of erosion and deposition began acting on the new mountains. At the higher elevations, glaciers cut away the weaker sedimentary rocks and granites over thousands of years, leaving the U-shaped valleys and glacial features we see today. Lower down the mountains, streams and rivers cut through the softer, sedimentary rock, while carrying away the sands and gravels to be deposited on the plains.

Watersheds Background Information:
At the most basic level, watersheds are areas of land that drain water to particular rivers, streams, lakes, aquifers, or eventually the ocean. Despite this simple definition, watersheds are very complex systems upon which we all depend. Everyone and every living thing in a watershed are bound together because they all depend on the same sources of water. Whatever happens upstream affects the quality of the water downstream.

The concept of a watershed is based on the basic principal that water flows downhill. Thus, the boundaries of a watershed are determined by the topographical features of a particular area of land. The boundaries of a watershed can be established by connecting the highest points of elevation between two adjacent areas on a map. All of the water that already exists within that area and all of the precipitation that falls within the traced line will drain down to form the watershed for that piece of land. The watersheds that we depend on today have been formed over millions of years by geologic forces altering the Earth's surface. Erosion, deposition, weathering, glacial movement, tectonic activity, volcanic activity, and mountain building have effected, and continue to effect, the ways in which water flows within our watersheds.

Watersheds and Water Quality Background Information:
Land usage in the form of crop farming, livestock farming, the development of cities, housing, and transportation all effect the water within a given watershed. Pesticides used in farming and animal waste find their way from farms to ground water and lakes and streams, as do chemical by-products from industrial areas, and oil and other pollutants from vehicles. Pollutants such as these can be characterized as point source pollutants (direct dumping of a pollutant in a stream or lake, for example) or non-point source pollutants (pollution resulting from storm water run-off, for example). Additionally, altering the land in order to develop urban/suburban areas or for farming purposes can lead to greater soil erosion, which means more sediments in waterways—a natural pollutant that can

potentially alter ecosystems and harm aquatic wildlife—or an inability for aquifers to recharge do to impermeable ground coverings, like cement, which do not allow water to seep into the ground.

The damming of rivers or streams within a watershed is a common way to divert water for crop irrigation or for other human purposes such as flood prevention and producing hydroelectric power. Damming or diverting water flow can reduce the amount of sediment within a waterway, which can once again harm aquatic wildlife and ecosystems dependent on the natural balance of the river or stream system. Damming and diverting water in a stream or river system can also reduce the amount of water available to ecosystems or communities downstream. For instance, in the Colorado River Watershed, the river very seldom reaches its delta at the Gulf of California because the water has been used upstream for various human purposes.

Additional Resources:

- Paleogeological information, images and resources are based on from work by Dr. Ronald C. Blakey, Dept. of Geology, Northern Arizona University, and available at: http://www2.nau.edu/rcb7/paleogeogwus.htm
- More information and details about the geological history of the Boulder Creek watershed can be found at http://bcn.boulder.co.us/basin/natural/geology/historic.html.
- More information about Colorado geology can be found at http://geosurvey.state.co.us/geology/Pages/Geology.aspx
- The book *Roadside Geology of Colorado,* by Halka Chronic and Felice Williams (2002), provides a great overview of Colorado geology, as well as information about local geology and geologic history for most areas in the State.
- In addition to the video resources included in the PowerPoint presentation, the following links may provide valuable supplemental materials and background information:
    - A National Geographic Program excerpt focused on the formation of the Rocky Mountains: http://www.youtube.com/watch?v=tjk9cFz152s
    - An animation created by the Department of Earth Sciences at Aarhus University showing glacial erosion over time: http://www.youtube.com/watch?v=D5uDaEpJHjE
    - The Annenberg Foundation's Learners.org Geology Video Collections: http://www.learner.org/resources/series78.html?pop=yes&pid=317
    - The Colorado Water Science Center: http://co.water.usgs.gov/
    - USGS Real Time Water Data for the Nation: A resource for flow and water quality data: http://waterdata.usgs.gov/usa/nwis/rt

Extension Activities and Opportunities:

A variety of learner-directed research and science fair projects can center on the structural geology and hydrology concepts included in this module. Some of these opportunities include:

- Comparing, contrasting, and potentially mapping the relative hardness and erodibility of local rocks and soils using a number of indexes and processes available online
- Collecting, comparing, and contrasting stream flow data, water quality, watershed size and differences in structural geology using learner collected data or data available from the sources below
- Creating working models of local watersheds in stream tables and experiments centered on the role of glaciers and streams in their formation and function
- Creating experiments using water (water fountains or dripping) to demonstrate the differences in hardness and erodibility of local rock layers.

The Boulder Creek Critical Zone Observatory Program offers a wide variety of data, map layers and other resources related to their research that can form the foundation for extension activities and are available at: http://czo.colorado.edu

The University of Colorado at Boulder PhET Program's Glacier Simulator: This interactive tool allows users to see and track glacier formation based on changes in weather and climate data. http://phet.colorado.edu/en/simulation/glaciers

The Community Collaborative Rain, Snow and Hail Network (CoCoRaHS): A citizen science and volunteer program centered on precipitation data collection: http://www.cocorahs.org/

NFS and Carleton College's Advanced Stream Processes Laboratory Activities: http://serc.carleton.edu/NAGTWorkshops/intro/activities/23422.html

Appendix: Recipes for Recreating the Front Range Sedimentary Rock Formations

The recipes below, when compacted and allowed to dry, will recreate common sedimentary rock layers found in the Colorado Front Range for the stream erosion activity. The hardness and erodibility of the resulting material will be dependent on a number of variables including the consistency of the sand and gravels used, humidity, and water chemistry. Experimenting with the recipes is recommended before producing them in large quantities. Recipes can be adapted to match local formations by changing the colors, materials and the amount of plaster or clay used.

- Fountain Formation Sandstones: These red, grainy sandstones are floodplain deposits of sand and small materials from the erosion of the Ancestral Rockies. Recreate them by mixing: 2000 ml of play sand, 250 ml of water, 160 ml of plaster, and 40 drops of red food coloring pressed into a 2-3 cm thick layer in a tray or cookie sheet.

- Fountain Formation Conglomerates: These 'mixed' rocks contain red sandstone, gravels and rounded pebbles left in streambeds and deltas during the erosion of the Ancestral Rockies. They can be recreated by mixing: 1000 ml of play sand, 500 ml of fine sand, 500 ml of tube sand or fine gravel, 250 ml of water, 160 ml of plaster, and 40 drops of red food coloring pressed into a 2-3 cm thick layer

- Lyons Sandstones: These fine grained, tan to pink, solidified sand dunes were formed when much of the West was a desert. Recreate them by mixing 2000 ml of very fine or filtered sand, 250 ml of water, and 140 ml of plaster. Just before spreading it on the tray, add 20 drops of red food coloring and mix unevenly to create a 1 cm thick layer of 'banded' sandstone with streaks of pink and red running through it.

- Lykins Formation Shales and Siltstones: These bright red, very soft shales and fine siltstones were formed by streams on the floodplain and shores as they deposited muds carried from the eroding Ancestral Rockies. Begin by dissolving 100 ml of light colored natural clay in 250 ml of water. The mixture can be adjusted until it has a thick consistency similar to that of chocolate milk. Add 1500 ml of the finest sands, 80 drops of red food coloring, mix and press into a 1 cm layer, and allow the materials to dry for at least 12 hours in the sun or is a warm place.

- Entrada Sandstones: These fine grained sandstones were formed when, once again, Colorado was dry and desert winds left giant sand dunes across much of Colorado. These layers can be recreated by mixing 2000 ml of fine or screened sand, 140 ml of plaster, 250 ml of water and 30 drops of yellow food coloring. Spread the mixture into 1-2 cm thick layers and let dry.

- Morrison Formation mud and sandstones. By far the most famous and hardest to recreate layers of sedimentary rock, the Morrison formation consists of blue, green, red and brown layers of softer sand and mudstones. Created by rivers carrying materials from as far away as Utah across the floodplains and remains of the Ancestral Rockies, these layers hold fossil evidence of the dinosaurs that roamed the warm, wet meadows where these layers were formed. To recreate these layers, begin by dissolving 50 ml of light colored natural clay in 125 ml of water. The mixture can be adjusted until it has a thick consistency similar to that of chocolate milk. Add 750 ml of the finest sands, and just before mixing, add 20 drops of both green and blue food coloring spread throughout the mixture. Without mixing completely, spread ½ of the mixture on the bottom of a pan or tray. Then dissolve 100 ml of natural clay, 40 drops of red food coloring into 125 ml of water and pour on top of the other layer. Finally add the remainder of the first mixture to create a layered sedimentary formation approximately

2 cm thick. Place the tray in the sun or a warm place for at least 12 hours to allow the resulting mixture to harden.

- Dakota Sandstones: These layers of very hard, tan to pink sandstones were once beaches along the ancient seas where the Great Plains now sit. Recreate them by mixing: 2000 ml of play sand, 250 ml of water, 200 ml of plaster and press into a 1-2 cm thick layer in a tray or cookie sheet.

- Benson, Niobrara and Pierre Formations: This combination of layers was formed along the edges of ancient seas and represent deposits formed during the multiple successions of inland seas. They represent layers of very soft sandstones, mudstones, shales, coal beds and limestone. To recreate them, start by dissolving 50 ml of light colored natural clay in 125 ml of water. The mixture can be adjusted until it has a thick consistency similar to that of chocolate milk. Add 750 ml of the finest sands, and pour the mixture into the bottom of the tray. Next add a thin layer of powdered charcoal or other dark material to simulate the coal beds created in ancient coastal wetlands. Finally, mix 500 ml of play sand, 250 ml of water, 100 ml of plaster, and 10 drops each of red, blue and yellow food coloring, as well as 20 ml of the charcoal mix, to create a weak, brown to grey sandstone mix. Press firmly onto the layers below and let dry. Of all the potential mixtures, this one is the most fragile. It is recommended this layer be left in the trays until the activity begins and let the learners remove the pieces as best they can.

Ice, Snow and H_2O

Module Overview:
Ice and snow play a critical role in supplying Colorado's rivers, streams, and communities with water throughout the year. The amount of snow that falls and is stored in the snowpack and glaciers is carefully monitored across the State, and around the world. Understanding how ice and snow impact our water supply, and how that may change in the future, is an important part of the scientific research conducted in the Boulder Creek Critical Zone Observatory Program.

In this module learners will explore the role of snow and ice in Colorado's water supply, as well as develop understandings of how ice, snow, soils, climate, and the Earth System interact to regulate Colorado's water supply. In the introduction, teams will use 3-D shaded relief maps of Colorado and the Denver area to explore Colorado's ecosystems and precipitation regimes, rivers and watersheds, as well as watershed structures. In the second activity, learners will use a simulated snow core to explore the roles of precipitation, wind, temperature and solar radiation in building and maintaining Colorado's snowpack. In the next activity, teams will calculate the density of snow and its water weight equivalent before attempting to compress it into glacial ice. Finally, learners will play a game to simulate Earth System interactions and water flow regimes in the tributaries of Boulder Creek.

