BREAKING UP ISN'T HARD TO DO: ROADS, TRAILS AND PERMAFROST

Overview:

In this lesson students learn about the challenges of road and trail development over permafrost.

Objectives:

The student will:

- view historical images of the trials of early road building on permafrost;
- explain potential impacts of human travel over roads and trails underlain by permafrost; and
- design and build a model roadbed to insulate frozen ground.

Targeted Alaska Grade Level Expectations:

[9] SA1.1 The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, and communicating.

[10] SA1.1 The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, analyzing data, developing models, inferring, and communicating.

[9] SB2.1 The student demonstrates an understanding of how energy can be transformed, transferred, and conserved by applying the concepts of heat transfer (i.e., conduction, convection, radiation) to Alaskan dwellings.

[10] SG4.1 The student demonstrates an understanding that advancements in science depend on curiosity, creativity, imagination, and a broad knowledge base by recognizing the role of these factors on scientific advancements.

Vocabulary:

abandon – to stop maintaining, practicing, or using
adjacent – having a common endpoint or border
aesthetic – pleasing in appearance
albedo – the percentage of light reflected by an object
carrying capacity – in land management, the amount of use an area can sustain without loss of quality
conduction – the flow of energy, such as heat or an electric charge, through a substance; in heat conduction energy flows by direct contact of the substances molecules with each other
convection – the transfer of heat energy through liquids and gases by the movement of molecules
corduroy road – logs laid side by side transversely (across) a road surface then covered with soil or other material
culvert – a transverse drain under a roadway
degrade – to make or be made unfit for some specified purpose
discontinuous permafrost zone – the major subdivision of a permafrost region in which permafrost occurs in some areas beneath the exposed land surface, whereas other areas are free of permafrost
ecology – the scientific study of the relationships between living things and their environments
infrastructure – the system of public works of a country, state, or region; the resources (as personnel, buildings, or equipment) required for an activity or business
mitigate – to cause to become less harsh or hostile, to make less severe or painful
persistent – existing for a long or longer than usual time or continuously
restoration – measures taken to return a site to pre-violation conditions
schematic – a graphic sketch or outline
subside – to tend downward
thermosiphon – a passive heat transfer device installed to remove heat from the ground
tracked vehicle – a vehicle that runs on continuous tracks instead of wheels
utilitarian – something useful or designed for use

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Whole Picture:

Alaska has fewer major highways than most other states, but these highways connect major urban centers and are central to the movement of goods. Secondary roads connect outlying areas to city hubs. In rural areas trails exist between communities, and to local subsistence gathering areas. Many of the roads and trails are underlain by permafrost, which makes them subject to changes when the permafrost thaws.

In the Arctic and sub-arctic region overland transportation faces special challenges. Roads and trails place stress on the active layer and the permafrost underneath, often causing thaw. The road, and even the surrounding land, may shift, buckle, and sink. Engineers use a variety of techniques to keep the permafrost stable so the roads on top remain passable. Gravel pads, "corduroy roads," culverts and air convection embankments are a few of the common building techniques. Trails are a big challenge because off-road vehicle use has dramatically increased in recent decades. Trails tend to erode and develop ruts filled with mud and water. A trail may take years to recover. Original ground cover plants may be replaced by other species if the ground is altered enough.

Materials:

- Rectangular plastic container, ~2.24L (one per group)
- Measuring cup
- Probe thermometer (one per group)
- Ruler (one per group)
- Heat lamp (one per group)
- Scissors
- P-gravel
- Top soil
- Straws (20+ per group)
- Popsicle sticks (20+ per group)
- Styrofoam plates
- Model Magic®, (black or brown)
- Access to freezer space
- Book: The Trail of '42: A Pictorial History of the Alaska Highway, by Stan Cohen
- PBS Home Video: Building the Alaska Highway
- STUDENT INFORMATION SHEET: "Alaska Science Forum: Melting Permafrost in Previously Forested Areas"
- STUDENT INFORMATION SHEET: "Roads, Trails and Permafrost"
- STUDENT WORKSHEET: "Roads, Trails and Permafrost"
- STUDENT LAB: "An Icy Inquiry"

Activity Preparation:

NOTE: This lesson will take two class periods. Day one provides important background. Day two is an engaging lab.

