

Using Computational Thinking and Models to Investigate Groundwater Contamination in Tucson, Arizona



Teacher Introduction Introducing the Unit Establishing the Problem

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Comp Hydro Unit Learning Goals

Hydrologic Learning Goals	Data Learning Goals	Computational Thinking and Modeling Learning Goals
<p>Contamination Plumes: Students will be able to describe the shape and direction of flow of the contamination plume and identify possible contamination sources. (1)</p>	<p>Plotting Data: Students will be able to plot sample location and contamination data on a map and interpret contamination plume shape and direction of movement. (1)</p>	<p>Trade-offs: Students will be able to identify and describe benefits and challenges of using computers to analyze data. (1, 2, 3)</p> <p>Students will be able to explain that computer models are best estimates based on the data available.</p>
<p>Water Tables and Aquifers: Students will be able to describe (slope and aspect) the regional water table as a surface located in a 3-dimensional space underground. (2)</p>	<p>Interpolation of Data: Students will be able to interpolate data in order to contour contamination concentrations and water table elevations. (1, 2)</p> <p>Students will be able to use well-data to determine the stratigraphic structure of an aquifer. (3)</p>	<p>Parameterization: Students will be able to divide the problem-space into discrete cells and assign values to those cells based on properties of the system. (2, 3)</p>
<p>Groundwater-Surface Water Relationships: Students will be able to describe the relationship of surface water to groundwater systems. (2)</p>	<p>Visualization: Students will be able to interpret 3D shape of water table from plan and cross-section views of contour maps. (1, 2, 3)</p>	<p>Boundary Conditions: Students will be able to identify system boundaries and explain how the boundary conditions affect a computational model. (1, 2, 3)</p>
<p>Groundwater Flow Drivers: Students will be able to interpret direction of groundwater flow in an unconfined aquifer from high gravimetric potential (head) to low gravimetric potential using a variety of representations and models. (2, 3)</p>	<p>Uncertainty: Students will be able to recognize where missing data contribute to uncertainty. (1, 2, 3)</p>	<p>Discretization: Students will be able to discuss how size of discrete intervals (cell size or contour interval) affects models and representations. (2, 3)</p>



Comp Hydro Arizona: Establishing the Problem

Hydrologic Learning Goals	Data Learning Goals	Computational Thinking and Modeling Learning Goals
<p>Groundwater Flow Constraints: Students will be able to identify the pattern that water moves faster through materials with greater permeabilities (e.g., clean sands and gravels) and slower through materials with lower permeabilities (e.g., silts and clays). (3)</p>	<p>Noise and Complexity: Students will be able to look for trends in noisy data and recognize that more data often leads to more complexity. (1, 2, 3)</p>	<p>Iteration: Students will be able to explain how computers repeat a sequence of commands many times (iterate) to complete a task. (1, 2, 3)</p>
<p>Groundwater Pathways: Students will be able to trace likely water pathways through aquifers using a variety of representations. (3)</p>		<p>Models as Best Approximations or Estimates (uncertainty): Students will be able to explain that computer models are best estimates based on the data available. (1, 2, 3)</p>
	<p>Comparing Models to Observations: Students will be able to perform and adjust several runs of a model to falsify models and work toward modeled and observed agreement. (1, 2, 3)</p>	



Comp Hydro Modules Overview

Understanding the Tucson International Airport Area (TIAA) Superfund Site and the Tucson Airport Remediation Project (TARP)

Pre-Assessment

Establish and Contextualize the Problem

How and why is this community affected by the TCE and 1,4 Dioxane pollution?

Students read newspaper articles, view videos, and see a demonstration of the TCE and 1,4 Dioxane groundwater contamination related to the TIAA Superfund Site. The overall driving question is established.

Explore, Model, and Investigate

Module 1 Shape of the Plume: Where is the contamination?	Module 2 Shape of the water table: What is the shape of the water table?	Module 3 Groundwater flow: How do water and contamination flow?
Lesson 1: Paper Maps: Locating Wells	Lesson 1: Physical: Piezometer Model of Water Table (Optional)	Lesson 1: Physical Model: Groundwater Flow Drivers and Constraints
Lesson 2: Paper Maps: Contouring the Contamination Plume	Lesson 2: Physical: Contouring Water Table Elevations	Lesson 2: Paper: Drawing Cross-Sections of the TIAA Superfund Area (Optional)
Lesson 3: Computer Models: Modeling Plume Shape	Lesson 3: Computer: Regional Water Table in 2D & 3D	Lesson 3: Kinematic: Table Simulation of Computer Modeling of Groundwater Flow
		Lesson 4: Computer: Net Logo Groundwater Flow With Embedded Assessment

Addressing the Problem

How is the contamination being cleaned up?

After using a Net Logo model to develop a pump and treat solution to the contamination, students visit the Tucson Water Advanced Oxidation Treatment Plant to see how Tucson Water cleans up the contamination.

