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

Closure
Addressing the Problem

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Addressing the Problem

Driving Question for the whole unit: How and why is this community affected by the TCE and 1,4 Dioxane pollution?

Below are some ideas for closing the unit. The goal would be to provide students with an opportunity to see how the three modules fit together; reflect on the major hydrologic, data interpretation, and computational thinking concepts they learned; and bring closure to their exploration of the TARP site.

Activity Label	Activity Description	Materials Needed
TARP and AOP	Students can learn about how Tucson Water and the other various agencies and entities are remediating the contamination, including learning about how the TARP and AOP plants work. A culminating activity could be a field trip to the TARP and AOP.	Web links about TARP and AOP https://www.tucsonaz.gov/water/aop https://www.tucsonaz.gov/files/water/docs/AOP_TARP_educational_signs.pdf

Field Trip to Advanced Oxidation Treatment Plant

Now that students have learned that the best way to clean up the TCE and 1,4 dioxane contamination is through the pump and treat method, they will have a chance to see how this process works on a field trip to the Advanced Oxidation Treatment Plant.

Driving Question: How does Tucson Water clean up the TCE and 1,4 dioxane contamination?

To arrange for a field trip to the Advanced Oxidation Treatment Plant, contact Tucson Water Public Information/Conservation Office (PICO) at (520) 791-4331 or e-mail pico@tucsonaz.gov.

For student who go on the field trip

1. TARP AOP Questions: Cleaning up the Groundwater in Tucson

For students who do not go on the field trip

Students who do not go on the field trip can complete the same questions using the signs that Tucson Water developed for the field trip.

1. TARP AOP Questions: Cleaning up the Groundwater in Tucson
2. Field Trip Signs https://www.tucsonaz.gov/files/water/docs/AOP_TARP_educational_signs.pdf

Name:

Cleaning up the Groundwater in Tucson

Because you have studied about the TCE problem, your friends and family may ask you how the TCE and 1,4 dioxane are removed from the water. Whether you went on the tour to TARP and AOP or read the field trip signs, you should be able to explain how this process works. Here are some questions your friends and family may ask you. Please write down what you would say to them.

1. What is the difference between the TARP water treatment plant and the AOP water treatment facility?

2. Why does Tucson have both water treatment plants?

3. What do the air stripper towers do at the TARP plant?

4. What is the first thing that happens when the water gets to the AOP?

5. What happens to the TCE and 1,4 dioxane in the AOP? How does this happen?

6. When the TARP plant was the only water treatment plant here, where did the TCE go?

7. Where does the water cleaned at the AOP and TARP go? What parts of Tucson drink it?

8. What questions do you have about the TARP or AOP facilities?

9. Ask your question in #8 and write down the answer here.

Action

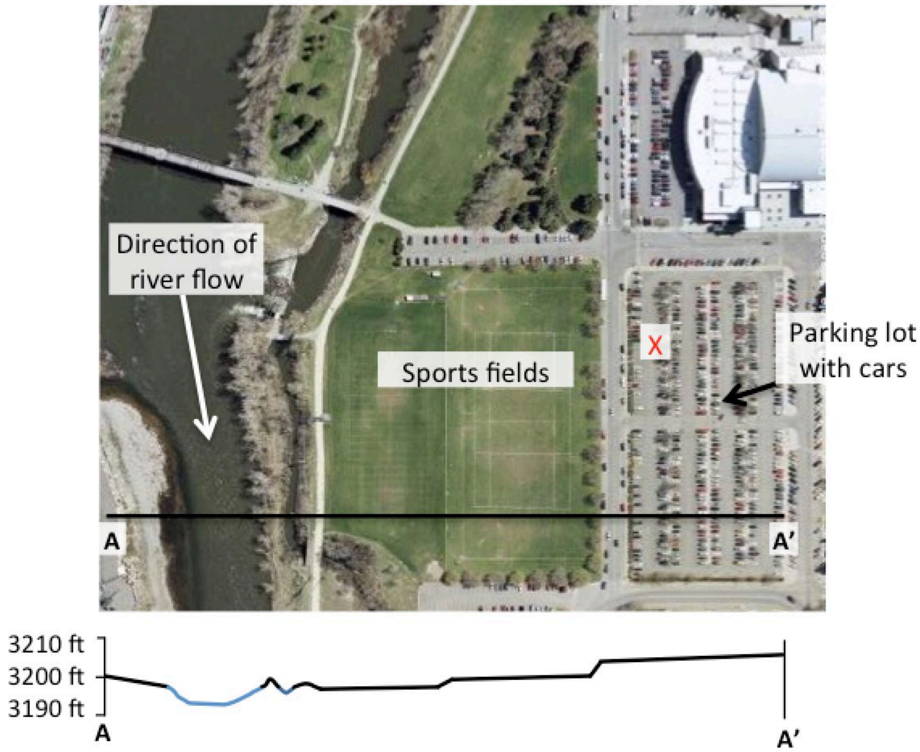
Driving Question: How and why is this community affected by the TCE and 1,4 Dioxane pollution and what can be done?