1. If this lesson is presented in a snow-free season, plan a walking field trip, if possible, around the community to observe roads and trails. Scout out areas ahead that may provide good examples of lesson content – areas with and without frost heaving, trail degradation, etc.
2. Review pages one through eight of the book The Trail of '42: A Pictorial History of the Alaska Highway by Stan Cohen to gain a historical perspective of the building of the Alaska Highway (more at teacher discretion). Review and mark pictures to share with the class. For example:
   - Page 21 shows a bulldozer clearing dense forest.
   - Page 24 shows a swath cut through the forest.
   - Page 30 shows the mud that developed when the insulating, protective layer was removed.
   - Page 24 shows the laying of corduroy road.
   - Page 32 shows early corduroy road in use.

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3. Two days prior measure and place damp potting soil in each of the plastic containers in preparation for STUDENT LAB: "An Icy Inquiry." Each one must contains exactly the same amount, at a depth of 1 ½ inches. Place containers in the freezer.
4. Prepare counter space for student lab. Set up one heat lamp for each small group. Labs will need to sit under a heat lamp for at least 20 minutes.

Activity Procedure:

Day One

1. ***Option 1: As season and weather permits.***
   Take a walking field trip to explore the roads and trails around your school and community (See Activity Preparation step one). Look for evidence of frost heaves, erosion, dips that indicate permafrost action, trails that show ruts and water seepage, etc. If students have a science journal, ask them to draw a picture and write a description of two areas that show evidence of permafrost thaw.

   Option 2: If weather or season prevents an outside walking trip.
   Show VISUAL AID: "Roads, Trails and Permafrost." Ask students to think about the roads and trails in and around their community. Do any of them show similar characteristics? Bumps, heaves, and cracks in paved or gravel roads? Ruts and mud with water seepage on dirt roads, driveways and trails? Discuss examples and ask students to describe
2. Hand out STUDENT INFORMATION SHEET: "Alaska Science Forum: Melting Permafrost in Previously Forested Areas." Choose a reading strategy that best suits the class.
3. Show students the book *The Trail of '42: A Pictorial History of the Alaska Highway* by Stan Cohen. Provide some background to explain the reason for building the highway (see Activity Preparation). Explain early road builders were unfamiliar with building on permafrost and had to learn building techniques very quickly. Show students some of the pictures in the book (see Activity Preparation). Page 22, for example, shows an engineer trying to chop into frozen ground.
4. Explain that engineers have been studying and developing more effective ways to build roads since those first attempts. Some early techniques turned out to work well and are still used. New methods continue to improve the odds of keeping roads passable. For example, page 24 in the book shows what is called a corduroy road. Builders learned that leaving the vegetation, then laying trees over the top crosswise, would help prevent the ground from thawing.
5. Tell students they will see two sections from the PBS Home Video *Building the Alaska Highway*. The movie talks more about the construction of the Alaska Highway and the difficulty builders had finding ways to build over permafrost. Choose Chapter 7 – Japan Invades Alaska (begins at about the 24-minute mark, ends at about the 30-minute mark) then Chapter 9 – Race Against Winter (begins at about the 43-minute mark, ends at about the 46-minute mark). Each of these depicts scenes of what it was like to build roads in the Arctic. (You may choose to watch other portions of the film at your discretion.)
6. Hand out STUDENT INFORMATION SHEET: "Roads, Trails and Permafrost." Explain modern road builders have learned a lot about building over permafrost. This information sheet discusses modern techniques and highlights a building project that used such methods. Choose a reading strategy that best suits the class.
7. Hand out STUDENT WORKSHEET: "Roads, Trails and Permafrost." Ask students to complete.
8. Introduce the lab that students will complete the following day. (See STUDENT LAB: "An Icy Inquiry.") Explain students will design and build a roadbed to keep "permafrost" (frozen potting soil) frozen the longest. Show students a container of frozen soil (see Activity Preparation) and the available materials. In groups students will build an insulating roadbed using the materials available, or materials they scavenge. Groups will be in competition. The group whose roadbed keeps the ice from melting the longest will win. (Consider offering an incentive, such as a "get out of homework free" one-time pass or other appropriate ideas available to you.)