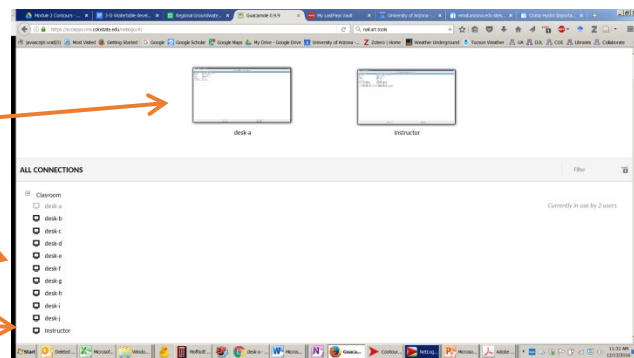
Post-Assessment

Using Net Logo on the CSU Remote Server

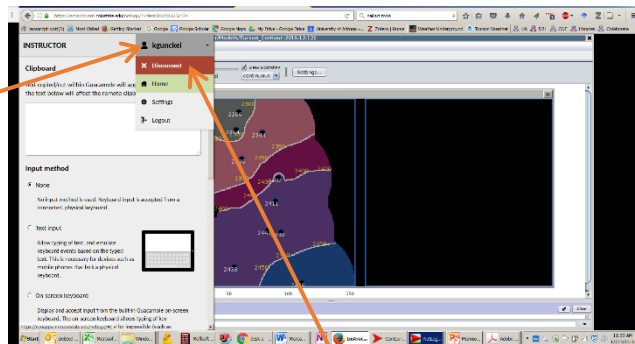
To request access, please contact Ty Boyack, Colorado State University:
Ty.Boyack@colostate.edu

Instructor Directions

1. Use this link
<https://ecoapps.nrel.colostate.edu/>
2. Type in user name and pass word.
username: "instructor"
password is "instructorpw"
3. Under "Connections" open the Classroom so you can see all student desks.
 - a. These screens show desks you currently have open.
 - b. Click on student desks to see what students are doing.
 - c. Click on Instructor desk to run your own desk.
4. Note: student logins do not map directly onto student desks. You will receive a separate email that lists the mapping. Use the mapping to identify which students are using each desk.

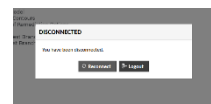


5. You can also see what each student is doing, click CTRL-ALT-SHIFT. A menu will slide in from the left. Click on your username, in the upper right.
6. From here, click on a student desk. You should now be able to see what that student is doing.
7. To change to a new desk, hit CTRL-ALT-SHIFT again. Always come back to this screen to change desks you want to see.
8. To disconnect from a student, hit CTRL-ALT-SHIFT. Choose the "disconnect" option. That will disconnect you from that student's desk and you can choose a new student desk.
 - a. WARNING: If you are on a student screen and you click the black exit X, you will also disconnect the student.
 - b. WARNING: Be aware of having too many desks open at one time. Everytime you open a desk you add load to the system and slow down the entire system for everyone. To avoid this, close each student desk from the CTRL-ALT-SHIFT screen before opening another student desk.

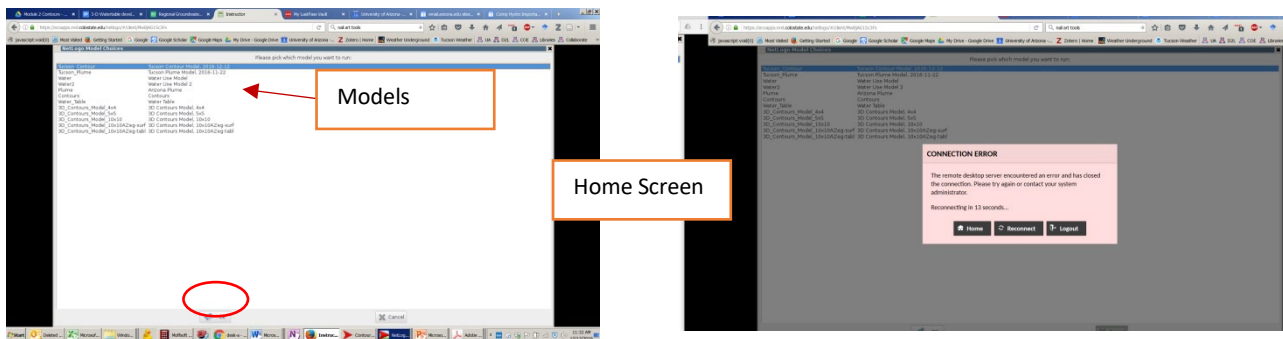


Comp Hydro Arizona: Establishing the Problem

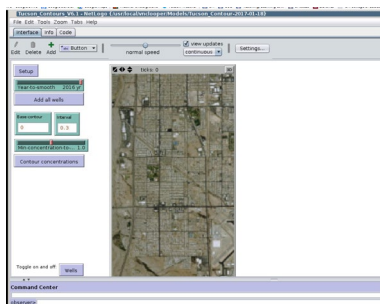
9. You may return to the home screen by clicking “Home.”
10. If a pink box comes up, you can either reconnect your session or log out.