Students can choose from the following options to take action by producing a product that documents their learning and educates others:

1. Make a video clip
2. Write a newsletter or article
3. Create and deliver a presentation to the Unified Community Action Board (UCAB)
4. Free choice

Post 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.



Surface profile along line A-A'

SPORTS FIELD (Pre & Post)

1. Could water falling on the sports fields as rain get into the river?
    a. (Choose 1) 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.

PARKING LOT (Pre & Post)

2. Could water falling on the parking lot as rain at the location marked with the X get into the river?
    a. (Choose 1) 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.

Computer Modeling Items (Modeling-C)

MODELS QUESTIONS (Pre & Post)

3. 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.

MODELS PROBLEMS (Pre & Post)

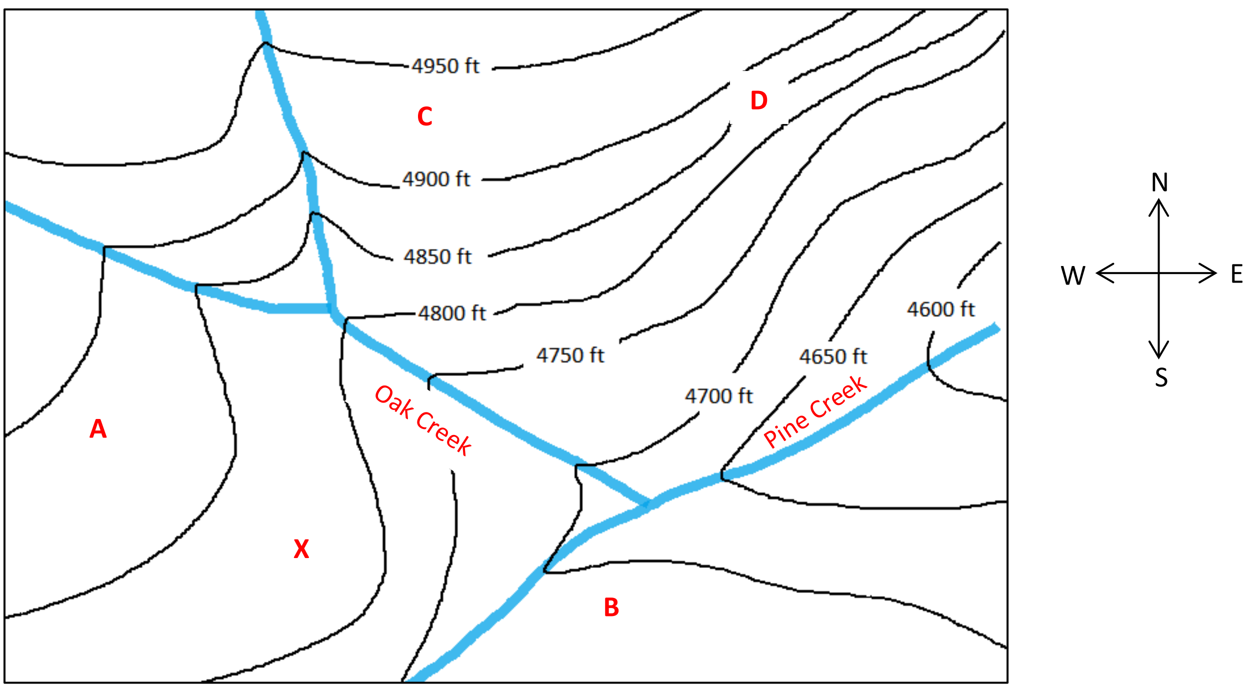
4. What are some problems with using a computer model to understand a real world water problem?