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Day Two

1. Divide students into groups. Hand out STUDENT LAB: "An Icy Inquiry" and review the directions, rules and expectations. The temperature probe will record changing temperature. The heat lamp will provide energy. Review conduction, convection and radiation. Ask students to consider the lab set up and explain where, within the lab, each type of energy transfer may occur. (Heat transfer from the heat lamp to the road surface is accomplished through radiation and conduction [through air]; the road surface transfers heat to the materials below [rocks, straws, sticks, etc.] through conduction; the air in the spaces in the rocks can transfer heat through convection, as can air in the straw hollows. It is also possible that some heat will transfer by conduction from the countertop to the container.)
2. Allow students time to investigate materials and plan the design of their road prior to putting the design together. Students can cut and layer styrofoam plates, All students must receive their container of frozen potting soil at the same time to begin building. Complete the lab according to directions, though the graphing section.
3. Once the winning group is determined, ask a group member to explain the design to the rest of the class. Award pre-determined incentive, if appropriate.

NOTE: To do an alternative lab, assign each group a different material to test to see which one insulates the best. Students would report on each material and compare graphs.

Ideas for Filming:

NOTE: Students will complete a short film about permafrost for the final project associated with this UNITE US unit. Each lesson leading to the final project contains ideas about what students might film as they compile clips. Students are not limited to the list and are encouraged to use their imagination and creativity when filming.

Students could film areas of frost heaves or potholes on local roads as well as trails in stages of degradation.

Students could film the lab, focusing time on planning, building and the final outcome.

Answers:

STUDENT WORKSHEET: Roads, Trails and Permafrost

1. Corduroy road was the primary method.
2. Any three of the following: thermosyphons (pipes that cool the ground), ducts and culverts, air-convection embankment (piles of large rocks create air currents), gravel pads, corduroy roads (leave the vegetation in place then put soil or road embankment on top).
3. A. 4 feet
   B. 9 feet
   C. 16 feet
4. Answers will vary but should indicate that a large track vehicle would damage the plants over which it rolled. Water would pool in the depressions and some plants might die due to habitat change. Others would be crushed. If no further travel occurred over the same route it is likely that the area would recover over time.
5. Answers will vary but should indicate that the change in trail use would likely have a negative impact on ecology. A foot trail used only seasonally would have minimal impact on local ecology, but frequent ATV travel over the same route would likely cause degradation either by erosion or water pooling and subsequent development of mud holes.

BREAKING UP ISN'T HARD TO DO: ROADS, TRAILS AND PERMAFROST

STUDENT LAB: An Icy Inquiry

1. Any two of the available materials
2. Answers will vary.
3. Answers will vary but should reflect continuous temperature measurements.
4. Graph should reflect an accurate portrayal of data collected during temperature measurement, and include labels on both the x and the y axis.
5. Answers will vary.
6. Answers will vary.
7. Answers should indicate an understanding that heat transfer from the heat lamp to the road surface is accomplished through radiation. The road surface transfers heat to the materials below (rocks, straws, sticks, etc.) through conduction. The air in the spaces in the rocks can transfer heat through convection, as can air in the straw hollows.

ROADS, TRAILS AND PERMAFROST

Permafrost thaw plays havoc with Interior Alaska roads. The road and its traffic put pressure on the ground below. Increased albedo caused by the dark road surface increases heat transfer. Photo from iStockphoto / RyersonClark.

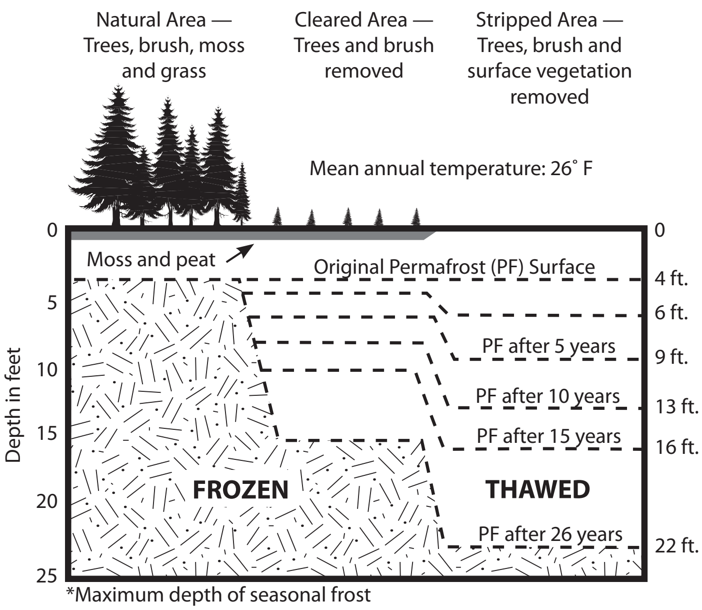
A braided trail in the initial stages of degradation. Photo courtesy of the Fairbanks North Star Borough Parks and Recreation Department.