The wrap-up focuses on reinforcing the importance of snow and ice in Colorado's water supply and the potential impacts of climate change, land use, and management decisions. The 'Background Information, Resources and Extensions' section of this guide provides additional activities related to ice, snow and water, as well as resources for research, science fair projects, and participation in citizen science projects.

Colorado Academic Standards:
Standard 1: Physical Science

- Prepared Graduates: Apply an understanding of atomic and molecular structure to explain the properties of matter, and predict outcomes of chemical and nuclear reactions
  - Grade 6-Concept 4: Distinguish among, explain, and apply the relationships among mass, weight, volume, and density

Standard 2: Life Science

- Prepared Graduates: Explain and illustrate with examples how living systems interact with the biotic and abiotic environment
  - Grade 6-Concept 1: Changes in environmental conditions can affect the survival of individual organisms, populations, and entire species
  - Grade 8-Concept 1: Human activities can deliberately or inadvertently alter ecosystems and their resiliency

Standard 3: Earth Systems Science:

- Prepared Graduates: Describe how humans are dependent on the diversity of resources provided by the Earth and Sun
  - Grade 5-Concept 1: Earth and Sun provide a diversity of renewable and nonrenewable resources
  - Grade 6-Concept 2: Water on Earth is distributed and circulated through oceans, glaciers, rivers, ground water, and the atmosphere

Learning Goals:

Learners will be able to:

- Measure mass and volume, and use these quantities to calculate density
- Gather, analyze, and interpret data on physical and chemical changes
- Gather, analyze, and interpret data that show mass is conserved in a given chemical or physical change
- Use evidence to model how water is transferred throughout the Earth System
- Identify problems and propose solutions related to water quality, circulation, and distribution - both locally and worldwide
- Develop, communicate, and justify an evidence-based scientific example of how humans can alter ecosystems

Key Concepts:

- Snow and ice play a critical role in Colorado's water supply
- Changes in snow density or volume do not impact the water weight equivalence or mass
- The amount of precipitation that falls as snow, as well as snowpack and glacier formation, are dependent on weather and climate
- Water moves through and is stored in snow, ice, lakes, soils and other Earth Systems
- Humans can influence water storage and availability by managing wildfires, runoff, water diversion, and by building and managing reservoirs

Guiding Questions:

- What are the major rivers and watersheds in Colorado? Where do these rivers go?
- What features form the boundaries between watersheds?
- What role do snow and ice play in Colorado's water supply?
- What role do precipitation, wind, temperature, and solar radiation play in the development and longevity of the snowpack?
- What physical changes occur when snow is compressed into glacial ice?
- What impact does snow compaction have on its weight, volume and density?
- What Earth System interactions regulate the flow of water throughout the year?
- What can humans do to regulate the flow of water throughout the year?
- What impact will climate change and land use decisions likely have on water resources in Boulder Creek, and across Colorado, in the future?

Activity 1: Introduction and Shaded Relief Maps

Overview:
The introduction uses three dimensional, shaded-relief maps of Colorado and the greater Denver area, or other local or regional maps, to establish sense of place, familiarize learners with the topographical features and biomes of Colorado, and explore Colorado's major rivers, watersheds and precipitation regimes. Learners will first identify the major biomes of Colorado and describe their precipitation regimes. Next learners will locate and follow the Continental Divide, identify the major rivers and, as a team, find points on the watershed boundaries for the Rio Grande, Arkansas, Platt, and Colorado Rivers. They will then identify and estimate the total land area likely to receive significant snowfall and areas that are likely to have glaciers and permanent snowfields. Finally they will identify river systems, areas, and communities that are likely dependent on snow and ice for year round water and features built to manage and expand water resources. Using local maps, teams will first identify major topographic features, land cover patterns, the Continental Divide, major rivers, and watershed boundaries. Next they will identify Boulder Creek, its tributaries, watershed boundaries and built features like irrigation channels, reservoirs and tunnels. Finally, participants will find and identify the research sites in the Boulder Creek watershed and identify areas that have significant snowpack, snowfields, and glaciers. The assessment section focuses on describing the Earth Systems interactions impacting snow, ice, and regional hydrology, as well as human efforts to influence and regulate water supplies.

Time Needed: 10-15 Minutes

Learning Objectives:
Learners will:
- Use maps to further their understanding of watershed features, structures and boundaries
- Use maps to identify the major rivers and creeks in Colorado and the Boulder Creek Watershed
- Use maps to develop a preliminary understanding of the roles ice and snow play in Colorado's water supply
- Use maps to find and identify built features for managing and expanding the flow of water on local and regional scales

Learner Engagement:
- Establishing sense of place using maps from regional to local scale
- Relating learner experiences in the mountains, with local rivers or creeks, or with remarkable local geologic features

Guiding Questions:
- What are the major rivers and watersheds in Colorado? Where do these rivers go?
- What features form the boundaries between watersheds?
- What role do snow and ice play in Colorado's water supply?
- What can humans do to regulate the flow of water throughout the year?

Common Misconceptions:
- Watershed boundaries are formed by mountains, not by subtle features of the landscape
- All of the water that falls West of the Continental Divide stays on that side of the watershed
- All rivers and streams eventually go to an ocean

Prerequisite Knowledge and Skills:

- A basic understanding of maps and projections
- A basic understanding of Colorado's ecosystems

Materials for the Teacher:

- A master set of topographic maps for reference
- An optional wall map or projection

Materials for the Class:

- A map of Colorado for each team or map projection
- A local map for each team or map projection

Safety and Logistics:

The plastic three-dimensional maps are inherently fragile so establishing basic ground rules for map handling is important. Be sure to provide an adequate number of place marks to easily facilitate the identification of major features.

Set Up:

1. Prepare the map sets by adding place marks or prepare digital maps

Procedures

1. Introduce the module by discussing the role of ice and snow in the Colorado water supply and the importance of year round water to both natural and human communities including:
    - Water is used in homes, industry, and plays a significant role in Colorado agriculture.
    - On average, people use nearly 350 liters (or 100 gallons) of water per day at home.
    - Approximately 80% of Colorado's water starts as snow.
    - There are complex interactions involving the entire Earth System that influence Colorado's water supply including, but not limited to: structural geology, soils, and groundwater; watershed structure; weather and climate; as well as interactions involving living systems, both natural and built.
2. Introduce the map handling guidelines, distribute the maps, and give the learners some unstructured time to explore them.
3. Describe the role of the place marks and have learners find their current location on the map.
4. Ask the learners to find, identify, and share the major biomes of Colorado, including areas that represent alpine, subalpine, mountain, foothill, steppe, grassland, and desert ecosystems.
5. Have the learners share their understandings of the precipitation regimes for each area starting with the area they live in.
6. Next have the teams locate and follow the Continental Divide and identify the major rivers including the Rio Grande, Arkansas, Platt, and Colorado Rivers.
7. Have the teams find points along the watershed boundaries for the major rivers, focusing their attention on the more subtle edges in the plains.
8. Next have the teams identify areas likely to receive significant snowfall and areas that are likely to have glaciers and permanent snowfields.
9. Finally have the learners locate areas and communities that are likely dependent on snow and ice for year round water, as well as large scale built features to manage and expand water resources.
10. To wrap up, ask the learners if all the precipitation that falls west of the Continental Divide stays on that side and have them follow the Platt River from the border to its headwaters in the greater Denver area.
11. Have the learners bring the Colorado maps to the center table and exchange them for maps of the greater Denver area, or other local maps.

12. Using local maps, teams will first identify major topographic features, land cover patterns, as well as find and identify the Continental Divide.
13. Have the learners identify and follow the major rivers and identify features along the watershed boundaries.
14. Then, have the learners identify Boulder Creek, its tributaries, and topographic features, focusing on key areas and built features like irrigation channels, reservoirs, and tunnels.
15. Finally, have the learners find and identify the research sites in the Boulder Creek watershed and identify areas likely to receive large amounts of snow or have snow and ice throughout the year.

Assessment:
Have the learners name and identify the major rivers in Colorado and in the greater Denver area, as well as the bodies of water they flow to. Have selected learners share the topographical features that act as watershed boundaries, list built features designed to manage and expand water resources and, finally, describe the characteristics of the Boulder Creek watershed. Conclude by posing the Guiding Questions to the group in either a written or discussion format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to include the basic features of topographic and shaded relief maps, map symbols and orientation, as well as other grade level topics like biomes, geography, geologic maps, measurement and estimations, etc. Local maps, either printed or digital, can replace the maps of the greater Denver area. The three dimensional characteristics of the shaded relief maps can be replaced using Google Earth of other mapping tools. The 'Background Information, Resources and Extensions' section of this guide contains links to map tools, Google Earth map layer, and other resources to aid in this process.

Activity 2: Weather Data and Snow Tubes

Overview:
In this activity learners will first examine a set of weather data from Niwot Ridge, an area in the headwaters of Boulder Creek near the Continental Divide. The data, collected in January of 2010, includes snow accumulation, average wind speeds, temperature, and average solar radiation. After noting significant trends in the data, including the precipitation events, low temperatures, and significant amounts of solar radiation, learners will be asked to identify these trends in a simulated snowpack core or snow tube. Scientists across the state, and around the world, use data to understand the snowpack, the water it contains, and to predict the amount of water that will be available when the snow melts. Key events in the data, as well as structural changes in the snow itself, are represented in the tubes including: snow compaction in the lower levels, formation of layers of ice from radiation-driven melting and refreezing events, and the deposition of fine-grained sediments during wind events. A method for creating snow tubes based on this data is included in the 'Preparation' section of this guide and basic instructions for making snow tubes from local data is included in the section titled 'Grade Level Adaptations and Local Variations'.

Time Needed: 10-15 Minutes

Learning Objectives:

Learners will:

- Interpret trends and patterns in sample weather data
- Match trends in the weather data to physical characteristics of the snow tubes
- Identify and describe physical changes to the snow and the snowpack over time

Learner Engagement:

- Having the learners describe the typical weather conditions in high mountain environments
- Share their experiences with snow, snowpack, and high mountain environments
- Share their understandings of the processes that impact the formation of the snowpack

Guiding Questions:

- What role do snow and ice play in Colorado's water supply?
- What role do precipitation, wind, temperature and solar radiation play in the development and longevity of the snowpack?
- What physical changes occur when snow is compressed into glacial ice?

Common Misconceptions:

- Once snow falls, it remains in a relatively stable state until it melts
- Layers of ice and crust formation in the snowpack are attributed to high temperatures, not the role of temperate and solar radiation combined
- Snow must first melt into water before evaporating, which discounts the process called sublimation.

Prerequisite Knowledge and Skills:

- Familiarity with the metric system
- The ability to interpret graphs and complex sets of data

Materials for the Teacher:

- Master data sheets and instructions for creating snow tubes
- Watertight clear plastic tubes, graduated cylinders or similar materials
- Snow, crushed or shaved ice
- Fine grained sand or dirt.
- Access to water, a freezer and a cooler/ice for storage
- 2-3 cm sections of snow tubes or prepared ice sections
- A tool for compressing the snow and ice inside the tube

Materials for the Class:

- 1 or 2 sets of data sheets for each team
- 1 or 2 snow tubes for each team
- Paper or hand towels to clean up any water or debris

Safety and Logistics:
Sharing roles, data sheets and access to the snow tubes are central to the success of this activity. Be sure to have learners immediately clean up water and debris to limit the risk of slips and falls.

