FROM THE SUBSURFACE TO THE SKY: TRACKING GROUNDWATER WITH DRONES

Stephanie Wilson
Virginia Institute of Marine Science

Grade Level
High School

Subject Area
Earth Science / Physical Science

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Activity Title
"From the Subsurface to the Sky: Tracking Groundwater with Drones"

Focus
Determining the inputs of nitrogen to coastal waters from drone based radiometric temperature data.

Topics covered:
- Technology and radiometric imagery
- Drones in science
- Groundwater
- Nutrients / pollutants
- Water cycle/ Watersheds

Grade Levels/Subject
High School Earth Science or Physical Science

VA Science Standards Addressed
ES.1 The student will plan and conduct investigations in which

a) volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools;
b) technologies, including computers, probeware, and geospatial technologies, are used to collect, analyze, and report data and to demonstrate concepts and simulate experimental conditions;
c) scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted;
d) maps and globes are read and interpreted, including location by latitude and longitude;
e) variables are manipulated with repeated trials; and
f) current applications are used to reinforce Earth science concepts.

ES.8 The student will investigate and understand how freshwater resources are influenced by geologic processes and the activities of humans. Key concepts include

a) processes of soil development;
b) development of karst topography;
c) relationships between groundwater zones, including saturated and unsaturated zones, and the water table;
d) identification of sources of fresh water including rivers, springs, and aquifers, with reference to the hydrologic cycle;
e) dependence on freshwater resources and the effects of human usage on water quality; and
f) identification of the major watershed systems in Virginia, including the Chesapeake Bay and its tributaries.

PS.1 The student will demonstrate an understanding of scientific and engineering practices by

c) interpreting, analyzing, and evaluating data
  - construct and interpret data tables showing independent and dependent variables, repeated trials, and means
  - construct, analyze, and interpret graphical displays of data and consider limitations of data analysis
  - apply mathematical concepts and processes to scientific questions
  - use data to evaluate and refine design solutions to best meet criteria

d) constructing and critiquing conclusions and explanations
  - construct scientific explanations based on valid and reliable evidence obtained from sources (including the students' own investigations)
  - construct arguments supported by empirical evidence and scientific reasoning
  - generate and compare multiple solutions to problems based on how well they meet the criteria and constraints

Learning objectives/outcomes

- Students will make a temperature heat map.
- Students will make a bar graph.
- Students will apply principles of radiometric image sensing to answer questions about data.
- Students will utilize graphs and images to make scientific inferences and compare data.

Total length of time required for the lesson

45 minutes to 1 hour

Key words, vocabulary

- **Drone:** short for an unmanned aerial vehicle (UAV), is an aircraft with no human pilot, the small aircraft is flown remotely by a pilot on the ground. These are essential pieces of technology used in scientific research, by the military, by the public for pleasure, and in many other applications. (You may ask the class if any of them have ever had a drone, seen a drone, etc.).
- **Radiometry:** temperature measurement
- **Radiometric Imagery:** when temperature measurement (radiometry) is incorporated into cameras. The images taken by the camera also have data on the temperature of the content in the photo.
- **Groundwater**: water that comes from the ground, i.e. water that is present within the subsurface. This water is typically fresh and also can be described as meteoric.
- **Nutrients:** Elements essential for life. Examples: nitrogen, phosphorus, carbon, some trace metals, etc.
- **Nitrogen Cycle:** The nitrogen cycle is the movement of nitrogen throughout an ecosystem – the full nitrogen cycle moves nitrogen through the geosphere, the atmosphere, and the biosphere. Nitrogen can change forms and may be present

as a gas, in fixed form as ammonium or nitrate, or it can be found in other larger compounds such as amino acids.

Background information

See background PowerPoint.

Background on Stephanie:

My name is Stephanie, and I am a marine biogeochemist. My research focuses on biogeochemistry and more specifically the cycling of nitrogen in coastal ecosystems. There are many sources of nitrogen to coastal waters including rivers, watershed runoff, wastewater and groundwater. Groundwater is an important source of nutrients, and specifically nitrogen, in many systems around the world. Despite being an important source, the amount of nutrients delivered to the coast in groundwater is largely unconstrained. Nitrogen and its cycling is extremely important to the environment; all organisms require nitrogen and in some forms it can promote primary production. Nitrogen can act as a pollutant when delivered in excess and can lead to eutrophication or stimulate harmful algal blooms. One of the ways that we can determine how much groundwater enters our coastal water ways and, therefore, how much nitrogen is exported to the ocean is to track groundwater with temperature.