Air convection embankment on Thompson Drive at the University of Alaska Fairbanks. Photo courtesy of the University of Alaska Fairbanks Mechanical Engineering Department.

ALASKA SCIENCE FORUM #594

Melting Permafrost In Previously Forested Areas

by Larry Gedney



Permafrost recedes more deeply into the ground under different surface conditions over a 26-year period. It remains constant if the overlying forestation is unchanged, but thaws rapidly as more vegetation is removed.

The first things that come to mind when talking about damaged tundra are pictures of water-filled trenches created when bulldozers during WWII, or oil rigs during the ensuing years, marched across it without understanding or regard for its fragility. Once the thin protective insulating layer of vegetation is damaged or removed, the underlying permafrost begins to melt, creating, in time, mushy ditches that used to be roads. These will remain for centuries.

What is less appreciated is that equally damaging effects can occur in regions south of the vast, treeless expanses of tundra, when clearing and construction on ice-rich ground occurs.

The Army Corps of Engineers took the problem seriously after the war when, in 1946, they established a long-term experimental station near Fairbanks to examine the relationship between vegetative cover and the stability of permafrost foundation material. Continuous monitoring under varying ground-cover conditions were made for a period of 26 years. Kenneth Linell of the U.S. Army Cold Regions Research and Engineering Laboratory has published a report on the findings.

First, the Army selected forested test plots about 3 miles northeast of Fairbanks near Farmers Loop Road. Here, the permafrost was estimated to extend to depths of at least 100 feet. The test areas were divided into three distinctive segments.

In the first, the natural vegetation was left intact. This amounted to a subarctic forest with white and black spruce, and a dense ground cover of moss, berries and other low plant growth.

In the second area, all trees and brush were removed to within about a foot above ground level and the major growth was kept trimmed, although a dense growth of shrubs, such as high-bush cranberries, was allowed to develop.

Finally, the third area was stripped bare to a depth of over a foot beneath the original ground level. Whenever new vegetation would begin to emerge, it was re-stripped. No attempt at snow removal was made on any of the test plots during the winter.

The permafrost levels measured at periodic intervals during the 26 years of the study revealed that any amount of removal of vegetation over ice-rich ground greatly increases the rate at which the underlying permafrost melts. Under the aboriginal forests, it remains stable, but clearing of any kind can have serious consequences on the foundation properties of dwellings, roads, airfields, and the like. Stripping invites total disaster.

To accelerate the problem, all one had to do was to build a heated structure over a cleared area, and it was practically guaranteed to sink out of sight within a few years. A splendid example is provided by the old KFAR broadcasting station on Farmers Loop Road near the University at Fairbanks. A visit to the site will reveal the curious sensation of encountering a colony of Lilliputians, since one must bend over to look into the windows from the outside.

The warming trend of recent Alaskan winters during the past few years may signal an even greater threat posed by thawing permafrost in the north. Paradoxically, the problem is not how to get rid of the permafrost--it's how to keep it frozen.

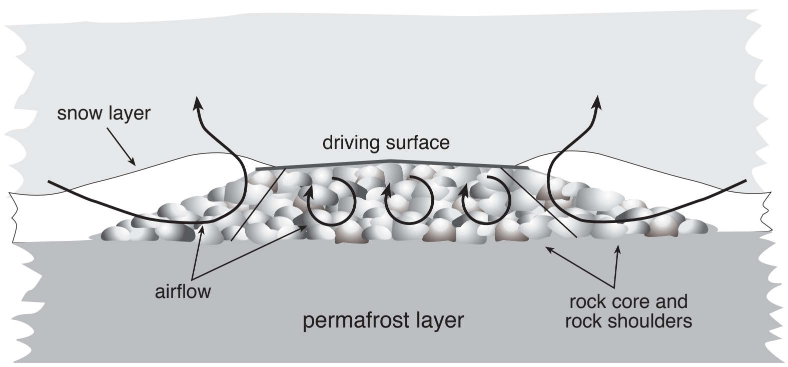
ROADS, TRAILS AND PERMAFROST

Modern road construction in the Arctic has a key focus: Keep the ground frozen! Builders incorporate a variety of techniques to accomplish this goal.