Set Up:

1. Using the provided tubes, or other materials, create three 0.5 cm and two 1.0 cm thick layers of ice for each set that will easily slide into the tubes. This is best accomplished in advance by filling the tube with a small amount of water, allowing it to freeze, then storing the ice layers in a freezer while you make more.
2. Create a tool from a rod, dowel or other material wrapped with tape that fits snugly inside the tube and can be used to compact the snow and ice layers.
3. Review and print the master data sheets and prepare data sheets for each team.
4. Create a set of snow tubes, following the chart in Appendix 1 by:
   - Adding an amount of snow that will result in the compressed depth found in the chart. Small amounts of water can be added to the lower layers to accentuate their compressed nature and ice-like consistency.
   - Slipping the layers of ice into the tube and pressing them onto the layers below.
   - Sprinkling a small amount (1 g) of fine sand or dirt onto the snow or ice layers.

Procedures

1. Begin by distributing the weather data sheets and describing the collection location, collection date, data types, and units.
2. Go through the data sheets having learners note significant events and trends including:
   - The precipitation events measure centimeters of snow, but not the consistency of the snow which can vary from fine powder to heavy, wet snow.
   - The wind speed is measured in meters per second and represents an average for the day, not the highest wind speeds measured. Though there are often significant amounts of wind on the ridge, there are only a few times when the average is above 30 meters/second or over 65 miles per hour.
   - The temperature on the ridge, measured in degrees C, rarely reaches the melting and freezing point of water.
   - Anyone who has been high in the mountains can relate to the power of the sun at those elevations. This powerful force is limited by cloud cover, mountain fogs, and is the primary melting agent for surface snow. It is also the engine for sublimation, which is the process that turns solid snow and ice directly into water vapor.
3. Next, pass out the snow tubes and inform the teams that their task is to use the data to find out which end of the tube represents the end of the month, or the top of the snow layers.

4. Once the bulk of the teams have had time to examine the tubes, have them describe the relationships among:
    - Snow compression at the bottom of the tube
    - Ice layers and the likely events that lead to their formation
    - The presence of wind-driven dust and debris on the snow
5. Finally, share that the end of the tube with the lighter snow and dust is the top layer and represents the end of the month.

Assessment:
Have the learners focus their attention on the layers that have ice, wind deposited dust, then ice again and have them describe the likely causal agents using the data. Conclude by posing the Guiding Questions to the group in either a written or discussion format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to many locations by changing the weather data and snow tubes to match local conditions. Higher level learners can use measurements and math to calculate the amount of compression for the snow layers, compare data from across the state or nation, as well as yearly data for the same sites, or use the methods described in the next activity to calculate the water weight equivalence of one or all of the snow and ice layers in the tube. Links to data sources and other resources can be found in the 'Background Information, Resources and Extensions' section of this guide.

Activity 2: Snow Density and Glacial Ice

Overview:
This activity focuses on the measuring and calculating the physical properties of snow and ice, and the forces needed to create glacial ice. It begins with a definition of glaciers, snowpack, snowfields, and reinforces the importance of snow and ice to Colorado's water supply. The teams will then be given worksheets, beakers, snow samples, a scale, and are first asked to measure the volume of the snow and measure its mass. They will then calculate the water weight equivalence of the sample and finally its density. Finally, teams will receive another beaker of snow, then repeat the process, and attempt to compress the snow to reach a density between 0.85 and 9.0, or the approximate density of glacial ice.

Time Needed: 10-15 Minutes

Learning Objectives:
Learners will be able to:
- Measure mass and volume, and use these quantities to calculate density
- Gather, analyze, and interpret data on physical and chemical changes
- Gather, analyze, and interpret data that show mass is conserved during snow compression

Learner Engagement:
- Having learners describe their experiences with different types of snow and ice
- Have learners share their understanding of the concepts associated with mass, weight, volume, and density.

Guiding Questions:
- What impact does snow compaction have on its weight, volume and density?
- What physical changes occur when snow is compressed into glacial ice?

Common Misconceptions:
- Changes in snow density changes the mass of the snow
- The compaction of snow alone cannot cause snow to melt

Prerequisite Knowledge and Skills:
- A basic understanding of measurement, mass, weight, volume, and density.

Materials for the Teacher:
- A large cooler with snow, potentially a variety of different types of snows or crushed ice
- A rubber-bottomed floor mat to place near the cooler
- Paper or hand towels, mops, and other cleaning supplies.

Materials for the Class:
- A laminated worksheet and markers for each team
- Two very durable beakers for each team
- A desktop scale and small calculator for each team
- Paper or hand towels, mops, and other cleaning supplies.

Safety and Logistics:
With learners packing and moving small amounts of snow from the cooler to the tables, careful supervision and clean-up is required to minimize the potential for slips and falls. The beakers the learners use should be very durable and be able to withstand the forces needed to compress the snow. Any sharp edges should be sanded down to avoid scrapes or cuts. Finally, learners should not be allowed to use tools or step on the beakers to compress the snow.

Set Up:
- Print activity worksheets, see Appendix 2.
- Assemble the materials for the activity making sure to check the beakers for cracks or sharp areas, as well as the operation of the scales.
- Collect snow or crush/ grind approximately 2000 ml of ice for each team with enough extra to allow for some melting and compression.

Procedures
1. Begin by discussing the formation of glaciers from snow over long periods of time and have learners share any relevant experiences involving snow, ice, and glaciers.
2. Distribute the worksheets and materials, reminding learners about safety and expectations.
3. Go over the steps outlined in the first section of the worksheet and facilitate the distribution of the snow and measurement process.
4. Review the results and key concepts from the activity associated with weight, mass, volume, and density.
5. Distribute a second beaker to each team and have them fill it with snow.
6. Complete the final section of the worksheet, focusing on the conservation of mass, the force needed to create glacial ice and the physical changes associated with changes in density.
7. Before wrapping up, have the learners empty the beakers, wipe down the laminated worksheets, turn off the scales, and clean up any snow, water or ice left on the surfaces or floor near their workstation.

Assessment:
Ask the learners to define the difference between mass and weight, as well describe their relationship with volume and density. Have the learners describe the relationship between the snow's mass and its water weight equivalence. Finally, after describing how scientists measure snow around the world (using weight, not volume), pose the guiding questions for the activity in either written or verbal format.

Grade Level Adaptations and Local Variations:
This activity, though universal, can be supplemented with a variety if different types of snow, images of local mountains, snowfields and glaciers, as well as other simple modifications for local adaptation. Higher level learners can focus more time and attention on the physical changes occurring in the snow and ice, how air and other materials can be trapped there, as well as how scientists use glacial ice to learn about historical climates and climate change.

The Boulder Creek Hydrology Game

Overview:
The last activity in this module is a fun game focused on the Earth System interactions that control hydrology in the Boulder Creek watershed. This activity was created using local weather and stream flow data and can be adapted to any region or watershed by changing the names, flow regimes and features. The game is played around a large-scale floor map showing the Boulder Creek Watershed, but could easily be played using another map, outdoors, or by laying out streams and water bodies on the floor with blue tape. It is also designed to accommodate up to 40 learners, but could be adapted for smaller groups by sharing the roles described below.

The activity begins by showing the class the large floor map, discussing the natural and built features of the watershed and describing the areas that will be part of the game. Each team will represent one or more critical areas of the watershed. To play the game, each team will receive a set of cards describing their site, as well as 8 cards representing 4 consecutive seasons over two years, gaming chips and a set of containers representing precipitation and water storage in soils, lakes, snow and ice. Sample cards are located in Appendix 3, and a complete set of cards is provided with the resources included with this guide. Each team will follow the directions on the cards, moving water represented by the chips to and from the appropriate containers, and preparing to release the water downstream at the end of each season or round. Events like fires, record snow years, massive melting events and the management of reservoir storage will allow the learners to develop understandings of the complex Earth System interactions that regulate the flow of water throughout the year. The wrap up focuses on these interactions and how changes to land use, fire management practices and climate change are likely to impact water flow in Boulder Creek.

Learning Objectives:
Learners will:
- Simulate flow regimes in Boulder Creek over a period of time
- Simulate the role of soil, lakes, ice, snow and reservoirs in water storage
- Simulate the impacts of fire and melting events on flow regimes
- Simulate water management and storage practices
- Describe the Earth System interactions that regulate water flow throughout the year

Learner Engagement:
- Having the learners describe their experiences with flood and drought conditions
- Sharing the direct and indirect impacts of wildfires on their lives
- Having the learners locate familiar places on the floor map or compare and contrast features on the map to their local environment.

Guiding Questions:
- What features of the landscape can store and release water throughout the year?
- What can humans do to regulate the flow of water throughout the year?
- What Earth System interactions regulate the flow of water throughout the year?
- What impact will climate change and land use decisions likely have on water resources in Boulder Creek, and across Colorado in the future?

Common Misconceptions:
- Once water soaks into the ground it is not released back into surface water systems
- Flooding events in mountain streams are caused by melting snow and ice alone
- There is little communities can do to mitigate the impact of climate change on water resources

Prerequisite Knowledge and Skills:
- Basic organizational skills and the ability to work together
- The ability to follow written directions

Materials for the Teacher:
- Master Data and Flow Sheet

Materials for the Class:
- A large floor map showing the Boulder Creek Watershed, other large scale maps, or an outdoor or classroom space with stream features marked with tape or chalk
- A set of laminated game cards
- 500 blue poker chips or other material representing water
- 8 containers marked with the name of each site to hold chips
- Sets of small containers or cups labeled Soils, Lakes, Ice, and Snow

Safety and Logistics:
Sharing roles, passing safely and accounting for dropped chips are important for this activity. It is designed to be fun, and at times chaotic, so tone setting and classroom management are critical.

Set Up:
1. Print and potentially laminate the game cards
2. Collect and label the station and storage containers
3. Divide the chips between the teams, giving slightly more to the higher elevation groups
4. Prearrange the floor map and materials placing cups, chips and game cards well away from the floor map, but in locations appropriate for their position in the watershed

Procedures
1. Begin by allowing learners time to explore the map, identify features and reinforce their understandings of the areas, land covers, and precipitation regimes in the watershed.
2. Point out the significant features on the map, focusing attention on the watershed boundary, the streams and built components of the system.
3. Show each section of the watershed that is represented in the game, and assign an area or areas to each group of participants.
4. Explain the roles of the materials and give the learners time to read and discuss their introduction cards.
5. Have each group give a brief overview of their area, focusing on the fast facts.
6. Have the group assign members to each role, which can rotate throughout the game:
    - A person in charge of reading the game cards
    - The coordinator and person responsible for the counting the precipitation chips
    - A person to manage runoff and coordinate stream flow
    - Two people to manage water storage
7. Explain how the game works by walking them through the first season:
    - Read the game cards
    - Count out the precipitation
    - Organize the water storage and runoff
    - Have each group give a brief overview to the group of what is happening in their location
8. Once the tasks are complete, organize the groups in lines to represent stream flow and have them pass the chips downstream. Discuss with the class ways to improve the flow and passing for the next round.