11. To run your own models, choose the Net Logo Model you wish to run from the models home screen. Then click “OK” at the bottom. If you click “Cancel” you will see a connection error message. You may return to the home screen by clicking “Home.”



Now you can use the Net Logo model.



Student Directions

1. You will have 10 “desks” for your class. Assign two to four students to each “desk”. Students will all be able to see the models from their own computer. I recommend that you plan ahead of time which student teams will get each login and password.
 - a. Note: More than one student can log on to the same desk. All students logged on to the same desk will see and be able to operate the same model.
 - b. Suggestion: Assign team member numbers and roles. Rotate which team member is in charge of manipulating the models.
2. Student logins do not map directly onto desks. Mapping is unique to each teacher. You will receive a separate email with the mapping once you have been assigned desks. Use this mapping to keep track of which students are on each desk.
3. Have students use this link
<https://ecoapps.nrel.colostate.edu/>
4. Type in user name and pass word.

Comp Hydro Arizona: Establishing the Problem

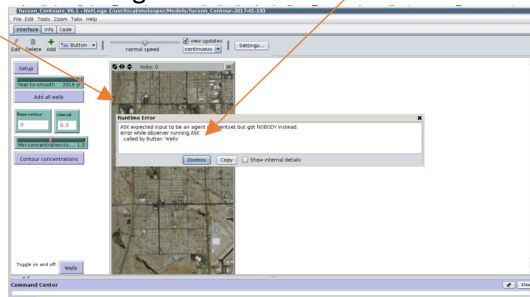
username: "a"
password: "pwa"

username: "b"
password: "pwb"

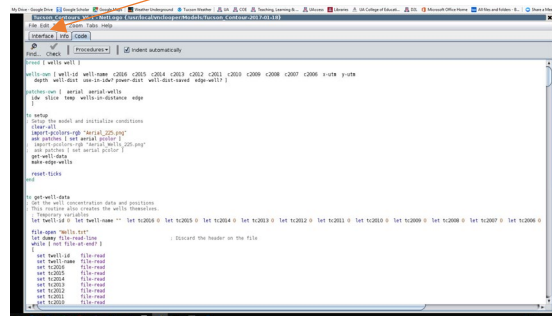
and so on through

username: "j"
password "pwj"

- Students click their desk connection and proceed to Step 11 to the models home screen.
- Special Note: Sometimes when students push the model and try to break it (not necessarily a bad thing), they get "runtime error" message. Just click the "dismiss" button and return to the model.



- Special Note: Sometimes when students push the model they get to a screen with a bunch of code. To go back to the model, simply click the "Interface" tab at the top.

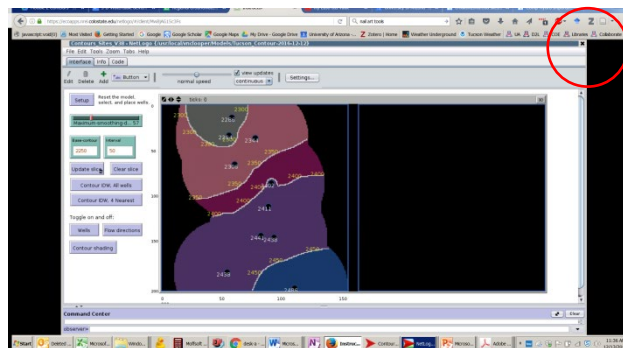


Logging Out

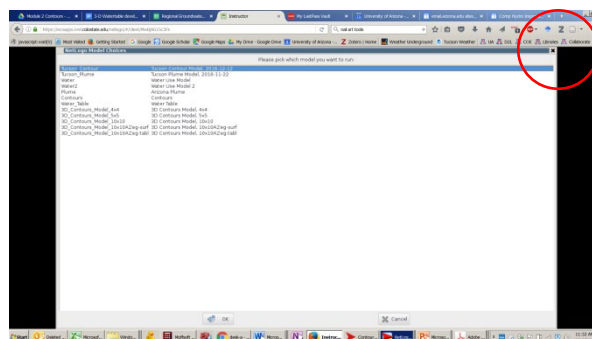
- Best practice is to have students log out at the end of the class period. There are two ways to do this.
 - Method One:

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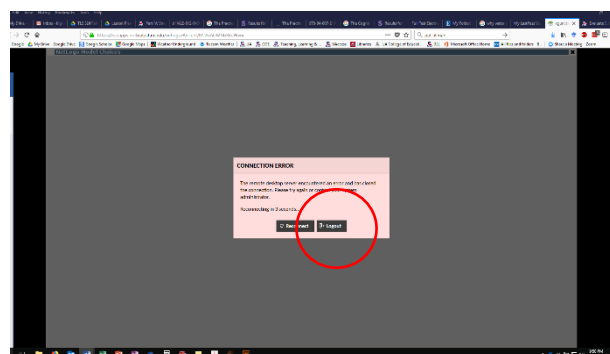
- i. Click the black X on the upper right corner.