Air as an Insulator

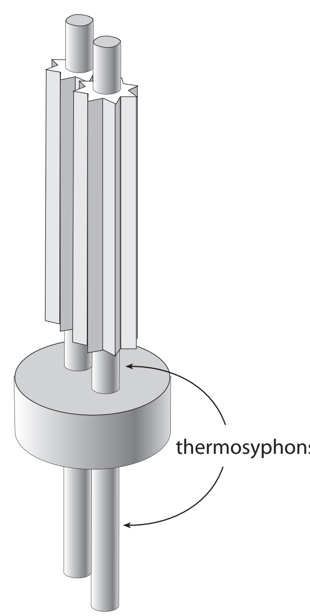
Using techniques and materials that allow airflow provides insulation between the frozen ground and the road above. Air is an excellent insulator because it is a poor conductor. In other words, it doesn't transfer much of the heat from the road to the ground underneath. Some ways to accomplish this include:

- Air ducts, such as culverts, are placed under the road to provide air circulation.
- Air-convection embankments pile large rocks under the roadbed to create pockets of air. Strong air circulation currents form that cool the permafrost. (See diagram below.)



Getting Rid of the Heat

Air is a good insulator, but roads don't hover over a cushion of air. There is still opportunity for heat transfer within a roadbed through its materials. Builders not only need to keep the heat from the blacktop from reaching the permafrost, they also need to get rid of any that does reach it. To do this, engineers developed special carbon dioxide-filled steel pipes, called thermosyphons, to draw away excess heat from under the road surface. Thermosyphons create a temperature difference that creates convection. The heat rises inside the pipe and is dispersed above the ground.



Insulating the Ground

Builders of the Alaska Highway discovered early on that leaving the vegetation in place and placing the road over the top helped keep the permafrost insulated. Instead of plowing off the surface, workers cut the trees then laid them back down and put material over the top. The method, called corduroy road, held up well for many years. Modern builders place a thick gravel pad over the vegetation to insulate.

Thompson Drive to Contain Permafrost Protection Measures

by Douglas J. Goering

(Reprinted with permission from Alaska Business Monthly. Originally published in July 2004.)

Alaska's harsh climatic conditions often have adverse effects on man-made infrastructure such as roads, buildings, railways, or pipelines. Over the years, a number of innovative solutions have been developed to help overcome these difficulties. One well-known example is that of the trans-Alaska oil pipeline, which employs a system of thermosyphon cooling devices that keep the vertical support members permanently frozen into the permafrost.

The design is unique, and was an outgrowth of important developments in the field of arctic engineering combined with a careful design process.

Many other types of infrastructure are affected by the presence of harsh climatic conditions and permafrost. One only needs to drive the highways of Interior Alaska for a short time to realize that challenges remain. Simply put, roadways and permafrost don't get along, at least not in the large portion of Alaska that is underlain by ice-rich permafrost. The process of clearing vegetation and constructing roadway embankments is one that often produces local warming of the ground surface. The warming, in turn, interferes with the thermal state of the underlying permafrost causing thawing. If the permafrost has a high ice content, a common occurrence in many of Alaska's permafrost areas, then the thawing will result in settlement (usually referred to as thaw settlement) and damage to above-ground structures. In the case of highways, the consequences of thawing permafrost are all too familiar to the residents of Interior Alaska who are often confronted with rough distorted roadways.

In 2001, the Alaska Department of Transportation began the design of a new section of roadway near the campus of the University of Alaska Fairbanks. The new road, named Morris Thompson Drive after the late Alaska Native leader, is to provide a new entrance to UAF by connecting Geist Road and Tanana Drive. The road has a length of a little more than a half-mile and includes a bridge over the Alaska Railroad, as well as concrete curbs, gutters, and sidewalks. The project area includes two sections of previously undisturbed permafrost and, thus, designers were concerned with the possibility of thaw settlement. Because of the inclusion of the concrete improvements, the consequences of any thaw settlement were more serious than usual. Re-leveling of distorted sidewalks, curbs and gutters represents an expensive maintenance issue. In order to avoid these difficulties, the decision was made to include advanced cooling technology in the project in an effort to avoid permafrost thaw.