9. Repeat the process, highlighting significant events and interrelationships throughout the first season. If time is limited, reduce the number or length of the briefings given by each team.
10. At the end of the first season, redistribute game chips back to the original containers, have the groups read their first game card and highlight the following events:
    - It is a record snow year for the entire watershed and more precipitation is stored as snow and ice, while the amount of precipitation remains the same
    - Fires will impact parts of the watershed, changing soil storage and runoff patterns
    - Areas that contain reservoirs, will gain the ability to choose how much water to hold or release, hopefully to limit flooding and store water for the summer and fall
11. Run through the second season of the game, stopping each season to highlight changes to the watershed and flow regimes.
12. At the end of the game, have learners describe how their area changed or adapted overall, the impacts of the events, and what they would do differently if given the opportunity.
13. Have the learners re-set the game board back to its original position and organize the game cards for the next group.

Assessment:
Have the class list, describe, and evaluate the impact of some of the Earth System interactions that regulate the flow of water in Boulder Creek throughout the year. Have them generalize the impacts of these interactions across Colorado. Have learners, based on what they already know, discuss some of the potential impacts of climate change, reduced snowfall and land use decisions on the future of water resources and pose the rest of the guiding questions for the activity to the group.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to many locations by changing the weather data, stations, events, and flow regimes. The process can be adapted for higher level learners by incorporating more discussion of events and processes, letting the entire group participate in management decisions, or by incorporating more site-level details, events, drought periods or by simulating potential impacts of climate change in a third round of the game.

Background Information, Resources and Extensions

Colorado has been called 'the mother of western rivers' with many major river systems starting in the high country along the Continental Divide. With its many ecosystems, local climates and flow regimes, understanding Colorado's water is an ideal application for Earth Systems Science. With approximately 80% of the water here starting as snow, the role of snow and ice in the State's hydrology cannot be understated.

Important research being conducted in the Boulder Creek Critical Zone Observatory strives to better understand the potential impacts of climate change, how land use change and fires impact the hydrologic system, and to better understand how topography, soils, snow and ice interact to regulate water flow throughout the year. Weather, snow and stream gauging stations across the watershed, and the state, measure the weight of snow and ice, track precipitation, temperature, wind and radiation. Scientists test water quality, snow depths, fire impacts and track glaciers in an effort to help us understand and live more sustainably in a dynamic world.

Snow and Glacier Background Material:
Today, a relatively small amount of the snow that falls in Colorado becomes glaciers, but that has changed repeatedly over time. As we learn in the Foundations for Flow module, long ago this area was at the equator, and at times under the sea. For long periods of time, Colorado was a dry desert and the mountains themselves came and went. In the recent past, large sections of Colorado were covered by mountain glaciers, as demonstrated by the prevalence of U-shaped valleys in the shaded relief maps. For thousands of years the amount of snow that falls here has gone up and down, while following a general downward trend associated with an interglacial period. Recently scientists have been tracking more abrupt changes and downward trends that are associated with a changing climate. These changes, especially those directly impacting snow and ice, will have an impact on the State's water resources, and scientists, policy makers and planners are working hard understand these changes so they can better prepare for the future.

When snow first falls, it is subjected to the blowing wind, which can form drifts and compact it. Warm temperatures and solar radiation melt the surface layers and evaporate water through sublimation, while its very mass compacts it into denser and harder materials. If enough snow falls season after season without melting, it can first form snowfields, permanent patches of snow across the high country. Snowfields come in all sizes from the very small patches in high mountain valleys, to great masses of snow that cover mountainsides. Slope, aspect, or which direction the slopes and snow are facing, weather, and solar radiation all play a role in understanding how snow falls, compresses, and melts. If enough snow, meters upon meters, falls in an area with steep enough slopes, the snow and ice, under its own weight, can start to move and scour the surfaces below. Glaciers, or rivers of ice, can hold millions of cubic meters of water, last for thousands of years, and cut deep troughs through the landscape as they slowly move downhill. Though the number and size of glaciers is dwindling, there are still a number of sizable glaciers in the Boulder Creek Watershed alone.

The impact of snow and ice is not limited to cities, farms, and water systems. Many species in Colorado are dependent on snow and its processes for their survival. Downstream, the seasonal flooding and scouring caused by spring snowmelt is critical for wetland species, whole ecosystems and even the endangered Sand Hill Crane. Entire industries and communities associated with winter and water sports are dependent on snow and the water it provides. Understanding snow an ice, weather and climate, as well as predicting the future are an important effort to say the very least. Agencies across Colorado, the U.S. and around the world focus their efforts on understanding relationships impacting the snow and ice. Resources created by some of these organizations are listed below.

Chip Game Background Materials:
This game strives to illustrate, in a fun an engaging way, the Earth System processes that provide and regulate water to Boulder Creek throughout the year. These processes are not unique to this watershed, and Boulder Creek can easily serve as an example of many watersheds throughout the State. The features, natural processes, events, and data included in the game all relate to research being conducted in the Boulder Creek Critical Zone Observatory Program. The information below provides a highlight of that research and background information for facilitation.

Each of the headwaters sections have many similar features including the Continental Divide, high elevations, glacial features, deep snows, wilderness or a protected status, and mountain ecosystems. Each section also has significant differences. While the North Fork's headwaters have a significant number of glaciers and lakes, its shallow soils and steep, exposed slopes limit the amount of water stored in the soils. Though not mentioned in the game cards, the headwaters of Boulder Creek contain a ski area, Eldora, which converts runoff to snow and, as mentioned, has deeper soils but few lakes and glaciers. The headwaters of the South Fork contain huge tracks of forested lands, deeper soils and a large number of wetlands, lakes and glaciers. The upper reaches of this area contain an important north-east facing valley encompassing the bulk of the St. James Wilderness Area. This area holds an amazing amount of snow and ice late into the season under its high walls and forest canopies. These different features have important impacts on the flow regimes, water storage, and seasonal patterns in the watershed, the significance of which can be missed in the fun and excitement of the game.

The importance of the reservoirs, snowfall, and groundwater recharge in the areas around Nederland and Coal Creek cannot be understated. While Gross reservoir provides water to the city of Denver, Gross Reservoir controls flooding and manages the water in the main branch of Boulder Creek. Both of these reservoirs, along with other small reservoirs in the area, are connected to treatment centers and distribution systems through miles of tunnels that cut through the mountains. Gordon Gulch, a smaller watershed on the North Fork of Boulder Creek, is the focus of interesting research that is highlighted in the game. The valley's two sides, one facing South and into the sun, the other shaded by the slopes, have very different land cover types and serve as an example of the differences between North and South facing slopes. Recent research has shown that there are also, in this case, significant differences in soils, groundwater storage, and seasonal flow patterns. The deeper soils and slower flowing groundwater on the North facing slopes adds its water storage capacity to the lasting snow cover under the forest canopy. The shallower soils on the South slopes compound the limited snow storage in meadows and sparse Ponderosa Pine forests on the sunny slopes.

Finally, the Fourmile and Boulder Valley areas highlight the role of fires and ecosystem transition in hydrologic systems, while reinforcing the importance of community efforts to provide stable water resources for homes, industry, and farms. The Fourmile fire, though just one of many in a long history of fires in the watershed, had devastating effects on people and significantly impacted Boulder Creek by contributing to flooding, landslides and temporarily decreasing water quality. It is important to consider that though devastating to people and communities, these fires are a natural part of the ecosystems and nutrient cycling in the area. The potential impacts of climate change and the spread of Pine Bark Beatle infestations on fire ecology are an important part of the scientific research being conducted at the University of Colorado and around the world.

Additional Resources:

- The University of Colorado's Institute for Alpine and Arctic Research homepage: http://instaar.colorado.edu/
- The National Snow and Ice Data Center's All About Glaciers website: http://nsidc.org/glaciers/
- The UDSA-Natural Resources Conservation Services homepage: http://www.wcc.nrcs.usda.gov/
- The UDSA-Natural Resources Conservation Services SNOTEL Program Fact Sheet: http://www.wcc.nrcs.usda.gov/factpub/sntlfct1.html
- The Colorado Department of Natural Resources, Colorado Water Resources Division webpage: http://water.state.co.us/Home/Pages/default.aspx
- Boulder Creek stream flow data and other resources from B.A.S.I.N.: http://bcn.boulder.co.us/basin/data/STREAMFLOW/STREAMFLOW.html
- Glossary of Selected Glacier and Ice Related Terminology: http://vulcan.wr.usgs.gov/Glossary/Glaciers/glacier_terminology.html
- USGS Real Time Water Data for the Nation: A resource for flow and water quality data: http://waterdata.usgs.gov/usa/nwis/rt

Extension Activities and Opportunities:

A variety of learner-directd research and science fair projects can center on snow, ice, and the hydrology concepts in this module. Some of these opportunities include:

- Collecting, recording and analyzing local snow data, calculating water weight equivalents, density, and compaction over time.
- Collecting and comparing local weather data and analyzing the relationships with stream flow data.
- Using stream and weather data to explore the relationships and delay between precipitation and peak flow events in larger streams and rivers.

The Boulder Creek Critical Zone Observatory Program offers a wide variety of data, map layers and other resources related to their research that can form the foundation for extension activities and are available at: http://czo.colorado.edu

The University of Colorado at Boulder PhET Program's Glacier Simulator: This interactive tool allows users to see and track glacier formation based on changes in weather and climate data. http://phet.colorado.edu/en/simulation/glaciers

The Community Collaborative Rain, Snow and Hail Network (CoCoRaHS): A citizen science and volunteer program centered on precipitation data collection: http://www.cocorahs.org/

Appendix 1: Snow Tube Master Data Sheet

Date	Snowfall (cm)	Average Wind Speed (m/s)	Average Temperature (C)	Average Solar Radiation (w/m2)	Recipe and Related Weather Events
1-Jan	10	21	-11	334	2 cm of Compressed Snow
2-Jan	0	19	-12	315	
3-Jan	0	35	-15	539	0.25 cm of Dirt or Sand
4-Jan	15	13	-19	551	3 cm of Compressed Snow
5-Jan	0	16	-11	399	
6-Jan	0	11	-12	433	
7-Jan	0	18	-20	989	0.5 cm Layer of Ice
8-Jan	5	19	-15	556	2 cm of Compressed Snow
9-Jan	0	16	-9	548	
10-Jan	0	7	-10	609	
11-Jan	0	6	0	563	1 cm Layer of Ice
12-Jan	0	22	-1	564	0.25 cm of Dirt or Sand
13-Jan	0	38	-7	975	0.5 cm Layer of Ice
14-Jan	6	14	-8	443	3 cm of Compressed Snow
15-Jan	0	16	-10	575	
16-Jan	0	10	-10	576	
17-Jan	0	11	-13	453	
18-Jan	0	16	-14	598	
19-Jan	0	14	-11	332	
20-Jan	21	14	-12	464	9 cm of Loosely Packed Snow
21-Jan	0	15	-9	512	
22-Jan	0	20	0	454	1 cm Layer of Ice
23-Jan	0	15	-1	1178	
24-Jan	4	43	-2	656	3 cm of Loosely Packed Snow
25-Jan	6	41	-9	777	0.5 cm of Dirt or Sand
26-Jan	0	21	-10	773	4 cm of Loosely Packed Snow
27-Jan	0	4	-11	765	
28-Jan	0	14	-9	1042	0.5 cm Layer of Ice
29-Jan	18	33	-9	630	10 cm of Loosely Packed Snow
30-Jan	0	8	-6	681	0.25 cm of Dirt or Sand
31-Jan	0	13	-11	655	

Appendix 2: Snow Density and Glacial Ice Worksheet

Snow, Ice and Glaciers are an important part of the system that provides Colorado with water year round. In this activity we will: weigh snow and ice, calculate the amount of water in snow, and use weight and volume to calculate the density of snow before trying to make glacial ice.