It will take you to the models home menu page. Click the black X in the upper right corner again.

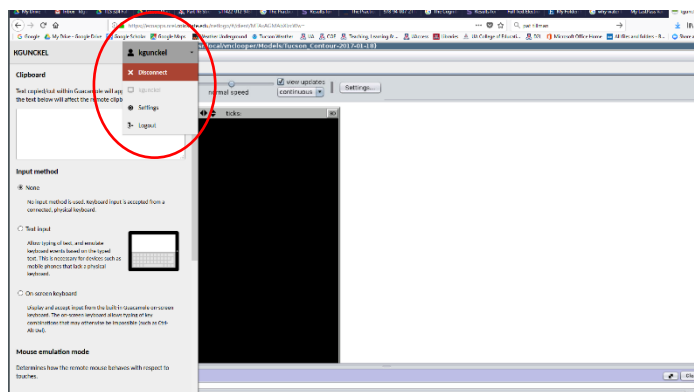


- ii. You should now see the pink connection error box. Click “Log Out.”



b. Method Two

- i. Hit CTRL-SLT-SHIFT. You should see a box come in from the right.
- ii. Click the down arrow next to your login name.
- iii. Click “Logout”
- iv. You can also click “Disconnect” and then click “log out” on the next screen.

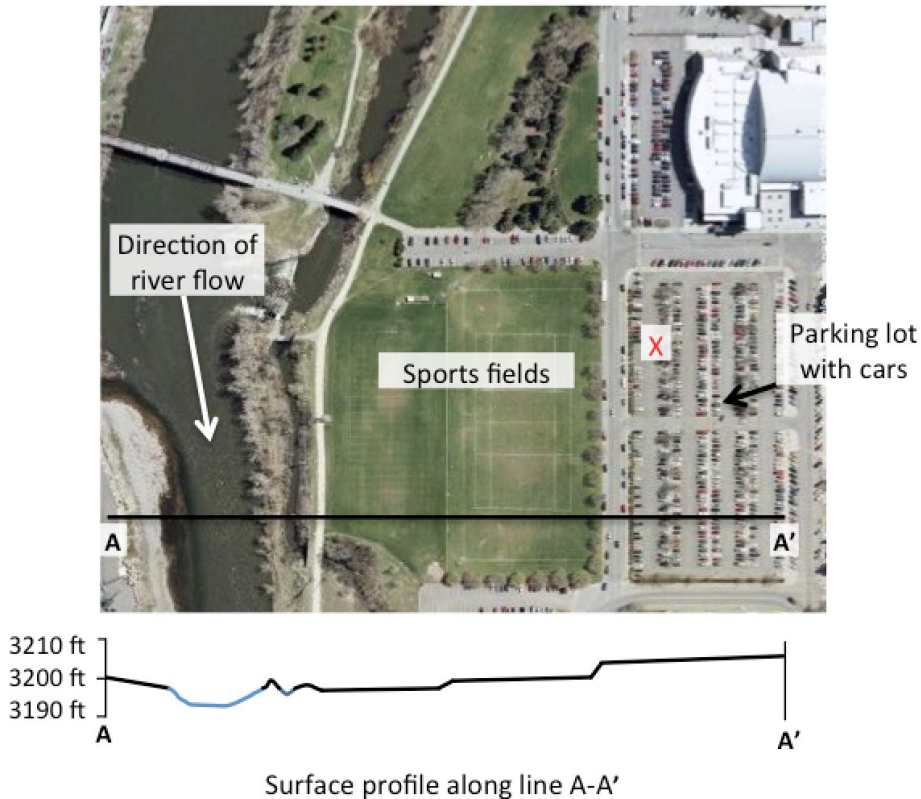


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2. If a student does not log out, the next student will not be able to log in on that desk. You can force a log-out at any time
 - a. Click CTRL-ALT-SHFT
 - b. Choose the student desk that is not logged out.
 - c. Click log-out.

Comp Hydro Pre-Assessment

The picture below shows part of a school campus with several grassy sports fields and a parking lot near a river. Use the picture to help you answer the next set of questions.



1. Could water falling on the sports fields as rain get into the river?
 - a. (Choose) YES NO
 - b. If you answered “yes,” explain how and why you think the water could get into the river. If you answered “no,” explain why the water could not get into the river. Please provide as many details as you can.

2. Could water falling on the parking lot as rain at the location marked with the X get into the river?
 - a. (Choose) YES NO
 - b. If you answered “yes,” explain how and why the water could get into the river. If you answered “no,” explain why the water could not get into the river. Please provide as many details as you can.