This lesson focuses on tracking groundwater with temperature, because groundwater temperatures remain fairly constant throughout the year, its temperature differs from surface water temperatures. For example, in the winter time surface waters are cold, whereas groundwater is often warmer and, when it is discharged to the surface water, you can see and measure areas with warmer water as the result of groundwater discharge. The opposite occurs in summer, when surface water is warm, but groundwater is cold. You may have felt this before if you were ever walking on the beach above the water line and felt cold water coming through the sand beneath your feet – this is cool groundwater! This temperature difference can be measured using radiometric imagery, which collects temperature data for each pixel in a photo. Unmanned aerial vehicles, better known as drones, can be equipped with radiometric cameras in order to take these kinds of images. The images are then examined for temperature signatures indicative of groundwater. The data derived from the images can be used to determine how much groundwater is entering the coastal zone. We can then measure the concentration of nitrogen present in the groundwater and multiply that by the amount of groundwater discharging to get a nutrient flux into the ecosystem. This flux can be compared to inputs of nitrogen from rivers and wastewater treatment plants within the same system. These are cutting edge techniques used by researchers that result in important information regarding nutrient inputs and cycling in coastal waters.

Handouts and materials

- Handouts
    - From the subsurface to the sky: Tracking Groundwater with Drones Worksheet (App. 1a)

- From the subsurface to the sky: Tracking Groundwater with Drones Worksheet ANSWER KEY (App. 1b)

Materials and supplies

Projector/Screen for introductory PowerPoint
Printed handouts for each student
Crayons/Markers/ Colored Pencils

Classroom Set-Up

Typical classroom set-up, no specific format or set-up needed

Procedure:

Introduction:

Attention Grabber:

- How many of you have ever seen a drone before? Have any of you ever had one or flown one? (The PPT has some pictures of drones)
- The introduction PowerPoint can be used to review concepts related to the lesson. It is an introduction to groundwater, drones, and radiometric imagery as a scientific tool.

PowerPoint Script:

Slide 1: Presentation Title

Slide 2: Attention Grabber

Ask students if they have ever seen a drone or flown a drone.

Ask students what drones can be used for?

Drones can be exciting to fly for fun, but they also have many practical uses. Drones are used to deliver supplies to remote areas, they can be used for surveillance or to look for things, and they can be very useful to scientists!

Scientists can use drones to take aerial images of beaches to look at how they change overtime, to look for and track organisms such as shark populations or phytoplankton, and to monitor water quality and temperature.

Today we are going to learn about how a scientist uses a drone to look at groundwater inputs to the ocean!

Slide 3: About the scientist

The scientist whose research we will learn about today is Stephanie Wilson. She was a PhD student at the Virginia Institute of Marine Science where she studied nutrients and biogeochemistry in coastal ecosystems like sandy beaches! She loves to be on the water and, so being a marine biologist is a great fit for her. She uses drones to look at groundwater and what groundwater may bring with it to the coast!

Slide 4: What is groundwater

You may ask the students if they know what groundwater is.

Groundwater is water that comes from… the ground! This water infiltrates the subsurface environment as shown in the figure. At the coastline, groundwater actually is released to the ocean (as shown in the figure).

How many of you have ever been to the beach? Have you ever been walking on the beach above the waves and felt cold water coming up through the sand underneath your feet? Or have you dug a hole and had it fill with water from the bottom? That was probably groundwater!

Slide 5: Why do we care about groundwater entering the ocean?

What do the students think?

Groundwater can bring with it nutrients that can be used by marine organisms. It can also bring with it metals, pollutants, and microplastics. It is important to think about what that groundwater might be transporting and how these groundwater constituents might affect the ocean ecosystem.

Consequences of groundwater inputs: Excess groundwater nutrient inputs to coastal waters can cause eutrophication, harmful algal blooms, and subsequent hypoxic zones/fish kills. Metals, pollutants, and microplastics can be toxic to our marine life (fish, shellfish, crabs, etc.) and in some cases cause fishing and shellfish aquaculture closures.

Slide 6: How do we find groundwater in the ocean?

Groundwater is very different than seawater. First – groundwater is fresh! Groundwater is often used as a drinking supply because it is not salty like seawater. Groundwater also has a different composition (i.e.. It is made up of different components that are distinct from ocean water). Groundwater also has a different temperature, because groundwater is in the ground it is usually the same temperature as the ground. This is not true for ocean water, the temperature of ocean water fluctuates with the air temperature, wind, and sunlight.

We can use these differences between groundwater and seawater to track down groundwater in the ocean!

Slide 7: Groundwater vs. Seawater Temperatures

We mentioned on the last slide that groundwater and seawater can have different temperatures. In temperate ecosystems, there are distinct seasons: summer, winter, fall, spring and air temperatures change with the seasons. What happens to the temperatures in winter? It gets cold! In summer? It gets hot!

The same thing happens to coastal ocean temperatures, in the winter coastal waters get cold and in the summer they get warm just as the air does. This is because the water is in contact with the air and can be heated by the sun.

Is groundwater in contact with the air? No! It is in the subsurface, underground. Temperatures in the ground do not fluctuate drastically as air temperatures do, they are pretty constant year-round. Therefore, groundwater temperatures are also fairly stable year round.