Step 1: Open the desktop scale and push the ON/OFF button

Step 2: Place the empty beaker on the scale and press the TARE button. This will automatically subtract the weight of the empty beaker when you weigh the snow.

Step 3: Go to the cooler and lightly pack the empty beaker with 400 ml of snow.

Step 4: Weigh the beaker and snow. Record the weight or mass in the space below.

Weight/Mass of the Snow in the Beaker is _____ grams

Step 5: Because one cubic centimeter of water weighs one gram, calculating the amount of water in the snow or its "water-weight equivalent" is easy! Record the amount of water in your snow in the space provided.

The mass of the snow is ____ grams = _____ cubic centimeters (cm^3) of water

Step 6: Calculate the density of the snow by dividing its mass by the original volume of 400 ml.

Density = Mass/Volume

Weight or Mass of the snow:	_____	**grams**
Volume of the snow:	**400**	**cm^3**
Divide the Mass by the Volume:	_____	**g/cm^3**

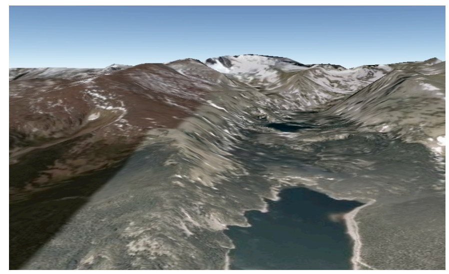
Step 7: Compress the snow as much as possible. Using the formulas below, calculate the density of the compressed snow. Try to compress the snow until you reach the density of glacial ice or **0.80 g/cm^3**

Attempt #1:			**Attempt #2:**			**Attempt #3:**		
Mass:	_____	**grams**	**Mass:**	______	**grams**	**Mass:**	_____	**gram**
Volume:		**cm^3**	**Volume:**		**cm^3**	**Volume:**		**cm^3**
Density:	_____	**g/cm^3**	**Density:**	_____	**g/cm^3**	**Density:**	_____	**g/cm^3**

Appendix 3: Boulder Creek Hydrology Game Sample Game Cards

HEADWATERS OF THE NORTH FORK OF BOULDER CREEK

<u>Introduction</u>:
The North Fork of Boulder Creek starts high in the mountains. The headwaters have the *Continental Divide* on its western slopes and is bordered by 10,000-foot mountains. This area has many *glaciers*, *snowfields*, lakes and a large *reservoir*. This valley can store a lot of lake water and ice, but has shallow soils and fast streams.



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THE HEADWATERS OF THE NORTH FORK OF BOULDER CREEK

<u>Summer #1:</u>

<u>The hot dry days of summer reach the mountains in July. Only 7 cm of rain fall but there are but massive amounts of runoff. The soils thaw, snow melts, even the glaciers loose some water.</u>

Draw 7 waters:

Put 2 in Soils and 2 in Lakes, send the runoff down the creek
Send 10 from Snow and 5 from Glaciers down the creek
Send 5 from Soils and 5 from Lakes down the creek

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Fire and Water

Module Overview:
Wildfires have been an important part of the ecosystems, nutrient cycling, and natural history in Colorado for thousands of years. Though potentially devastating, wildfires play an important role in shaping the ecosystems and watershed structures we see today. Scientific research in the Boulder Creek Critical Zone Observatory focuses on the impacts of the 2010 Fourmile Fire and the Earth System interactions between fires, soils, erosion, and water quality in Boulder Creek.

This module, following the current research, explores the complex relationships that exist between wildfires and the environment. The introduction serves as a primer for understanding fire ecology, dominant land covers in the Boulder Creek Watershed, and the Earth System interactions that control fire intensity. In the first activity, learners will use Google Earth Historical Imagery to predict fire intensity in various locations and current land cover images and fire data to evaluate the accuracy of their predictions. The second activity focuses on an experiment designed to compare the impact of precipitation events on erosion in areas affected by varying fire intensity. The final activity introduces learners to soil structures, infiltration and groundwater retention potential in sample soils, while incorporating an inquiry focused on the relationships between fire intensity, changes to soil, surface materials, and runoff.

The module wrap-up uses a modeling process to help learners to organize, verbalize and evaluate the interactions between the Fourmile Fire and Earth System. The class will use the model to explore relationships impacting fire ecology, then fires impacts on hydrology and water quality. Finally, learners will use the model to discuss the potential impacts of climate change, Bark Beetles, and land use change on wildfires in the Boulder Creek Watershed.

Colorado Academic Standards:
Standard 2: Life Science

- Prepared Graduates: Explain and illustrate with examples how living systems interact with the biotic and abiotic environment
  - Grade 6-Concept 1: Changes in environmental conditions can affect the survival of individual organisms, populations, and entire species
  - Grade 6-Concept 2. Organisms interact with each other and their environment in various ways that create a flow of energy and cycling of matter in an ecosystem
  - Grade 8-Concept 1: Human activities can deliberately or inadvertently alter ecosystems and their resiliency

Standard 3: Earth Systems Science:

- Prepared Graduates: Evaluate evidence that Earth's geosphere, atmosphere, hydrosphere, and biosphere interact as a complex system
  - Grade 5-Concept 2: Earth's surface changes constantly through a variety of processes and forces
  - Grade 6-Concept 1: Complex interrelationships exist between Earth's structure and natural processes that over time are both constructive and destructive

Learning Goals:

Learners will be able to:

- Develop, communicate, and justify an evidence-based explanation about how ecosystems interact with and impact the global environment
- Compare and contrast the flow of energy with the cycling of matter in ecosystems
- Gather, analyze, and communicate an evidence-based explanation for the complex interaction between Earth's constructive and destructive forces
- Develop and communicate an evidence based scientific explanation around one or more factors that change the Earth's surface
- Identify problems, and propose solutions related to water quality, circulation, and distribution - both locally and worldwide
- Develop, communicate, and justify an evidence-based scientific example of how humans can alter ecosystems

Key Concepts:

- Wildfires and fire intensity involve complex relationships in the Earth System
- Wildfires play an important role in the transfer of nutrients, materials, and energy
- Wildfires are a deconstructive force in the Earth System
- Wildfires have significant impacts on the structure and function of watersheds and change the Earth's surface
- Fuels and fire management, as well as post-fire erosion control, are an important part of protecting communities and limiting changes to water quality and flow regimes
- Changes to the environment associated with climate, land use change, management, and Pine Bark Beetles will have a significant impact on fire ecology in the Boulder Creek Watershed

Guiding Questions:

- What Earth System interactions influence the development and intensity of wildfires?
- What Earth System interactions do wildfires influence?
- What role do wildfires play in the transfer of nutrients, materials, and energy?
- How are wildfires deconstructive forces in the Earth System?
- What role do wildfires play in changes to the Earth's surfaces?
- How do wildfires, topography, soil structures, and precipitation regimes combine to impact how water is transferred throughout the Earth's systems?
- How do fuels and fire management, as well as post-fire erosion control efforts, impact the landscape, water quality, and flow regimes?
- How will changes to the environment associated with climate, land use change, management, and Pine Bark Beetles impact fire ecology in the Boulder Creek Watershed?

Activity 1: Fire Ecology, Soils and Earth Systems Science

Overview:
The introduction to this module uses PowerPoint slides, Google Maps and soil/land cover samples to familiarize learners with land cover patterns and forest types in the Boulder Creek Watershed, common soils and soil structures, as well as introduce or reinforce concepts related to fire ecology and fire intensity. Learners will then use the Google Earth's Historical Imagery Tool to predict patterns in fire intensity across the Fourmile Fire impact area and use current images, along with fire data, to test the accuracy of their predictions. The class will hypothesize about the impacts of changes to surface structures and soils on water quality and flow regimes in the Boulder Creek Watershed. These activities are easily adapted to any location or fires, recent or historical.

Time Needed: 10-15 Minutes

Learning Objectives:

Learners will:

- Develop an evidence-based explanation about how wildfires interact with and impact the environment
- Use fire as an example to compare and contrast the flow of energy and the cycling of nutrients and materials
- Describe fires role as a destructive force in the Earth system.
- Develop and communicate an evidence based scientific explanation of the role fires play in changing the Earth's surface
- Communicate the impacts and interactions linked to differences in fire intensity

Guiding Questions:

- What Earth System interactions influence the development and intensity of wildfires?
- What Earth System interactions do wildfires influence?
- What role do wildfires play in the transfer of nutrients, materials and energy?
- How are wildfires deconstructive forces in the Earth System?

Common Misconceptions:

- The effects of wildfires are spread evenly throughout the impacted landscape
- Historically, only low and medium intensity fires were dominant in the Boulder Creek Watershed, and throughout Colorado

Prerequisite Knowledge and Skills:

- A basic understanding of ecosystem structures and Earth System processes

Learner Engagement:

- Have learners share their experiences and knowledge related to wildfires

Materials for the Teacher:

- PowerPoint presentation, notes, and background materials
- Computer with Google Earth software, screen, projector or smart board

Materials for the Class:

- A set of soil samples and land cover

Safety and Logistics:
A large number of Coloradans were directly or indirectly impacted by the Fourmile Fire and other fires across the State. Therefore, care should be taken when addressing wildfire related content.

Set Up:
1. Prepare boxes, 3-liter bottles, or other clear containers with layers of materials representing local soils and land cover structures
2. Check the computers, projector, internet connection and map files
3. Test and preview the PowerPoint presentation and presentation materials
4. Open Google Earth, appropriate layers (kml's) and adjust the locations and perspective

Procedures
1. Introduce the module by relating learner's experiences with wildfires, their understandings of fire ecology, as well as the local and global impacts.
2. Use the PowerPoint presentation to discuss the dominant land cover types in the Boulder Creek Watershed, as well as fire ecology and fire intensity.
3. Using Google Earth, show learners the extent of the Boulder Creek Watershed and, combined with the soil and land cover samples, refine their understandings of the distribution of soils, slopes, and land covers.
4. Next, using Google Earth's Historical Imagery Tool, add the Fourmile Fire Boundary layer (kml) to a pre-fire land cover image.
5. Explore the Fourmile area, focusing on the slopes, streams, and land covers. Carefully address the presence of houses, roads and developed areas, as well as the fire's impacts.
6. Navigate to an appropriate part of the impact area and have learners describe the varying land covers and slopes.
7. Applying their understandings of fire intensity, have learners predict, mark or outline areas they believe will have low, medium, and high intensity fires.
8. Using the Fourmile Fire Intensity layer (kml), show the learners the estimated fire intensity for each area, compare it to their predictions, and turning off the Historic Imagery Tool, explore the post-fire images, fire variations, and impacts.
9. Focusing on Fourmile Creek, explore the fire intensities, slopes, and evidence of erosion to prepare the learners for the next activities in the module.
10. If time allows, explore the layers and land covers from historical fires in the watershed and across the state.