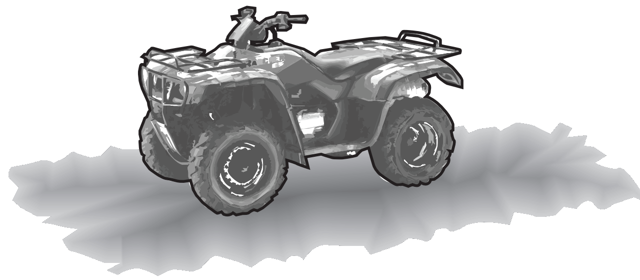
KEEP IT COOL

Two different types of cooling technology are being incorporated into the Thompson Drive project. The first uses the same cooling principle as the thermosyphons on the trans-Alaska oil pipeline, although a new configuration is being utilized. The devices, known as hairpin thermosyphons, are completely buried beneath the roadway surface and do not have exposed fins like those used on the pipeline. These thermosyphons work by pulling heat from the permafrost beneath the roadway during the winter months. The heat evaporates a refrigerant in the lower portion of the thermosyphon, known as the evaporator. Refrigerant vapor then travels upward to the upper portion of the hairpin where it condenses in the condenser, releasing heat just beneath the roadway surface. Heat from the condenser is then dissipated to the cold winter air above the road surface. The enhanced winter cooling that results from the operation of the thermosyphons lowers the permafrost temperature during winter in order to keep it from thawing during subsequent summers.

A second type of cooling technology, known as an air convection embankment (ACE), has also been incorporated into Thompson Drive. ACE embankments are constructed of rock with a size range of roughly 6 to 12 inches. Ideally, all fine material is excluded from the ACE material resulting in highly porous layers that allow air to circulate freely.

These layers promote air circulation during winter months when the pore air tends to be cold and heavy in the upper portion of the layer and relatively warm and light below. The warm air rises, carrying heat with it, while cold air from above sinks and cools the underlying permafrost. In this way, ACE layers can provide the same type of enhanced winter cooling as described previously for thermosyphons. If designed properly, ACE layers can also prevent permafrost thaw.

A Trail Tale



Not all over-land routes are on the road system. In fact, trails are a prominent means of travel for many rural Alaskans. Snow machines, dog sleds and ATVs are more common than cars and trucks in many areas. And trails aren't always planned; routes tend to be simply the most convenient path from point to point. Even trails can disturb permafrost, though. Permafrost may lie just two inches below moss, lichen and other plants that insulate the ground. When repeatedly crushed they die. An ATV trail can quickly degrade into muddy tracks with deep, permanent puddles. In an attempt to avoid the ruts and mud, riders try a different route and the same thing happens again. A trail will eventually become "braided" with a number of tracks in various stages of decline. No single solution to trail degradation will work in all instances.

- Plan ahead and choose routes that won't cause permafrost thaw.
- Add surface material, such as locally cut timbers or railroad ties to make a corduroy trail.
- Add wood chips to insulate.
- Drive carefully and cautiously, using a wider turn radius; minimize wheel spinning.

In the Arctic and sub-Arctic roads and trails, important routes for transport of goods, facilitators of travel for social reasons or means to enjoy Alaska's natural beauty are often dependent on a solid foundation-permafrost.

NAME: ____________________________
ROADS, TRAILS AND PERMAFROST

Directions: Based on the information you have learned about building roads and trails in Alaska answer the following questions.