If we look at this graph, we can see how the surface water changes temperature throughout the year, but the groundwater temperature does not change very much throughout the year. This difference in groundwater and seawater temperature can be used to track groundwater in the ocean!

Slide 8: Tracking groundwater

When we use temperature to track groundwater in the ocean we need to measure the temperature differences in groundwater and seawater.

One way to do this is to use specialized cameras that take radiometric images.
Radiometry or temperature measurement is incorporated into the camera so that when the camera takes and image or a video the temperature data is collected for the things in the photo.
Radiometric imagery is unique because it allows you to determine the temperature of the things in a photo or video.
The camera that Stephanie, the marine biologist, uses is shown in the orange circle attached to a drone. Stephanie flies this drone with the camera attached to take pictures of the ocean water to look for temperature differences due to groundwater discharge to the ocean.

Slide 9: Examples of radiometric images

As you can see in these photos there are two people standing outside, in the normal photo you see the two people as a regular image, but the radiometric camera shows us the temperature of the people and their surroundings! As you can see the people are much warmer (more orange and yellow) that the surrounding area!

Slide 10: The drone in Action

Here is the drone that Stephanie uses to take her measurements. It is called an M600 drone and its name is “Sarabi” . There are some videos here of the drone getting ready to fly early in the morning at sunrise.

Slide 11: Drone in Action, cont.

Here is a photo of the drone flying over the water. We fly the drone over beaches to look at the surface water temperatures. We can then look at the images to see if there are any signatures of warmer or colder water that could indicate groundwater flow to the beach!

Slide 12: Drone aerial images

Here are some of the images taken by the drone while Stephanie was taking measurements on some beaches in Virginia during winter time. As you can see there are three beaches shown here and they look fairly similar when you compare the regular images right? So let’s take a look at the temperature images associated with them.

Slide 13: Radiometric images

Here are these same beaches shown as radiometric temperature images. Here the black or darker colors (dark purple) are cold temperatures and the warmer colors (yellows, light purples, pinks) are warmer temperatures.
Do you see any differences between the photos in the water?
The first beach, beach A, has no purple color in the water, but beach B has a little bit in the top left corner of the water, and beach C has a bunch of purple in the water right?
This warmer water/the purple areas shown in the radiometric images are signs of groundwater!
This is how Stephanie finds groundwater in the ocean and then these images can be used to figure out how much groundwater is coming into the ocean and she can measure what is in the groundwater, for example nutrients, to determine the input of nutrients from groundwater.

Slide 15: Comparison of regular and radiometric images of beaches along the York River

These photos show the beaches long the York River near to Gloucester Point Virginia. You can see that the land is warmer than the water, because the land is yellow/orange in the radiometric image indicated warmer temperatures. If you look closely in the middle beach there are some irregular patterns of warm water (pink streaks), which indicate groundwater discharge. You can also see a gradual darkening of the purple color as you move out from the beaches to the deeper water, indicating that the shallow water is warmer than the deeper water.

Slide 16: Comparison of regular and radiometric images of VIMS

This comparison is really just a fun one to show students. VIMS stands for the Virginia Institute of Marine Science and that is where Stephanie conducted her research and where the drones used in this research are kept. You can see it is a very pretty location near the water. An interesting note – these thermal images are used sometimes to look at hotspots on buildings and can also be used to locate lost people or locate animals in forests by searching for heat in the images. There are many applications for radiometric imagery and drones in science and other fields.

Slides 18-20: Images from the Worksheet

These are available in case the instructor would like to show them on the board when reviewing.

Independent Worksheet Time:

- Students will be given time to complete Handout #1 (App. 1). Alternatively this could be done as homework and reviewed the following day.

Think-Pair-Share or Group Review Time:

- Students should get in pairs or a small group and compare their answers on the worksheet. Do their graphs look similar? What inferences did they make?

Class worksheet and concept review:

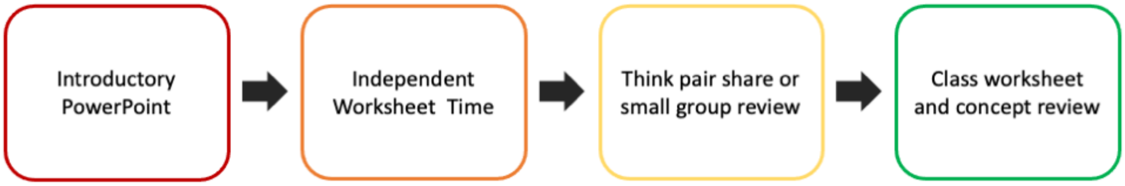
- Go through the worksheet and use this to review concepts.

Closing/Summary:

- Pose a question to the class: What other ways can drones and/or radiometric imagery techniques you have learned about today be used in science and research?
- Could ask the class what other applications they can come up with that they could use drones or radiometric imagery for in science.