Assessment:
Using the PowerPoint Presentation, Introduce the Earth Systems Science model and help learners apply it to the relationships controlling wildfires, fire intensity and their impacts. Conclude by posing the guiding questions to the class in a verbal or written format.

Grade Level Adaptations and Local Variations:
This activity can be easily adapted to include content related to ecology, general fire ecology, land cover, and soils. Using Google Earth, learners can compare the areas impacted by different types of fires, fire intensities, or compare land cover and soil types across the watershed. This activity is easily adapted to other locations, fires and events, as well as other mapping technologies.

Activity 2: Fire Intensity, Erosion and Water Quality

Overview:
In this activity, learners will explore the impacts of different intensity fires on erosion and water quality by simulating precipitation events on recently burned slopes. In order to facilitate this inquiry learners will be introduced to the concept of flow, its measurement in volume over time, and practice their pouring and science process skills. Next, learners will be introduced to the concepts of pH and electrical conductivity as indicators of water quality and practice using the meters while collecting baseline data on the water used in the inquiry. Learners will then pour a fixed amount of water, over a fixed amount of time, on similar locations in four prepared models simulating unburned, low, medium, and high intensity fires in the Gordon Gulch area. Next, learners will compare the results of the erosion and runoff collection, or lack thereof, noting the visual differences in the movement of materials and water quality. Finally, learners will measure, compare and contrast differences in pH and electrical conductivity in the available samples. The wrap up will focus on using the Earth Systems Science model to explore wildfire impacts on erosion, water quality, and hydrology.

Time Needed: 15-20 Minutes

Learning Objectives:
Learners will:
- Practice inquiry and science process skills related to the experiment
- Develop an evidence-based explanation about how wildfires interact with and impact the environment
- Use fire as an example to compare and contrast the flow of energy and the cycling of nutrients and materials
- Describe fires role as a destructive force in the Earth system
- Develop and communicate an evidence-based scientific explanation of the role fires play in changing the Earth's surface
- Communicate the impacts and interactions linked to differences in fire intensity

Guiding Questions:
- What Earth System interactions do wildfires influence?
- What role do wildfires play in the transfer of nutrients, materials, and energy?
- How are wildfires deconstructive forces in the Earth System?
- What role do wildfires play in changes to the Earth's surfaces?
- How do wildfires, topography, soil structures and precipitation regimes combine to impact how water is transferred throughout the Earth's systems?

Learner Engagement:
- Having learners describe what they have heard or their experiences related to fire, water quality and erosion events.

Common Misconceptions:
- Ecosystems and land cover remain stable for long periods of time
- Wildfires cause permanent water quality issues in streams and rivers

Prerequisite Knowledge and Skills:
- Basic inquiry and science process skills
- The ability to use a stopwatch and measure volume

Materials for the Teacher:
- PowerPoint presentation, notes and background materials
- Computer with Google Earth software, projector and screen, or smart board
- Paper or hand towels, mops and other cleaning supplies
- A set of materials to repair the models between groups

Materials for the Class:
- Plastic bins, containers or outside space to build slopes
- Surface soils, sand, grass, pine needles, burned pine needles and ash
- Small containers and funnels to collect runoff from slopes
- Eight small beakers or other volumetric containers for each group
- Two stop watches per group
- pH paper and/or electrical conductivity meters
- Access to tap water and a small amount of distilled or deionized water
- Blank paper for recording results
- Buckets for water and waste products
- Paper or hand towels, mops and other cleaning supplies

Safety and Logistics:
Sharing roles, data, and opportunities are central to the success of this activity. Close monitoring and clean-up of spilled water and materials will limit slip and fall hazards.

Set Up:
1. Prepare containers, tables or outdoor spaces by creating slopes with sand, removing valuable materials, and adding drainage systems if needed.
2. Cover the slopes with an equal amount of base materials from local soils.
3. Add materials to create the models described below:
    - A section of the model with a thin layer of living grass and soil, soil base materials, and pine needles representing an unburned area.
    - A section with a thin layer of non-living grass, or one with the green stalks removed, soil base materials, and a mix of unburned and burned pine needles representing a low intensity burn area.
    - A section of the models without the grass layer and covered by a mix of well burned pine needles. This layer, representing a medium intensity burn, should not be as thick or tall as the first two layers.
    - A section of base materials covered by a 1 cm thick layer of ash mixed with mineral soil materials (preferably orange, red or another light color) and topped with a 1 cm thick layer of ash. This section, representing an area after a high intensity burn, will need significant maintenance and clean-up between groups.
    - Add small funnels and containers to the bottom of the slopes to collect runoff.
4. Prepare trays with paper, pencils, 8-10 beakers, two stopwatches, an electrical conductivity meter, and pH paper or meters.

Procedures

1. Introduce the activity using the slopes and soil boxes to describe the impacts of different fire intensities on soils and surface structures.
2. Prepare the class for the inquiry by reviewing the steps and considerations for a scientific investigation and explaining the use of the models.
3. Define and explain the role of consistent pouring location and flow for validity and variable control.
4. Have the teams practice pouring 250 ml of water, over 5 seconds, between the beakers until they have a consistent pour and flow rate.
5. Introduce the concepts associated with electrical conductivity, pH, nutrient cycling, and water quality.
6. Have the learners collect and record baseline data on the water used for the experiment.
7. Have the learners hypothesize about the potential differences in runoff and erosion in each section of the model
8. Conduct the experiment, compare observed results, and measure pH and electrical conductivity.
9. Have each team share the results of the inquiry and as a group, explain how this experiment can inform us about changes in the real world.
10. Have the teams replace as much of the eroded material as possible, empty the water collection containers, and return the models to their original state as best they can.
11. Finally, have the learners clean the tables, floors, and refill the beakers with water.

Assessment:

Using the PowerPoint presentation, help learners apply the Earth Systems Science model to the relationships between wildfires, erosion, runoff, and water quality. If time allows have the learners elaborate on the roles of fire in other ecosystems. Conclude by posing the guiding question to the class in a written or verbal format.

Grade Level Adaptations and Local Variations:

The structure of this inquiry can be adapted to accommodate different levels of facilitation and abilities. The science process skills and water quality sections can be extended for higher level learners and the materials can be easily adapted to match those found in any location.

Activity 3: Just Passing Through, or Not

Overview:
This inquiry is an adaptation of a GLOBE Program activity originally titled "Just Passing Through" that is available for download at http://www.globe.gov/tctg/passthrough_beg.pdf?sectionId=101.
The activity centers on upside down soda bottles, with the tops removed and caps replaced with screens, filled with a variety of soil mixtures and placed in a beaker. Deviating from the original lesson, the containers used in this activity have a notch and pour spout cut into the top edge just above the soil level, and three of the six containers demonstrate the impacts of low, medium and high intensity fires on valley soils, while one serves as a control for the experiment. The high intensity fire sample will have been treated to simulate the effects of hydrophobic soils on runoff, infiltration rates, and water quality.

Time Needed: 15-20 Minutes

Learning Objectives:
Learners will:
- Practice inquiry and science process skills related to the experiment
- Develop an evidence-based explanation about how wildfires interact with and impact the ground and surface water
- Communicate the impacts and interactions linked to differences in fire intensity

Guiding Questions:
- How do soil structures and land cover differ over a variety of landscapes?
- How do differences in soil structures impact groundwater flow and storage?
- How do varying fire intensities impact surface and groundwater?
- How do wildfires, topography, soil structures, and precipitation regimes combine to impact how water is transferred throughout the Earth's systems?

Learner Engagement:
- Having a sample of the class describe their understandings of groundwater and the importance of groundwater resources

Common Misconceptions:
- Wildfires impact on local hydrology are limited to surface water and erosion

Prerequisite Knowledge and Skills:
- Basic inquiry and science process skills
- The ability to use a stopwatch and measure volume

Materials for the Teacher:
- PowerPoint presentation, notes, and background materials
- Computer with Google Earth software, screen, projector or smart board
- Paper or hand towels, mops and other cleaning supplies
- A set of materials to repair the models between groups

Materials for the Class:

- Containers to hold soil samples and beakers to prevent spilling
- Six soda bottles of any size
- Scissors or a sharp knife
- A small amount of window screen or cloth
- Soil base materials from a variety of locations
- Pine needles and other land cover materials
- 18 graduated beakers or other containers and tools for measuring volume
- Access to water and buckets for water and waste materials
- Two stopwatches for each group
- Pencil and paper
- Optional pH and electrical conductivity meters

Safety and Logistics:
Sharing roles, data and opportunities are central to the success of this activity. Close monitoring and clean-up of spilled water and materials will limit slip and fall hazards. Extra care should be applied to prevent the 'top heavy' containers from spilling.

Set Up:

1. Prepare the six soda bottles per team by removing the bottoms with a sharp knife and removing the center section of the caps
2. Cut a notch and pour spout into the bottom of the bottle, the top when it is upside down, approximately 3 cm from the edge.
3. Place a small amount of screen or cloth in the cap and put it back on the bottles
4. To create the soil models, dig soil pits in a variety of locations, collect the materials, and note the relationships between the layers so the ratios can be simulated in the bottles.
5. To create soils common to the Boulder Creek watershed in 20 ounce bottles follow the directions below:
    - High Elevation or Mountain Soils: The shallow nature of these soils is simulated by adding large quantity of gravel and small amounts of surface soils. Add 750 ml of gravel or saprolite, 50 ml each of C, B and A horizon soils, topped with less than 1 cm each of organic soils and pine needles.
    - Soils found in the canyon bottoms and along streams can be simulated by adding repeating 75 ml layers of gravel or saprolite, play sand, small rounded rocks, white sand, then small amounts (50 ml) of C, B, and A horizons topped with 2 cm each of organic soils and pine needles.
    - Fourmile Valley Soils can be created using 500 ml of saprolite or gravel, 150 ml of C and B horizon soils, and 75 ml of A horizon soil topped with 2 cm layers of organic soils and pine needles. The label for this container should also describe it as the control for the experiment.
    - The low intensity fire sample mimics the soils above but the pine needles should be replaced with a mix of burned and unburned needles.
    - The medium intensity fire sample mimics the valley soil sample but the top layers should be replaced with 0.25 ml of organic soils and 0.25 cm of burned pine needles.
    - The high intensity fire sample mimics the valley soil sample but the top layers are replaced with a 0.25 ml mixture of ash and light colored soils, topped with a 0.25 cm of fireplace ash. Spray a small amount of Scotch guard, or its natural alternative, on the mixture, heat if needed, and cover with another layer of fireplace ash.