1. What was the primary method used by early builders of the Alaska Highway to preserve the permafrost?

____

2. What are three modern methods that road construction engineers use to insulate the ground and disperse heat?

____

____

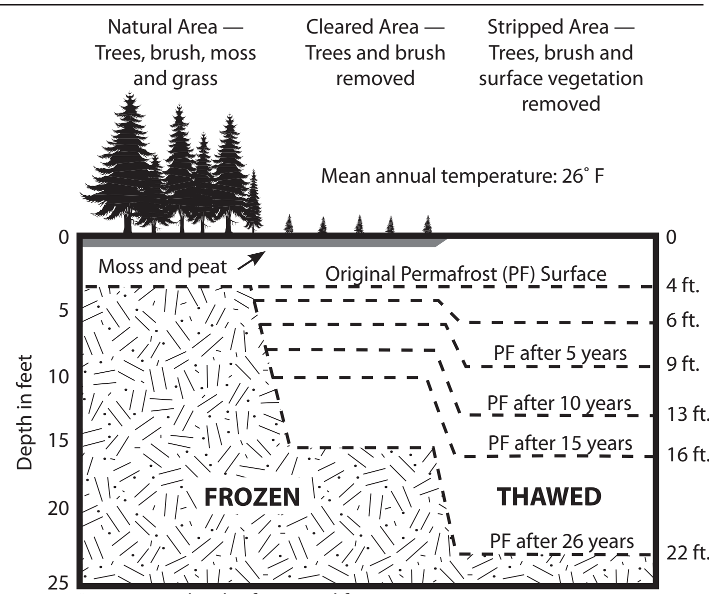
____

3. Look at the diagram to the right.

   a. How deep below the active layer was the original permafrost line? ____________

   b. After 5 years, permafrost under the stripped section was found to be at what depth?__________________________

   c. After 15 years, permafrost under the stripped section was found to be at what depth?__________________________



*Maximum depth of seasonal frost

Critical Thinking

4. A company is searching for potential natural gas drilling sites in Alaska. Explorers use a large track vehicle to reach the areas of interest. The path takes them through boreal forest and over tundra. What changes might you see in the ecology of the area where the track vehicle drove?

____

____

____

____

5. Near your community there is a trail to a berry patch that has been used for many years. People used to walk to the patch but now they take four wheelers. What effects do you think the change in use has had on the trail's ecology?

____

____

____

____

NAME: ____________________________

AN ICY INQUIRY

Directions: Complete the following lab then answer the questions that follow.

Goal: To design and build a roadbed that will keep the ground under it frozen longer than those designed by your classmates.

Rules:

- Every group starts with the same size pre-frozen container of potting soil – provided by the teacher.
- Groups can use two different insulation materials provided and scavenged for the roadbed.
- All road surfaces will be made of Model Magic®.
- To be a fair contest, all groups must stay together during timed steps.

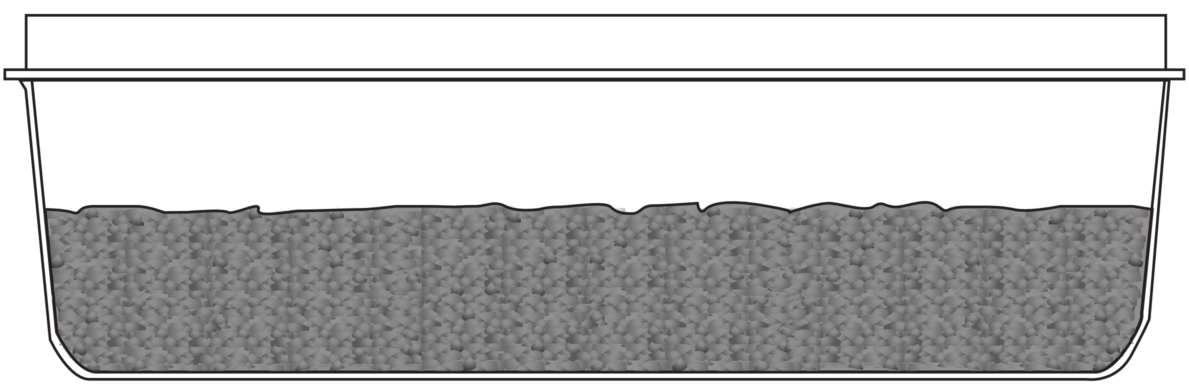
STEP 1 – Design the Roadbed
TIME: 10 minutes

1. Choose two insulation materials for your roadbed.

 ____

 ____

2. Sketch your plan for a roadbed on top of the soil in the graphic below. Include only the available material in your plan.