Comp Hydro Arizona: Student Pre-Assessment

3 . Answer the following

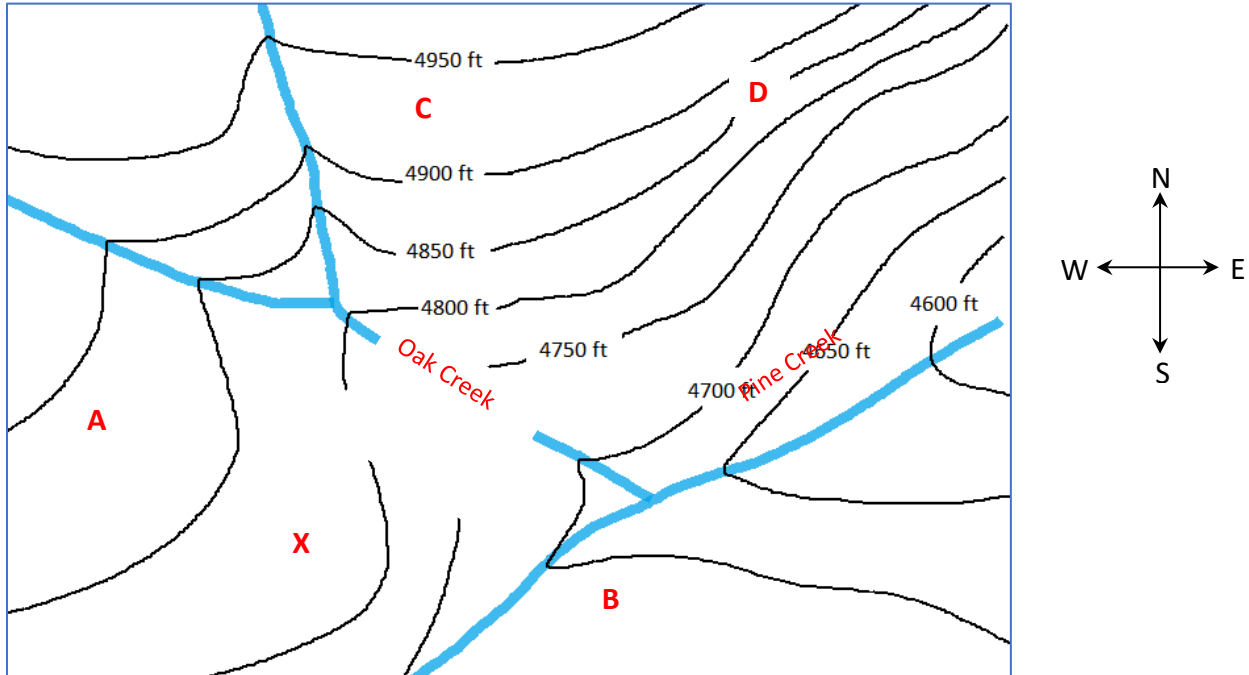
a. What do you think scientists use computer models for?

b. Write a question about a real world water problem related to contamination or flooding that a scientist could use a computer model to answer.

4. What are some problems with using a computer model to understand a real-world water problem?

5. How can a scientist judge if a computer model is accurate?

Use this contour map of a land surface to answer the questions below.



6. a. What would be a reasonable estimate for the elevation of the land surface at the X on the map? (Circle a response)
- A. 4800 ft
 - B. 4850 ft
 - C. 4815 ft
 - D. 4765 ft
- b. Please explain why you chose that answer.

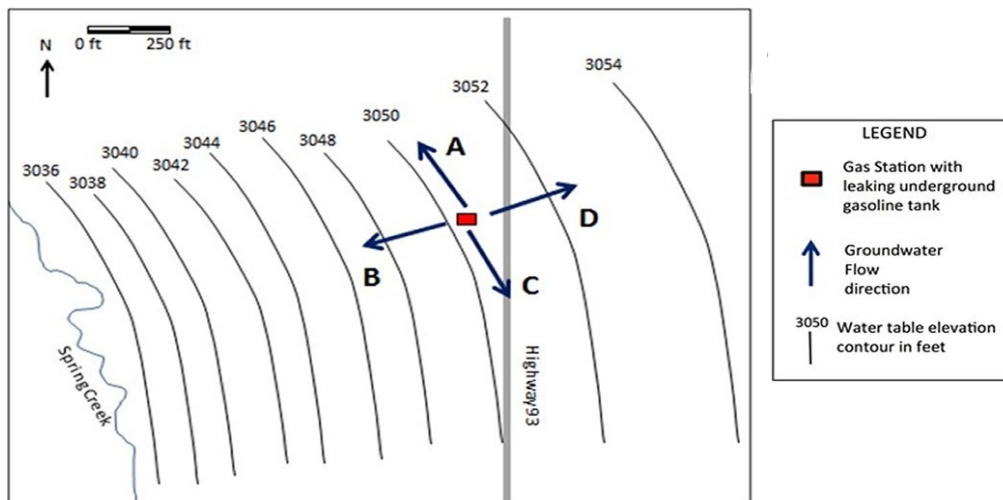
7. a. Which direction is Pine Creek flowing?
- b. Explain how you decided on your answer.