Lesson Plan Activity Flow Chart:

Subsurface to the sky: Tracking Groundwater



1. **Assessment**
   The students will be required to fill out a handout as they go through the activity to mark their progress. After having time to work independently on the worksheet students will compare their answers in pairs or small groups. After reviewing answers as a team the whole class will review the answers together, sharing answers and engaging in teacher-led discussion as questions are answered.

Appendix 1a:
From the Subsurface to the Sky: Tracing groundwater with Drones

Name: ________________________ **Date:** _____________

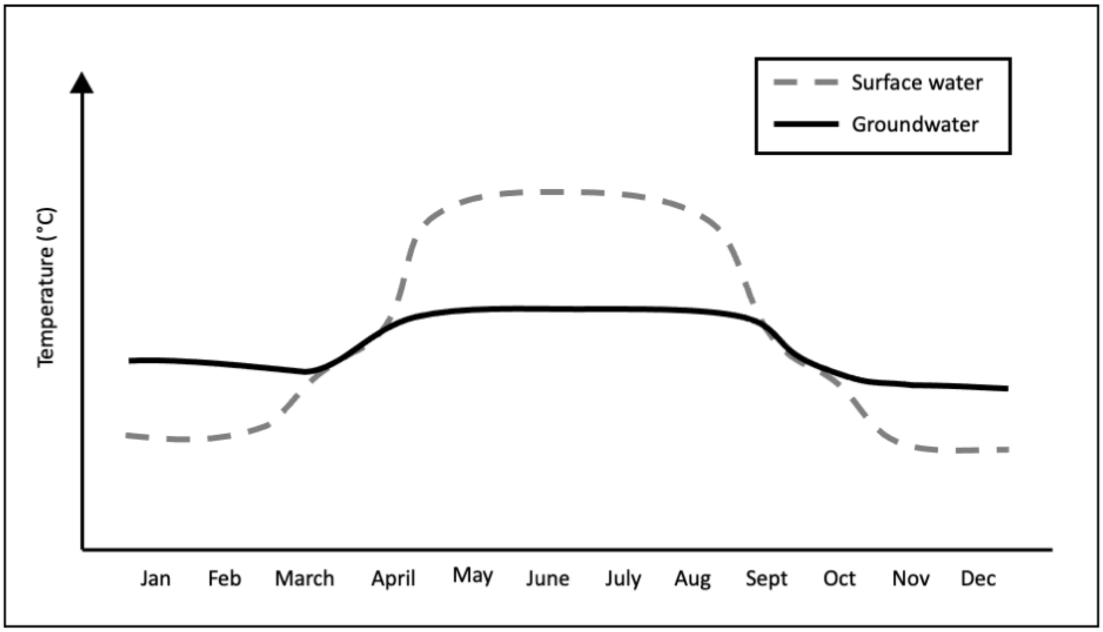
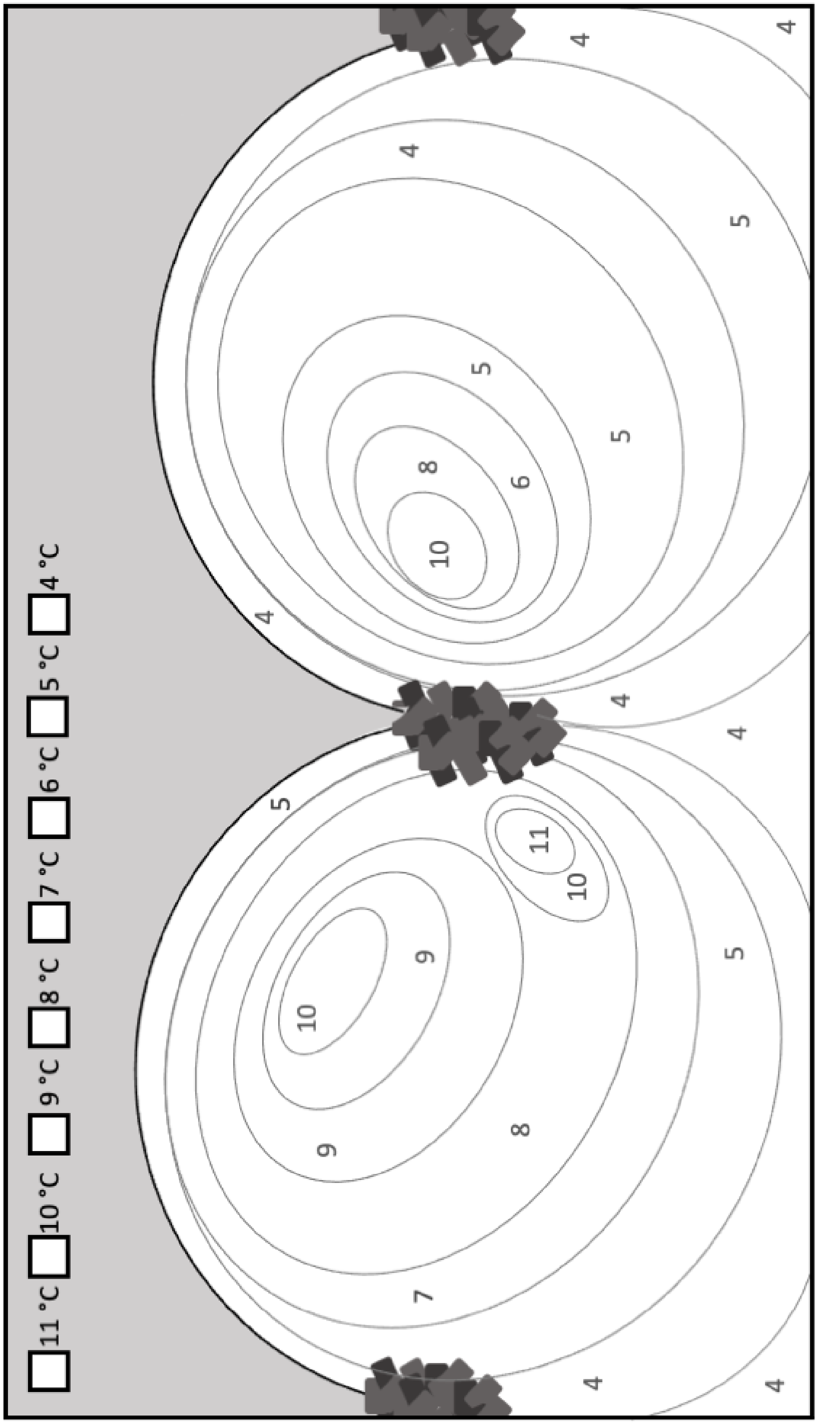