6. If following the previous activity, refill the water containers, add the extra beakers, and towels for clean-up.

Procedures

1. Introduce the activity using the bottles and soil boxes to describe the differences in soil structures and fire impacts.
2. Prepare the class for the inquiry by reviewing the steps and considerations for a scientific investigation, explaining the use of the models, introducing infiltration and the relationships between soil structures and water holding capacity.
3. Remind the class of the importance of consistent pouring and flow for variable control.
4. Have the teams remove high mountain and valley sets from the containers and prepare the beakers for catching the runoff.
5. Pour 250 ml of water into the models, and simultaneously start the stopwatch.
6. Compare the differences in runoff while waiting one minute for the water to drain.
7. Record, compare, and contrast the quality and volume in the lower beakers and relate to differences in soil structures.
8. Have the learners create a set of hypotheses describing the differences in runoff, infiltration and water holding capacities for the inquiry section of the activity.
9. Remove the valley and low intensity soils and explain the valley soils' role as the control for the experiment, before repeating the steps above for them and the remaining sets.
10. Introduce the concept of hydrophobicity, explain how it was simulated, and its role in the relationships between wildfires, soils, and hydrology.
11. Finally, have the learners organize their data, compare the results and create evidence-based generalizations about the relationships between soil structures, wildfires, changes to soils, groundwater, and surface water.
12. At the end of the activity, have the teams empty and rinse the beakers, clean up any water and materials, and reset the materials for the next team.

Assessment:

The activity and module wrap-up uses the modeling process to help learners to organize, verbalize, and evaluate the interactions between the Fourmile Fire and Earth Systems. As a class, have learners use the model to explore relationships impacting fire ecology, then fires impacts on hydrology and water quality. Finally, guide the learners in the use of the model to discuss the potential impacts of climate change, Bark Beetles, and land use change on the Boulder Creek Watershed. Conclude by posing the guiding questions to the class in a written or verbal format.

Grade Level Adaptations and Local Variations:

The structure of this inquiry can be adapted to accommodate different facilitation types for different ability levels and experiences. The science process skills, soil structure, geography and water quality sections can be extended for higher level learners and the materials can be easily adapted to match local land cover and soils.

Background Information, Resources and Extensions

Wildfires have been an important part of Colorado's natural and built communities for thousands of years. They are one of the many dynamic processes that shape the Earth System and impact the Critical Zone. Understanding the complex relationships between wildfires and water involves not only fire ecology, but soils, topography, ecosystems, erosion, deposition and finally, hydrology and water quality. The Boulder Creek Critical Zone Observatory, with its wide range of landscapes, ecosystems, and hydrologic features, serves as an ideal platform for understanding these relationships, as well as representing landscapes and ecosystems across Colorado and the Western United States.

Wildfires reflect the Earth System relationships between the geosphere, hydrosphere, atmosphere, and biosphere with the interactions between slopes, aspect, and soils; precipitation and humidity; wind and the seasons; as well as the forest and ecosystem structures that provide the fuels. The connections between fire and water are not limited to the interactions involving soils, erosion, and streams. The deposition of ash directly into streams and lakes, the role of particulates in cloud formation and precipitation, as well as fire's role in releasing carbon dioxide and impacting climate, all add to the complicated web that connects fire and water.

Topography and Soils Background Information:
To begin understanding fire and water, the best place to start is with the landscape itself and the base materials that form its foundations. Each of the communities in the watershed, from the mountains to the plains, have topographical and soil features that impact the relationships between fire and water. In fact, we usually think of wildfires burning in the forested foothills, but before development, wildfires burned regularly across the plains, deserts, riparian areas and high mountain valleys now managed and changed by logging, farms, roads, and communities.

Soils are formed from the base or parent material below them and organic and inorganic materials washed down the slopes or leached from the decomposing duff, or leaf litter, above them. The process, which can take thousands of years in some cases, begins with the chemical and physical weathering of the parent materials by water, ice, plants, wind and other forces, as well as the deposition of materials. In some stable soils these processes can form a distinct layer of chemically weathered, yet undisturbed, material just above the solid bedrock called saprolite. Soil scientists use a term called 'horizons' to describe the layers found in stable soils, and the bedrock and saprolite form the lowest or 'C' horizon. Above the bedrock and saprolite is a layer of inorganic material, the results of the weathering process, stained yellow, orange or red, by minerals leached from the layers above it. These 'B' horizons usually form the bottom of 'root zone' where plants are active, and contain concentrated minerals and 'pore spaces' that hold water. The richest and most active layer in the soil, other than the organic layers on top, or 'O' horizons, is the 'A' horizon. This layer is a mixture of the decomposed plant materials from above and the inorganic materials below them. Depending on the location and processes that form them, these layers can be just millimeters thick, or in some cases meters thick. Soil structures, materials, and the nutrients they contain directly impact the plant communities they support, as well as the way water moves over and through them. Each of the communities in the Boulder Creek Watershed has distinct features and soils that impact the relationships between fire, plant communities, and water.

In the high-mountain or alpine communities, characterized by low growing plants and grasses, the topography and soils have been shaped over time by the glaciers and erosion that formed them. There are areas of exposed basement rock, the remains of sedimentary layers, and steep walled, U-shaped valleys with large deposits of unsorted sand and gravel left by the glaciers known as glacial till. On the exposed areas and slopes, the soils may be only a few centimeters deep. In the valleys, a thin layer of topsoil may cover tens of meters of glacial till in snaking banks called moraines left along the sides and bottoms of the areas where glaciers once scoured the landscape.

Glacial deposits, till, and valley features also dominate the subalpine and montane ecosystems just below the headwaters. These areas, characterized by spruce/fir, aspen, and more importantly Lodgepole Pine forests, lie on eroded sedimentary layers, cover vast deposits of glacial till, and exposed basement rock. The glacial features in this area can also include small to medium sized lakes, which in some cases have been 'improved' for water management with dams and would be classified as reservoirs. The deep deposits of glacial till and gentler slopes can hold vast amounts of water and in some cases serve as important groundwater recharge zones.

The foothills ecosystems, dominated by Ponderosa Pines, sage meadows and valleys filled with willow and aspen stands, lies on top of the eroded and up-ended sedimentary layers left by tectonic uplift. Over time, streams and rivers have cut deep V-shaped valleys, in some cases down to the underlying basement rock, and left steep slopes, layered valley deposits, and soils as diverse as the terrain itself.

The plains, dominated by stream and river deposits, as well as changes to these deposits over time including meandering valleys, terracing, and layered deposits, lie on top of soft shales and the remains of sedimentary layers. These deep soils, often dominated by clays left from the eroding shales, can hold a vast amount of water, are highly susceptible to erosion, and are nutrient rich, thereby supporting a large number of farms in the lower reaches of the watershed.

Fire and Ecosystems Background Information:
Wildfires, as well as their impacts, vary across a landscape based on the amount of fuels available in each location and the impacts of topography, soil moisture, humidity, wind, precipitation, and the structure of the ecosystems themselves. In areas with a small amount of fuels, like open meadows, the fire can move through fast, barely scorching the groundcover and plants. In these low intensity fires, common also to steep, low-fuel slopes, the resulting changes to ecosystems and soils are limited to charred base materials and groundcover, with little to no impact on the underlying soils or canopy cover. In areas with more fuels medium intensity fires are common. These longer duration fires, which can reach the canopy in some locations, result in the burning of ground cover, the loss of organic layers in the soil and some root damage, as well as physical and chemical changes to the upper layers of the soils. When the organic layers burn, hydrocarbons are released and may penetrate underlying soils. As the hydrocarbons cool, it creates a waxy surface layer coating the soil surfaces. This waxy coating makes the soils resistant to water, or hydrophobic.

In areas with large amounts of fuels, and therefore longer fire durations, fire's impact can be severe. Fuel ladders, or smaller trees and branches under the canopy, can help the fires reach the tops of the trees, resulting in crown or stand replacement fires. In these high intensity fires, the surface soils and organic layers can be completely burned, leaving only ash. Extensive root damage can occur, and the soils can become severely hydrophobic. These high intensity fires often leave sterilized, mineral soils, which can take many years to recover, and are highly susceptible to surface erosion as the activities in the module show. The varying nature of fire intensity means that sections of the landscape only meters apart can be impacted quite differently.

Wildfires are an important part of many ecological processes in Colorado, and across the Western U.S. including nutrient cycling, ecological succession, ecosystem distribution, and hydrology. The relatively dry conditions limit the decomposition of organic matter by microorganisms and therefore the redistribution of nutrients in the ecosystem. Wildfires, though destructive, free the nutrients in the organic material so they can be recycled and distributed across the watershed by water and wind. Each of the ecosystems described above have different relationships with wildfires, including different fire-types and fire frequencies, or the average time between fires.

While the alpine ecosystems rarely burn due to cold, wet weather and snow, fires are more common in the subalpine and montane zones. In fact, Lodgepole Pine forests are specifically adapted to fire. These forests tend to burn with a high intensity, completely burning the stands of trees, and then re-seeding again with close growing stands of pines. Fires also burn frequently in the foothills, but with more diversity in fire intensity. The open meadows trend towards low and medium intensity fires between the stands of Ponderosa Pines, whose thick bark protects them from fire damage. Regular fires in the more forested areas, often on North-facing slopes, keeps the amount of fuel, or fuel load, low resulting in, again, low and medium intensity fires under the canopy. When fuels build up, either through fire suppression or natural process like a series of wetter years, high intensity stand replacing fires can result. Historically, all three types of fires were common across the foothills. On the plains, grass or range fires were a common sight before development in the dry summer months, and like higher elevation fires, were an important part of nutrient cycling and ecological succession.

Fire and Water Background Materials:
Across Colorado, we find evidence of past fires and their impacts on landscapes, ecosystem distributions, and hydrology. Some impacts, like changes in forest structures and water quality, are short term, while others, like the impacts on soils, slopes, erosion, and the deposition of sediments in stream channels can have lasting impacts. In general, fires impact the flow of water, changing both surface and groundwater flow regimes, and water quality. These changes are primarily the result of the release and mobilization of materials from burned plants, increases in surface erosion caused by the removal of the groundcover and canopy features, and changes to soil structures including the formation of hydrophobic soils. These changes, when compounded by steep slopes, shallow soils, and precipitation or melting events, can have significant impacts on streams, rivers, lakes, and reservoirs.

Fire's impacts on water flow regimes, both above and below ground, begin with changes to the groundcover and canopy structures. By removing the protective plants and forest canopy, more precipitation falls directly on the surface, resulting in increased overland flow and the mobilization of materials. When the duff or organic layers are completely burned in higher intensity fires, precipitation and overland flow have direct access to the underlying soils. The removal of the duff layer also allows surface water to flow unimpeded by the pine needles and leaves which slow it, collect the larger particles, and allow time for the water to soak into the ground. Finally, by burning the root structures that hold the soils together, medium and high intensity fires can weaken the soil structure itself. These changes, which can be compounded by the creation of hydrophobic soils, result in more water flowing downslope, faster, and carrying more materials in flooding events. In some cases, the weakening of soil structures and increased infiltration of groundwater can result in landslides on slopes, further adding to the materials available for mobilization. On the other hand, hydrophobic soils can decrease groundwater infiltration in some areas and actually reduce the likelihood of landslides. To say the very least, wildfires impacts on soils, erosion, and water flow are a great example of the complex interactions in the Earth System.