Comp Hydro Arizona: Student Pre-Assessment

8. a. Where is the slope of the land the steepest?
A. A
B. B
C. C
D. D
- b. Please explain why you chose that answer.

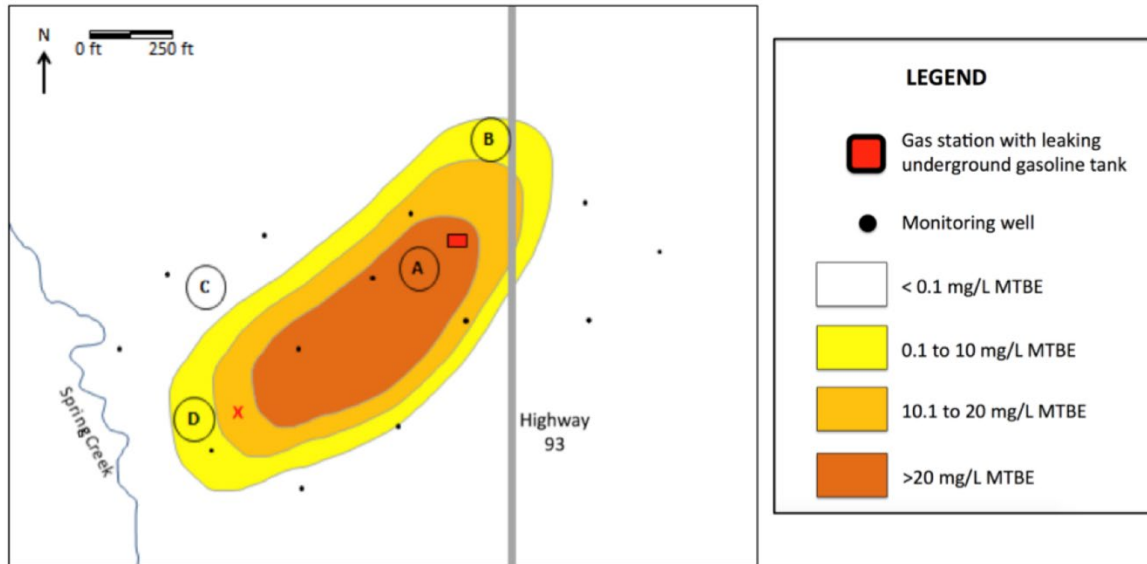
A gas station has been leaking gasoline from an underground storage tank. A chemical called MTBE that occurs in gasoline has been found to be contaminating the groundwater.

9. a. The map shows the site of the gas station and the water table elevation contours. Which of the four arrows on the map best shows the direction contamination will flow from the leaking storage tank? (Circle a response)
- A. Arrow A
B. Arrow B
C. Arrow C
D. Arrow D



- b. Please explain why contamination will flow in that direction.

The map below shows a computer-generated picture of the contamination (pollution) plume from the leaking storage tank. The plume map was created using MTBE concentration data from the monitoring wells on the map. Use this map for the following questions.



10. a. What would be a reasonable estimate of the concentration of MTBE from a groundwater sample taken from a well at the X? (Circle a response)

- A. 0.2 mg/L
- B. 3.0 mg/L
- C. 14 mg/L
- D. 31 mg/L

b. Please explain why your choice is the best estimate of concentration.

11. a. At which location would you be most uncertain about the concentration of MTBE modeled by the computer? (Circle a response)

- A. A
- B. B
- C. C
- D. D

b. Please explain why you are most uncertain about the concentration at that location.

12. a. How important is it to you that groundwater is protected in your community? (Circle a response)

- A. Not at all important

- B. Slightly important
- C. Moderately important
- D. Very important
- E. Extremely important

b. Please explain your reason for your answer.

13. a. How important is it to you that you understand how computer models can be used to address real world problems like groundwater contamination or flooding? (Circle a response)

- A. Not at all important
- B. Slightly important
- C. Moderately important
- D. Very important
- E. Extremely important

b. Please explain your reason for your answer.

14. Which of the following things do you think you could do? (Check all that apply)

- A. I could explain a map of groundwater contamination to someone else.
- B. I could use a computer groundwater model to decide if I could trust what someone else tells me about groundwater.
- C. I could use a computer groundwater model to show someone else how groundwater contamination is being cleaned up.
- D. I could use a computer groundwater model to predict where groundwater contamination is moving or how it is changing.