Figure 1: Graph showing the surface water and groundwater temperatures throughout the year

1. At what times in the year are the groundwater and surface water temperature most different from one another?

2. Will groundwater that flows out to surface water be warmer or colder than the surface water in winter?

3. You just finished flying your drone during winter over two beaches to collect surface water temperature data. Color in the figure below showing the surface water temperatures measured by your radiometric camera. Choose a color for each temperature then color the surface water according to your key.



4. What patterns do you see in the surface water temperatures? Are there any areas of warmer or cooler temperatures and if so where are they?

5. Does your temperature data suggest there is groundwater discharge occurring at these beaches? Why or Why not?

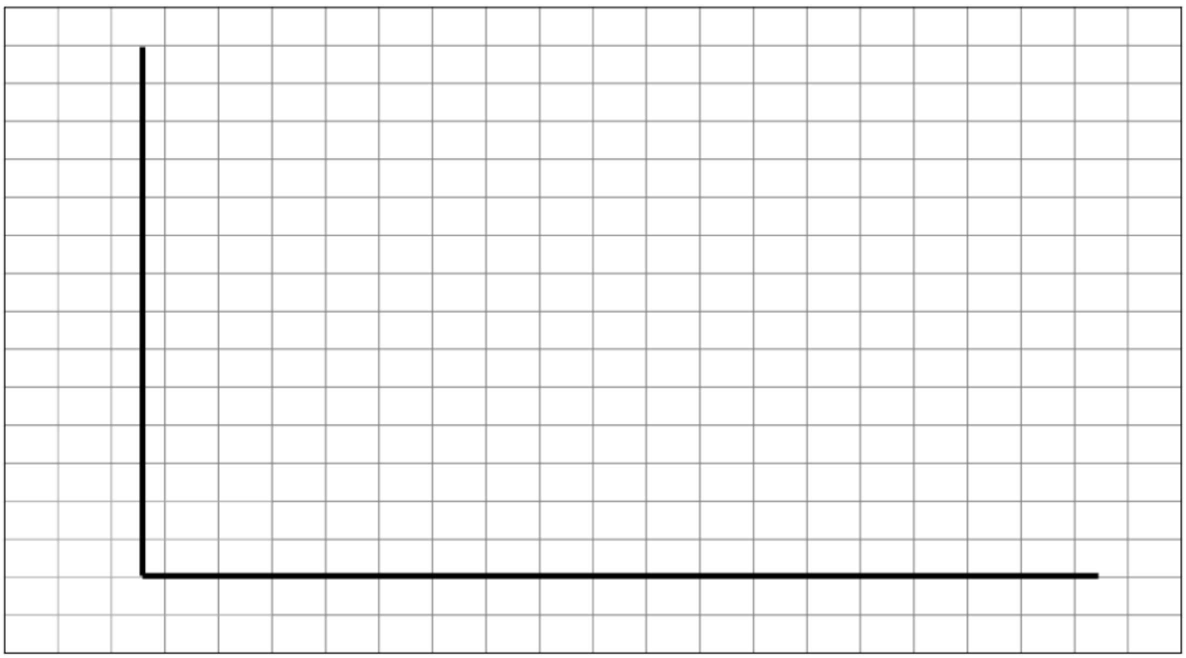
6. You have now gone out and measured the nitrogen concentration in the groundwater on the beaches and find that they are 5 mg/Liter. If the groundwater discharge rate is 200 Liters per day, how much nitrogen is released to the surface water each day in mg/day? Use the equation below to calculate the groundwater export.