The next consideration in the relationships between fire and water are the mobilized materials themselves. Fires produce vast amounts of easily dissolvable, nutrient rich ash and combustion products, as well as mobilize large amounts of organic material, soil particles, and in some cases entire slopes. When these materials reach the stream and rivers their impacts can be profound.

Ash and other dissolved materials, including fire products and minerals from the exposed soils, have a duel role. While they add valuable nutrients to the hydrologic system, which can encourage plant growth and can be deposited downstream in flooding events, they can greatly impact other living things in the short term. Ash and fire products, which contain a large amount of lye, can almost instantly increase the pH of water beyond the tolerances of living things like fish and macroinvertebrates. Though the nutrients in the water are very valuable to agriculture and other uses, the increased pH can burn plants and their roots, as well as make the water unusable for drinking water or commercial uses.

While pH is commonly understood, and incorporated in many learning environments, measurements of the valuable dissolved minerals are less common, including the measurement of electrical conductivity included in these activities. In brief, water in its pure form is a relatively poor conductor of electricity. As more material is dissolved into it, particularly solids like salts, minerals and nutrients, its ability to conduct electricity is increased, or in other terms, the amount of electrical resistance is reduced. Therefore, conductivity meters use electrical resistance between the meter's poles as a way to measure the total amount of dissolved solids in a water sample. While most water bodies register between 20-300, electrical conductivity in impacted streams can go over 2000 Um/cm^3! We include the measurement of electrical conductivity in the module to help reinforce learner understanding of fire's role in nutrient cycling. For more information on electrical conductivity visit: http://www.waterontheweb.org/under/waterquality/conductivity.html.

Finally, the impacts of increased flow and flooding on communities are easy to understand, while the impacts of increasing particle or sediment loads can be hard to comprehend. Clays, sand, and gravel released from the soils can bury living things, their eggs, and cover biologically active organic materials with sediments. Flooding events add even more materials by further mobilizing existing sediments from the stream channels. These materials can further impact stream structures and hydrology by filling in pools, decreasing stream flow, and creating blockages, as well as shorten the lifespan of reservoirs and lakes by adding large mounts of materials. Floating or suspended organic materials can block the sun, increasing turbidity and decreasing the potential for photosynthesis and available oxygen. Additional organic material provides food for decomposers, increasing the biologic oxygen demand in the system, and further limiting the amount of oxygen available for living things. For more information on stream chemistry and water quality, as well as citizen science opportunities visit: http://www.waterontheweb.org/index.html.

Additional Resources:

- The Science Education Resource Center at Carleton College has an excellent overview of Earth Systems Science available at: http://serc.carleton.edu/introgeo/earthsystem/nutshell/.
- A brief overview of the Earth Systems Science modeling process model is available at: http://www.cotf.edu/ete/ESS/ESSmain.html.
- Colorado State Forest Service's Wildfire website: http://csfs.colostate.edu/pages/wildfire.html
- U.S. Forest Service Fire Prevention and Education website: http://www.fs.fed.us/fire/prev_ed/index.html
- Colorado State University, Fire Ecology Institute for Educators: http://csfs.colostate.edu/pages/fire-ecology.html
- Fires Effects on Water Quality from ForestEncyclopedia.net: http://www.forestencyclopedia.net/p/p621
- Fourmile Fire information from Boulder County, CO: http://www.bouldercounty.org/live/environment/land/pages/fourmilefire.aspx

- USDA-Natural Resource Conservation Service's Soil Information website: http://soils.usda.gov/education/facts/
- USDA-Natural Resource Conservation Service's Soil Formation and Glossary: http://soils.usda.gov/education/facts/formation.html
- Boulder Creek Critical Zone Observatory's Soil Research website: http://czo.colorado.edu/inter/soil_weather.shtml
- The University of Colorado's Institute for Alpine and Arctic Research homepage: http://instaar.colorado.edu/
- The Colorado Department of Natural Resources, Colorado Water Resources Division webpage: http://water.state.co.us/Home/Pages/default.aspx
- Boulder Creek stream flow data and other resources from B.A.S.I.N.: http://bcn.boulder.co.us/basin/data/STREAMFLOW/STREAMFLOW.html

Extension Activities and Opportunities:
A variety of learner-directed research and science fair projects can center on wildfires, soils, and the hydrological concepts from this module. Some of these opportunities include:

- Contacting your local or regional fire information officers to find locations for upcoming prescribed burns and collecting and comparing pre and post-fire soils, hydrology or fire intensity research projects.
- Collecting and comparing soil, water, and potentially fire data from your area for analysis and learner research.

The Boulder Creek Critical Zone Observatory Program offers a wide variety of data, map layers, and other resources related to their research that can form the foundation for extension activities and are available at: http://czo.colorado.edu

The USDA "FireWorks" Curriculum featuring Ponderosa, Lodgepole, and Whitebark Pine Ecosystems: **www.fs.fed.us/rm/pubs/rmrs_gtr065.pdf**

NOVA-Online's Wildfire Simulator: http://www.pbs.org/wgbh/nova/fire/simulation.html

Glossary

A Horizon: The top layer of soil, just below the duff and characterized by the presence of humus.

Alluvial Plain: An area of the floodplain characterized by the deposition of sediments linked to decreasing stream velocity.

Alluvium: Deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water.

Aquifer: A geologic formation(s) that is water bearing.

Aspect: The direction the majority of a slope faces. Usually expressed in cardinal directions.

B Horizon: The second layer of soil characterized by the deposition of materials leached from the organic layer above it.

Bedrock: A general term for solid rock that lies beneath soil, loose sediments, or other unconsolidated material.

C horizon: A layer in soil taxonomy often used to refer to the bedrock or saprolite.

Canopy: The covering formed by interlocking tree branches or the dominant land cover.

Condensation: The process of water vapor changing to the liquid phase.

Conductivity or Electrical Conductivity: A common water quality measurement quantifying the concentration of salts, minerals or dissolved solids in a water sample using electrical resistance.

Crevasse: An open fissure or deep crack on the surface of a glacier created due to shear stress from the movement of the glacier.

Defensible Space: Natural or man made areas around a building or structure where vegetation is cleared to limit the spread of fires.

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

Drainage basin: The land area where precipitation runs off into streams, rivers, lakes, and reservoirs. Also called a watershed.

Duff: A layer of decomposing organic matter on the surface of soils (pine needles, leaves, etc).

Entrainment: The process by which rocks from the landscape are incorporated inside a glacier.

Erosion: The process in which a material is worn away by a stream of liquid (water) or air, often due to the presence of abrasive particles.

Estuary: A place where fresh and salt water mix, such as a bay, salt marsh, or where a river enters an ocean.

Evaporation: The process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces. See transpiration.

Evapotranspiration: The sum of evaporation and transpiration.

Fire intensity: A term used to describe the severity, types of fires, or their impact on soils.

Flood plain: A strip of relatively flat and normally dry land alongside a stream, river, or lake that is covered by water during a flood.

Frost cracking: The process in which rocks are broken up by water trapped in crevices freezing and expanding, further cracking the rock or breaking pieces off.

Fuel Load: The dry weight of fuels in a given area.

Fuel: Biological or man made materials that combust during fires. Like fire intensity, they can be classified as light, medium or high levels of fuel.

Glacial Striations: Long grooves in the bedrock cut by glacial abrasion as the glaciers move across the surface.

Glacial Till: A random, non-homogenous mixture of rocks, gravel, boulders, and rock flour left behind in clumps as glaciers leave an area.

Glacial Valley: Broad, often smooth, U-shaped valleys cut into mountains by glaciers.

Glacier: A mass of ice formed on land by the compaction and recrystallization of snow that moves very slowly down slope or outward due to its own weight.

Ground Fire: A fire that occurs underground in the soils, roots, and duff.

Ground water: Water that flows into and saturates soil or rock layers

Headwater(s): The source and upper reaches of a stream or river system.

Horizons: A term used to describe the layers formed in stable soils and differentiated by color, texture or other characteristics.

Humus: The organic component of soil, formed by the decomposition of leaves and other plant material by soil organisms.

Hydrocarbons: Any compound made of the elements carbon and hydrogen. Often used to define fossil fuels such as petroleum or natural gas.

Hydrologic cycle: The cyclic transfer of water vapor from the Earth's surface into the atmosphere, and back to Earth.

Hydrology: A branch of geology focused on the Earth’s water and water systems.

Hydrophobic: A term used to describe materials that, due to polarity, repel water.

Impermeable layer: A layer of solid material, such as rock or clay, which does not allow water to pass through.

Infiltration: Flow of water from the land surface into the subsurface.

Irrigation: The controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall.

Ladder Fuels: Materials or ecosystem structures that allow fuels to spread vertically through the forest canopy.

Leaching: The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals or contaminants, are washed into a lower layer of soil or are dissolved and carried away by water.

Meander: A term used to describe the shape of a stream that naturally twists and curves across the land surface.

Meltwater: A term referring to the water released from a glacier or snowpack due to melting.

Moraine: An accumulation of unconsolidated debris such as soil or rocks which are collected by a moving glacier and deposited in a location as the glacier moves or melts.

Morphology: A term used to describe the shape and physical form of something.

Non-point source (NPS) pollution: Pollution discharged over a wide land area, not from one specific location.

O horizon: The top layer of soil composed of dead and decaying plant matter.

Parent Material: The base material from which soils are formed, usually bedrock.

Permeability: The ability of a material to allow the passage of a liquid, such as water.

pH: A term used to describe the amount of free hydrogen ions in a solution and used to describe the strength of acids, bases, and solutions.

Point-source pollution: Water pollution coming from a single area or source.

Pool: An area of a stream where the water is slow and the stream area widens, often interspersed with riffles and runs.

Porosity: A measure of the water-bearing capacity of subsurface rock.

Reservoir: A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

Riparian Zone: The portion of the land located next to a stream or river, often wetter than the surrounding landscape.

Runoff: That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers.

Saprolite: Chemically weathered bedrock that has not mobilized.

Sediment: Usually applied to material in suspension or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas.

Sedimentary rock: Rock formed of sediment, and specifically: (1) sandstone and shale, formed of fragments of other rock transported from their sources and deposited in water; and (2) rocks formed by or from secretions of organisms, such as most limestone.

Shale: A type sedimentary rock formed by layers of mud and clay that is soft and highly stratified.

Snowpack: An accumulation of snow throughout the year that has not yet turned into ice.

Surface Fire: A fire that occurs in surface fuels.

Surface water: Water that is on the Earth's surface, such as in a stream, river, lake, or reservoir.

Thinning: The removal of understory and canopy trees to reduce fire fuels.

Transpiration: The process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface. See evapotranspiration.

Tributary: A smaller river or stream that flows into a larger river or stream. Usually, a number of smaller tributaries merge to form a river.

Turbidity: The amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter.

Understory: Vegetation that grows underneath the tree canopy or dominant land cover.

Water cycle: The circuit of water movement from the oceans to the atmosphere and to the Earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transportation.

Water quality: A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water table: The top of the water surface in the saturated part of an aquifer.

Watershed: The land area that drains water to a particular stream, river, or lake.

Weathering: The breakdown, or decomposition, of surface materials by mechanical, chemical, or biological processes.

Wildland Urban Interface: The point where natural and built communities meet.