Establishing the Problem Overview

Introducing the Tucson International Airport Authority Superfund Site and The Tucson Airport Remediation Project

Situating this unit in the Tucson Airport Authority Superfund Site will provide motivation to learn about groundwater, connect what students learn to a situation that has and is affecting their community, and provide a context for learning and applying new understandings. The context will also let students raise important social justice issues related to the environment, water quality, and community action. Therefore, setting the scene and establishing the problems to be investigated and modeled is a critical first step in this unit.

Driving Question for the Unit: Where is the TCE and 1,4 Dioxane and how did it get here?

The answers to these questions are complex. This unit will address the science questions of where the contamination is and where it came from, how it got into the water and the wells, and how it moved through the groundwater. The unit will also address what is being done to clean up and monitor the water. The science questions are also intimately connected questions about who the contamination affected and why. The answers to those questions are embedded in issues of social injustices, both historical and present. Students will likely ask these questions during the unit. It is important to encourage students to see how the science questions are linked and the science answers can both empower and raise new issues.

Activity Label	Activity Description	Materials Needed
Pre-Assessment 40 minutes	Students take the unit pre-assessment.	Comp Hydro Pre-Assessment
Mapping the Problem 20 minutes	Students look at maps of disease occurrences from 1965-1985 and read a newspaper article about contaminated wells. Students are introduced to TCE and 1,4 Dioxane.	<ol style="list-style-type: none"> AZ Daily Star Article: May 2017 South-side Tucsonans Mobilize for Another Water-Pollution Struggle https://tucson.com/news/local/south-side-tucsonans-mobilize-for-another-water-pollution-struggle/article_25aafd92-3a5a-5550-bbd6-9fc0d02cd0dd.html Cancer Rates TCE Map https://www.newspapers.com/clip/18749277/arizona_daily_star/ Establishing the Problem Teacher page
Community Videos 10 minutes	Students watch brief video clips of community members talking about their experiences with disease and tainted wells.	Video clips <ol style="list-style-type: none"> What the Water Gave Me https://vimeo.com/71819153

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Activity Label	Activity Description	Materials Needed
Groundwater Flow Model 10 - 15 minutes	Students look at a simulation using the Groundwater Flow Model to see how contaminants (solvents containing TCE and 1,4 Dioxane) could migrate into private wells.	Groundwater flow model and associated pumps and dyes. Requires advanced set-up of the model.
Introduction of the Driving Question 5-10 minutes	Students discuss questions they have about what they have read and observed. Questions are raised about where the contamination is now, how it got there, and how it is being cleaned up. Class is introduced to driving question and the outline for the upcoming unit: 1. Where is the contamination? 2. What is the shape of the water table? 3. How does groundwater flow? 4. What is being done?	Establishing the Problem Student Page

Establishing the Problem

Time: 20 minutes

The article could be used as bell work.

1. Introduce the Comp Hydro Unit and the water pollution problem by asking students if they have heard of the Tucson Airport Remediation Project (TARP) or groundwater pollution in the Tucson area.
2. Have students read the May 16, 2017 article on 1,4 Dioxane contamination titled “South Side Tucsonans Mobilize for Another Water Pollution Struggle.” For struggling readers, emphasize that they should read at least the first page of text. https://tucson.com/news/local/south-side-tucsonans-mobilize-for-another-water-pollution-struggle/article_25aafd92-3a5a-5550-bbd6-9fc0d02cd0dd.html
3. Project the map of cancer rates. https://www.newspapers.com/clip/18749277/arizona_daily_star/
4. Have students discuss, in small groups, the following questions about the article and map. The questions and space to write answers are on the student page.
 - a. Why is Linda Robles worried about the water?
 - b. What are some patterns that you notice on the map?
 - c. What questions does this situation raise for you? What do you want to know more about?
5. Have student groups share some of their questions with the class.
6. Review for students a brief history
 - a. In the 1950s, residents on the south side of Tucson began noticing high incidences of cancer and other serious diseases.
 - b. TCE (Trichloroethylene) and 1,4 Dioxane are chemicals were found in the groundwater.
 - c. Residents sued the City of Tucson to get the water cleaned up.
 - d. Currently, both TCE and 1,4 Dioxane are being removed from the water. No one is currently drinking contaminated water.

Community Video

Time: 10 minutes

Show the video: What the Water Gave Me by Maya Castillo

<https://vimeo.com/71819153>

This clip is about 4 minutes long. It is powerful and draws explicit attention to the social justice issues involved in the TIAA Superfund contamination.