$$Y_{gw} = C_{gw} * D_{gw}$$

Variable	Definition	Units
Y_{gw}	Groundwater Nitrogen Export	mg/day
C_{gw}	Groundwater Nitrogen Concentration	mg/Liter
D_{gw}	Groundwater discharge Rate	Liters/day

7. Below is a data table showing the nitrogen input to the system you are studying from wastewater treatment plants in the area and from rivers. Fill in the groundwater input with the number you calculated in Question #6, then make a bar graph to compare the these inputs on the graph below.

Source	**Nitrogen input (mg/day)**
Rivers	5,000
Wastewater	500
Groundwater	



8. Which of the sources you graphed in Question #7 is the largest source of nitrogen to these coastal surface water?

9. What percent of the total nitrogen exported to this system does groundwater represent? Use the values given in Question #7 table in the following equation to calculate the percent of groundwater nitrogen:

$$\% \, GW = \left(\frac{Groundwater}{(Rivers + Wastewater + Groundwater)}\right) * 100$$

10. Why is it important to know how much nitrogen is being delivered to the coast in groundwater?

11. What else do you think might be transported in groundwater?

Appendix 1b: ANSWER KEY

From the Subsurface to the Sky: Tracing groundwater with drones!

Name: _________________________ **Date:** _____________

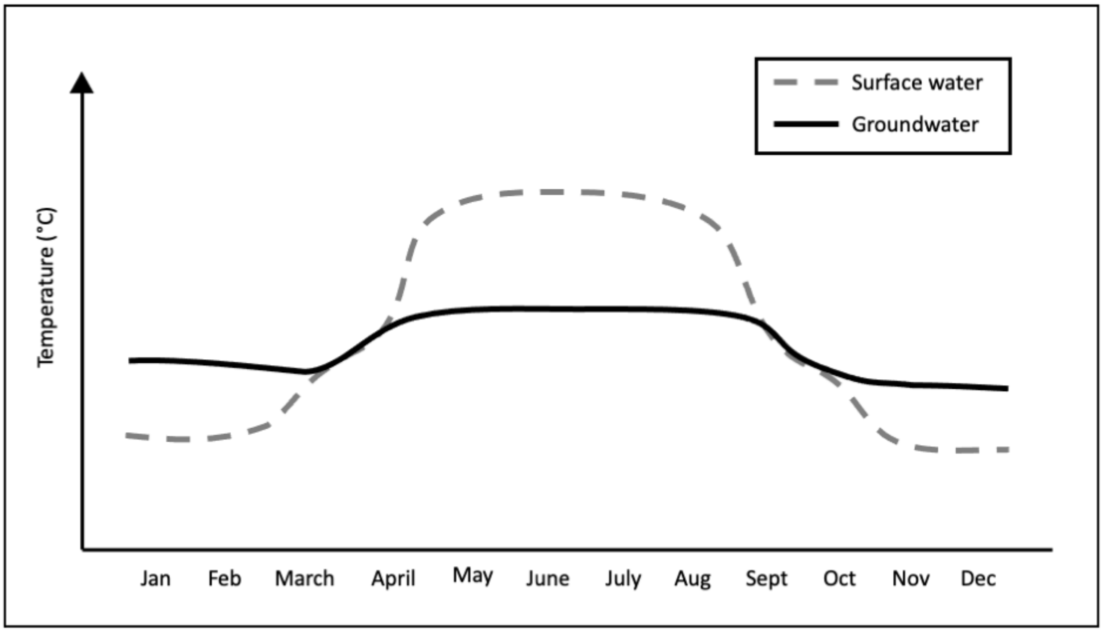


Figure 1: Graph showing the surface water and groundwater temperatures throughout the year in a temperate ecosystem.