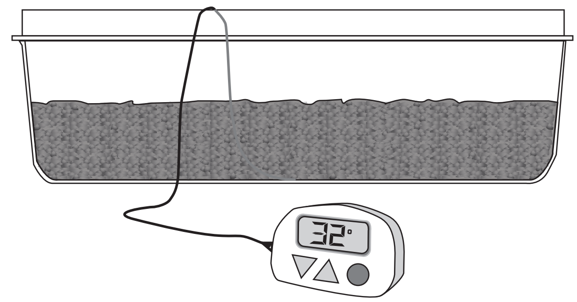
STEP 2 – Gather Materials

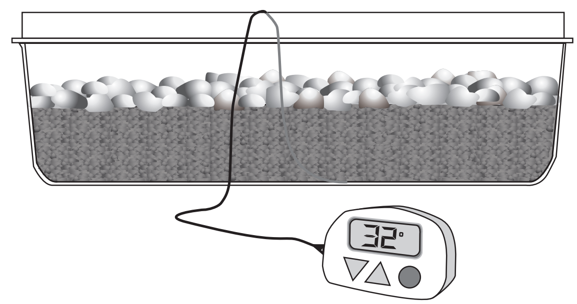
- Gather all needed material including Model Magic®, which will be used for the road **surface**.
- Prepare your road surface by flattening Model Magic®. Road surface must be ¼ inch thick. It will lie on top of the roadbed.

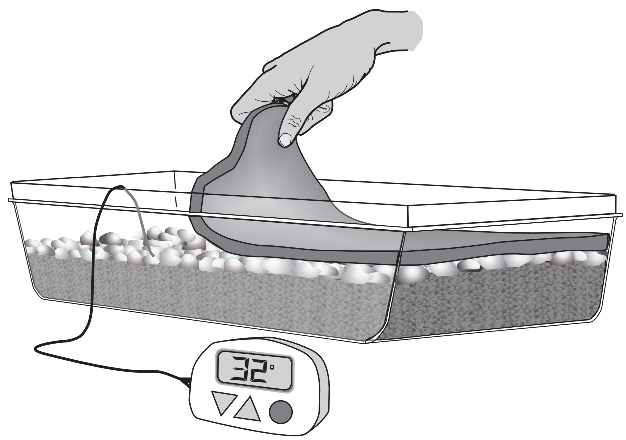
NAME: ______________________________
AN ICY INQUIRY

STEP 3 – Construct the Roadbed
TIME: 10 minutes

- Place the thermometer probe so that it is centered on top of the frozen soil. Secure the cord to the side with tape, if needed, until the roadbed is placed.
- Construct the roadbed, as designed, on top of the frozen soil and thermometer probe. The roadbed must stay inside the container and leaving room for the road surface. The road surface can be no higher than the top edge of the container.



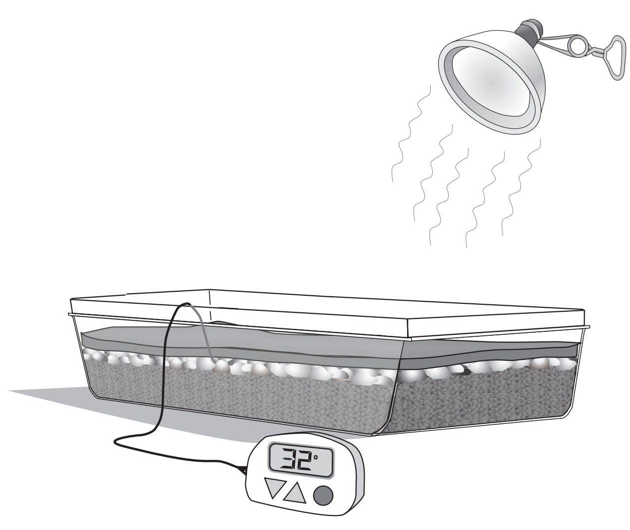




- Lay the road surface. All road surfaces MUST be the same thickness – ¼ inch thick.
- Mark your lab to distinguish it from others.

STEP 4 –Place Lab

- With teacher supervision, place the container under a heat lamp (off) and measure the distance from the lamp to the road surface. Each group's container must be equal distance from each lamp.
- Turn on heat lamps at the same time.



NAME: ____________________________

AN ICY INQUIRY

STEP 5 – Take Measurements

Measure the temperature at time intervals noted on the chart below.

3.

Time	Temperature	Observation
Start		
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		
12 minutes		
14 minutes		
16 minutes		
18 minutes		
20 minutes		
22 minutes		
24 minutes		
26 minutes		
28 minutes		
30 minutes		

STEP 6 – Results

In the space below, graph your results. Give the graph a title and label both the X and the Y axis. Provide a key, if necessary.

4.

NAME: ______________________________

AN ICY INQUIRY

Further Questions.

5. Why did you choose the material you did to construct your roadbed? Please explain what each material represented and what you hoped it would add to the insulating quality of the roadbed.

6. What would you have done differently?

7. Describe the transfer of energy from the heat lamp to the soil. Be thorough and use relevant terminology.