Questions to ask

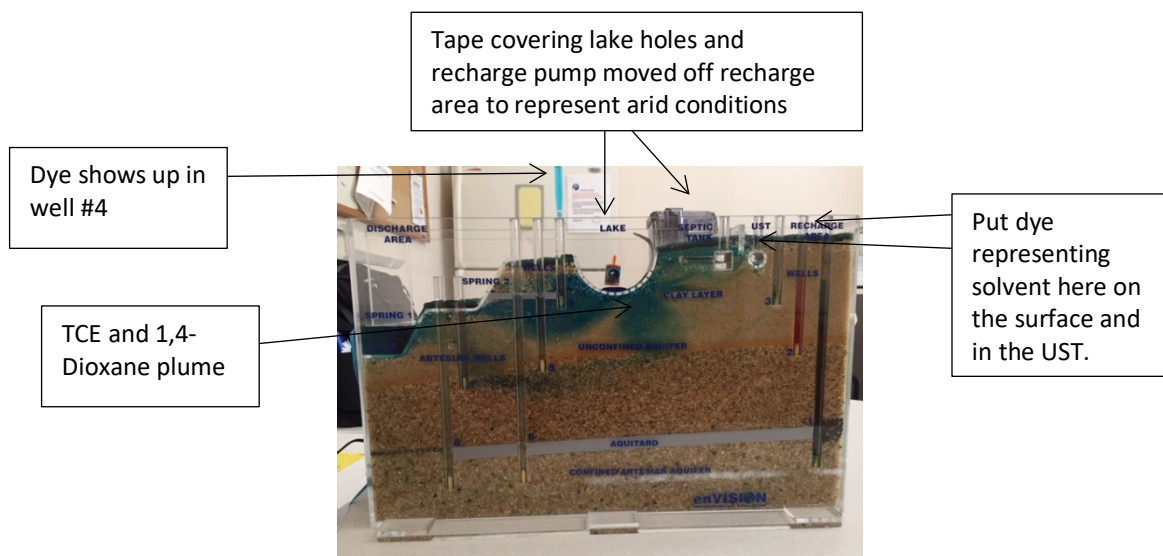
1. Have you heard of this situation before? What do you know?
2. Do you have any family members or friends who were affected by this problem?
3. What stories have you heard?
4. How and why is it that this community is affected by this pollution? Why are other parts of Tucson not affected?

Groundwater Flow Model

Time: 10-15 minutes

Preparation: (Set up model before class)

1. Set up the model according to the manufacturer's directions.
2. Before setting up the model, place electric tape over the holes in the lake so that the lake does not fill. This will make the model behave more like an arid environment.
3. Follow the directions on the groundwater flow model video to set up the simulator.



Model of the TIAA Context

TIAA Superfund Site Demonstration

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1. Introduce the model. Briefly show the recharge zones, the wells, the river.
2. To model the contamination in the TIAA Superfund Site
 - a. Move the recharge pump away from the recharge zone. This situation simulates the Tucson area during most of the year when there is little groundwater recharge.
 - b. Insert a bulb syringe into well #4. This well represents a municipal well. Pump some water out to show that it is clear.
 - c. Put some dye directly on the green sponge in the recharge zone. Observe what happens to it. It should mostly sit in the green sponge and a small bit may infiltrate into the top of the coarse sand.
 - d. Move the recharge pump back to the recharge zone to let some water flow into the model. Observe what happens to the dye. It should begin to move down and to the left.
 - e. Periodically move the recharge pump on and off the recharge zone to simulate episodic monsoon storms that infiltrate rapidly into the groundwater system.
 - f. Periodically pump from well #4. Eventually, the water from well four will turn the color of the dye.
 - g. You can also put some dye in the UST (underground storage tank) and follow it's pathway the same way.

Questions to ask during demonstration

1. Where is the groundwater? How does it move?

The groundwater fills the pores between the grains of sand and gravel. The groundwater moves through the connected pore spaces. It is important that students see that groundwater is not an underground lake or river.
2. How did the contamination get into well #4?

The contamination was solvents spilled directly onto the ground or stored in leaking tanks (on the surface and underground). This solvent soaked into the ground. When it rained, it mixed with the rainwater and infiltrated into the ground, eventually flowing with the groundwater into the area of the wells. The wells then pumped the contaminated water out of the ground.

Introduction of the Driving Question

Time: 5-10 minutes

Lead a closing discussion that sets up the driving question for the unit.

1. Ask students: What questions does this raise for you? What do you want to know more about?
2. **Introduce the driving question for the unit: Where is the TCE and 1,4 Dioxane and how did it get here?**
3. Provide a brief outline for the upcoming weeks
 - a. Where is the contamination?
 - i. We will be learning about how computers can map where the contamination is.
 - b. What is the shape of the water table?
 - i. To understand better where the contamination is located, we will be using computer models to help us visualize the water table underground.
 - c. How does groundwater flow?

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- i. To help us understand how the contamination got where it is, we will be using computer models to show how the contamination moves underground.
- d. What is being done?
 - i. At the end of the unit we will take a field trip to the water treatment plant to learn how Tucson Water removes the contamination from the groundwater.

TARP Online Resources

Arizona Department of Environmental Quality

https://azdeq.gov/environ/waste/sps/Tucson_Airport_Remediation_Project.html#ir

US EPA

<https://www.epa.gov/superfund/search-superfund-sites-where-you-live>

Tucson Water

https://www.tucsonaz.gov/files/water/docs/AOP_TARP_educational_signs.pdf