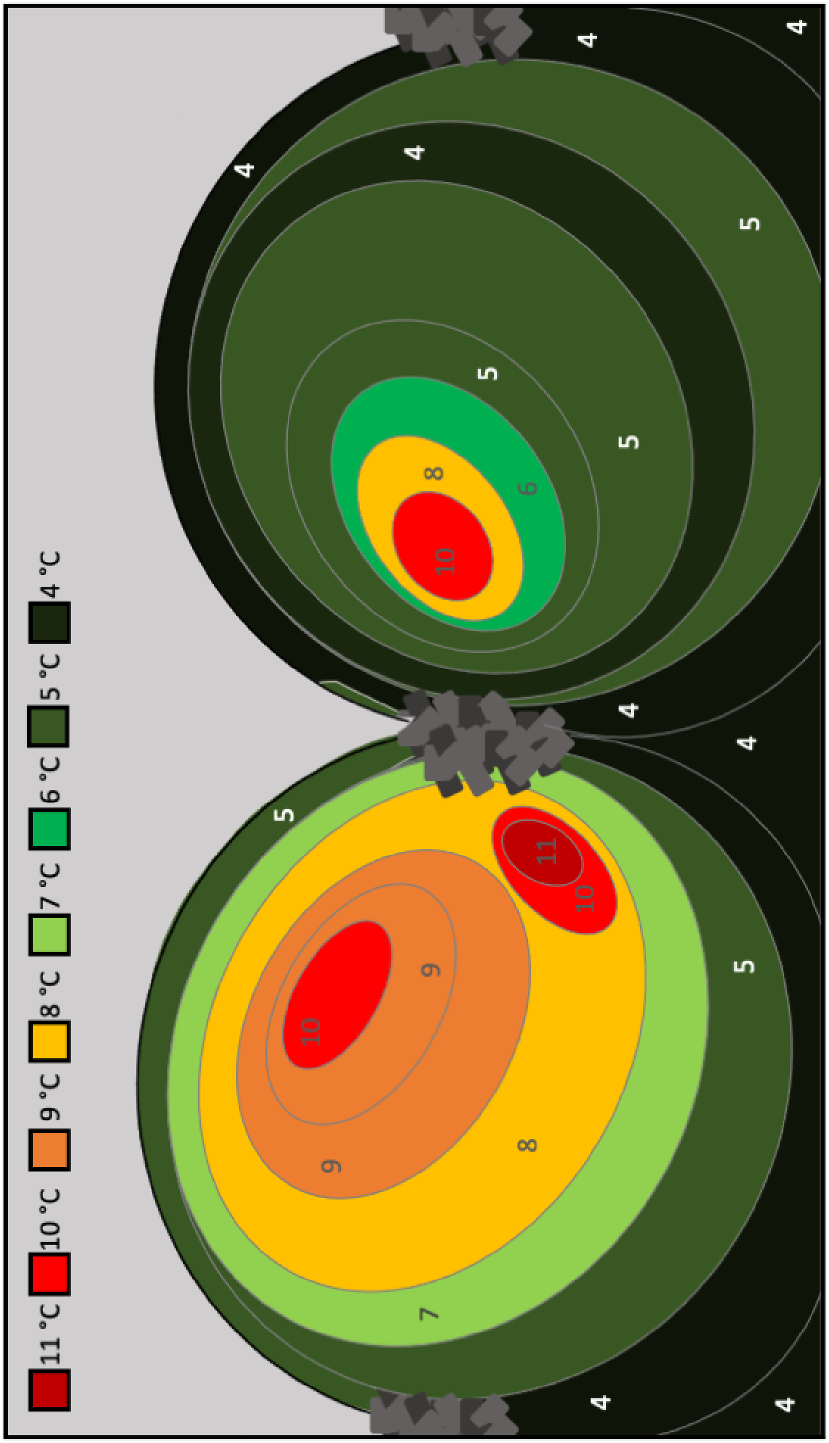
1. At what times in the year are the groundwater and surface water temperature most different from one another?

In winter time (January – beginning of March and November-December) the groundwater temperatures differ from surface water temperatures. During winter the groundwater temperatures are warmer than the surface water. This is because the air is cold and it is therefore decreasing the surface water temperatures, but the groundwater is protected from the cold air and so it is warmer than the surface water.
In the summer time (May-August) the groundwater and surface water temperatures are also different. The groundwater is cooler than the surface waters again because the hot air is warming up the surface water, but the groundwater is protected from the warm sun and warm air, so it remains cool.

2. Will groundwater that flows out to surface water be warmer or colder than the surface water in the winter?

The groundwater will be warmer than the surface water.

3. You just finished flying your drone during winter over two beaches to collect surface water temperature data. Color in the figure below showing the surface water temperatures measured by your radiometric camera. Choose a color for each temperature then color the surface water according to your key.



4. What patterns do you see in the surface water temperatures? Are there any areas of warmer or cooler temperatures and if so where are they?

There are spots of warmer water on both beaches (red and orange in the key). The beach on the left hand side of the figure has a larger area of warm water and the warmer water seems to be concentrated near the center where the two beaches are separated by rocks.

5. Does your temperature data suggest there is groundwater discharge occurring at these beaches? Why or Why not?

Yes, the patches of warm water indicate groundwater discharge. The discharge is higher on beach 1 than on beach 2 because there is a greater temperature signature. The warm water indicates groundwater discharge because it is winter and the groundwater is warmer than the surface water.