MODELS EVALUATION (Pre & Post)

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

Surface Elevations (Map interpretation and Data Interpolation –D)

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

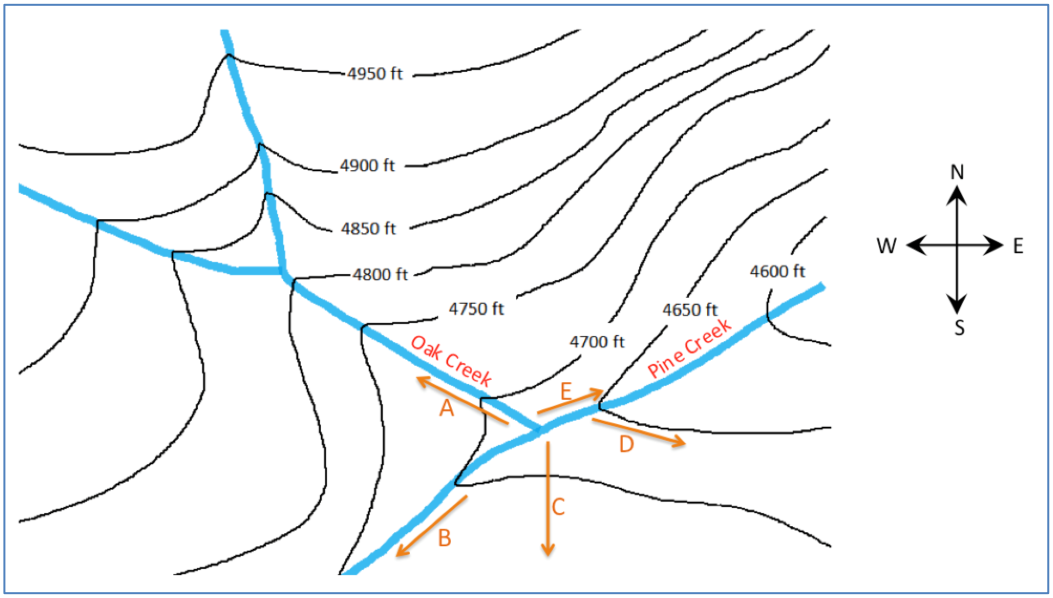


TOPO INTERPOLATION (Pre & Post)

6. a. What would be a reasonable estimate for the elevation of the land surface at the X on the map?
      A. 4800 ft
      B. 4850 ft
      C. 4815 ft
      D. 4765 ft

   b. Please explain why you chose that answer.

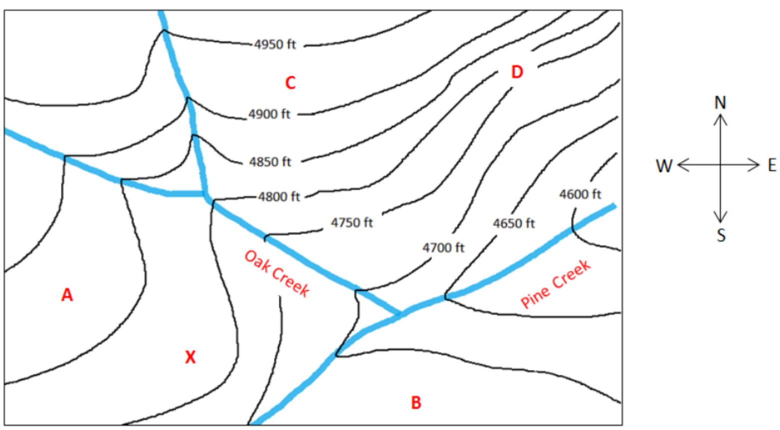
PINE CREEK FLOW (Pre & Post)



7. a. Which arrow or arrows show the direction that Pine Creek is flowing? (Choose one or more arrows.)

   b. Explain why the arrow or arrows you chose show the direction Pine Creek flows.

TOPO GRADIENT (Pre & Post)

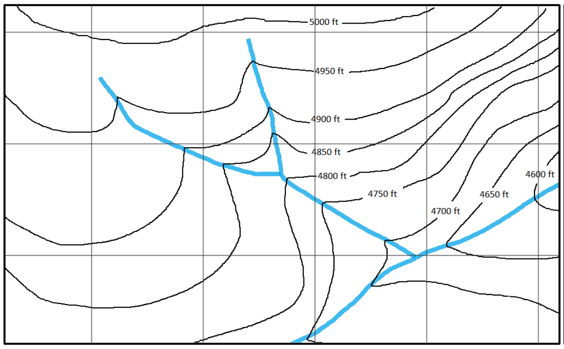


8. a. Where is the slope of the land the steepest?
   A. A
   B. B
   C. C
   D. D

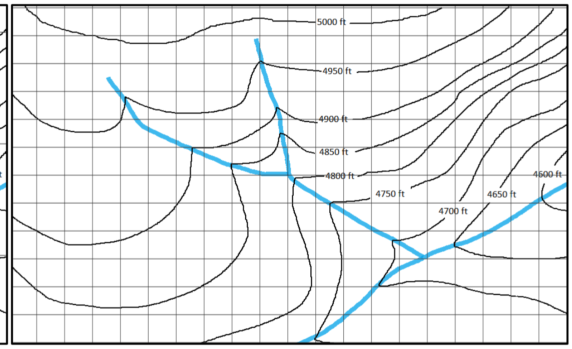
   b. Please explain why you chose that answer.