6. You have now gone out and measured the nitrogen concentration in the groundwater on the beaches and find that they are 5 mg/Liter. If the groundwater discharge rate is 200 Liters per day, how much nitrogen is released to the surface water each day in mg/day? Use the equation below to calculate the groundwater export.

$$Y_{gw} = C_{gw} * D_{gw}$$

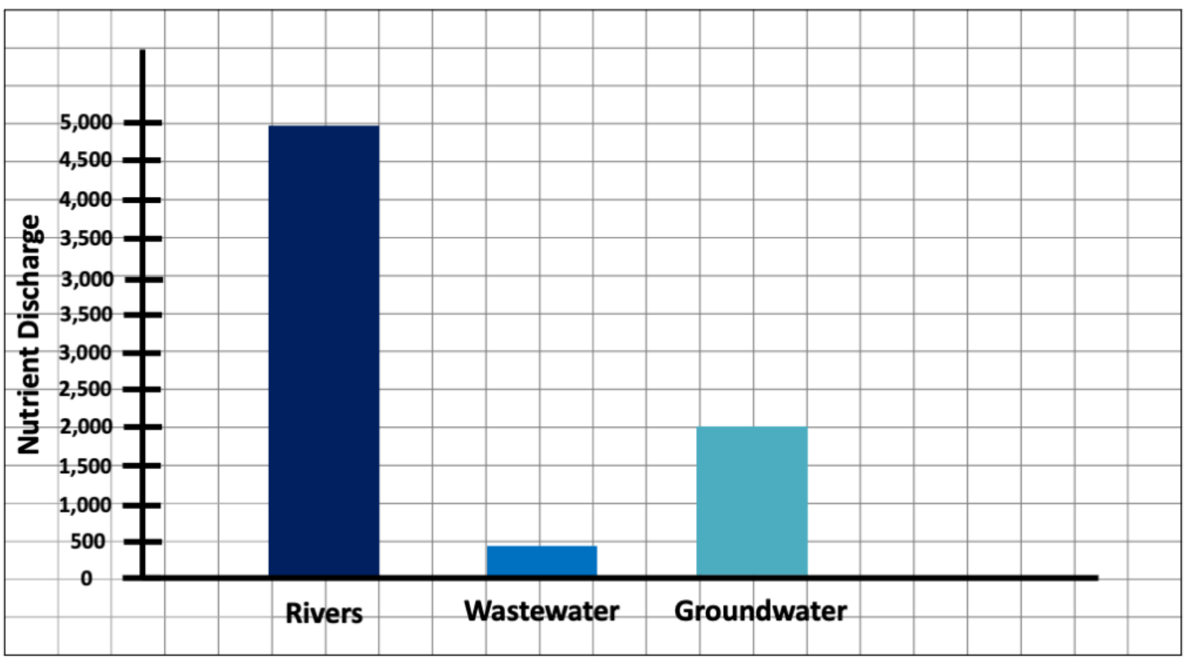
Variable	Definition	Units
Ygw	Groundwater Nitrogen Export	mg/day
Cgw	Groundwater Nitrogen Concentration	mg/Liter
Dgw	Groundwater discharge Rate	Liters/day

$$Nitrogen\ Concentration\ \frac{mg}{Liters}\ x\ Groundwater\ Discharge\ \frac{Liters}{Day} = Nitrogen\ discharge\ \frac{mg}{Day}$$

10 mg/L x 200 L/Day = 2,000 mg/Day

7. Below is a data table showing the nitrogen input to the system you are studying from wastewater treatment plants in the area and from rivers. Fill in the groundwater input with the number you calculated in Question #6, then make a bar graph to compare the these inputs on the graph below.

Source	Nitrogen input (mg/day)
Rivers	5,000
Wastewater	500
Groundwater	2,000



8. Which of the sources you graphed in Question #7 is the largest source of nitrogen to these coastal surface water?

Rivers are the largest source of Nitrogen to the coastal water.

9. What percent of the total nitrogen exported to this system does groundwater represent? Use the values given in Question #7 table in the following equation to calculate the percent of groundwater nitrogen:

$$\%\ GW = \left(\frac{Groundwater}{(Rivers + Wastewater + Groundwater)}\right) * 100$$

Total nitrogen exported to the system: River input + Wastewater input + Groundwater input

5,000 + 500 + 2,000 = 7,500

Percent of nitrogen input from groundwater: (Groundwater input / Total input) x 100

(2,000 / 7,500) x 100 = 26.7 %

10. Why is it important to know how much nitrogen is being delivered to the coast in groundwater?

Nitrogen is a nutrient that when there is too much / excess it can lead to negative ecosystem impacts such as eutrophication and harmful algal blooms. We need to know how much nitrogen is entering our waterways in order to better manage and protect our coastal ecosystems.

11. What else do you think might be transported in groundwater?

Pollutants, microplastics, metals, other nutrients, microorganisms, etc.