Map Discretization/Sampling (C)

The diagram below shows two different grids to divide the map into cells to develop a computer model of water flow. Use this diagram for the questions below.



Grid A



Grid B

TOPO GRIDS (POST ONLY)

9. What is the purpose of dividing the area into cells?

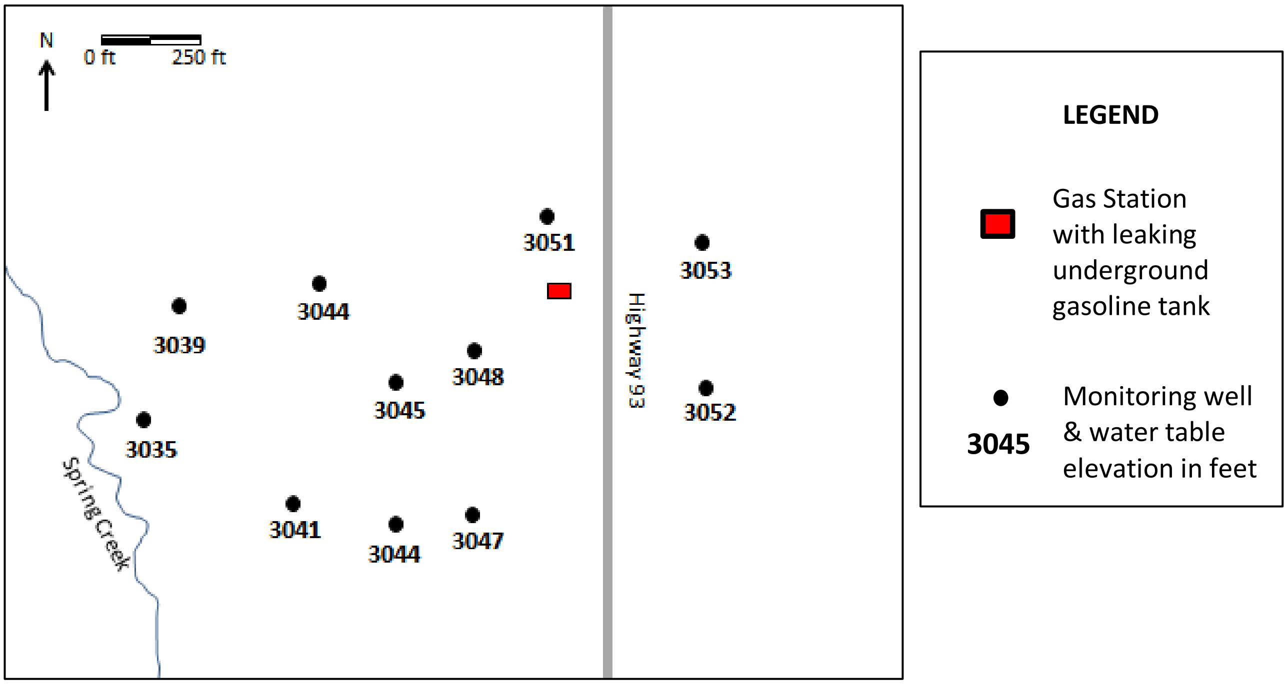
GRID B (POST ONLY)

10. Give at least one advantage and one disadvantage of using Grid B (smaller cells) for your computer model.
    a. Advantage:
    b. Disadvantage:

Groundwater Items

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.

Water Table Elevation Contour Interval: (Discretization – C)



RONAN CONTOUR INTERVAL (Post only)

11. a. The map above shows the location of the gas station and some monitoring wells. The numbers next to the wells show the elevation of the water table. What groundwater elevation contour interval would be the best choice for making a contour map of the water table?

    A. 0.2 foot
    B. 2 feet
    C. 20 feet
    D. 200 feet

    b. Please explain why your choice is best for showing groundwater elevation on this map.

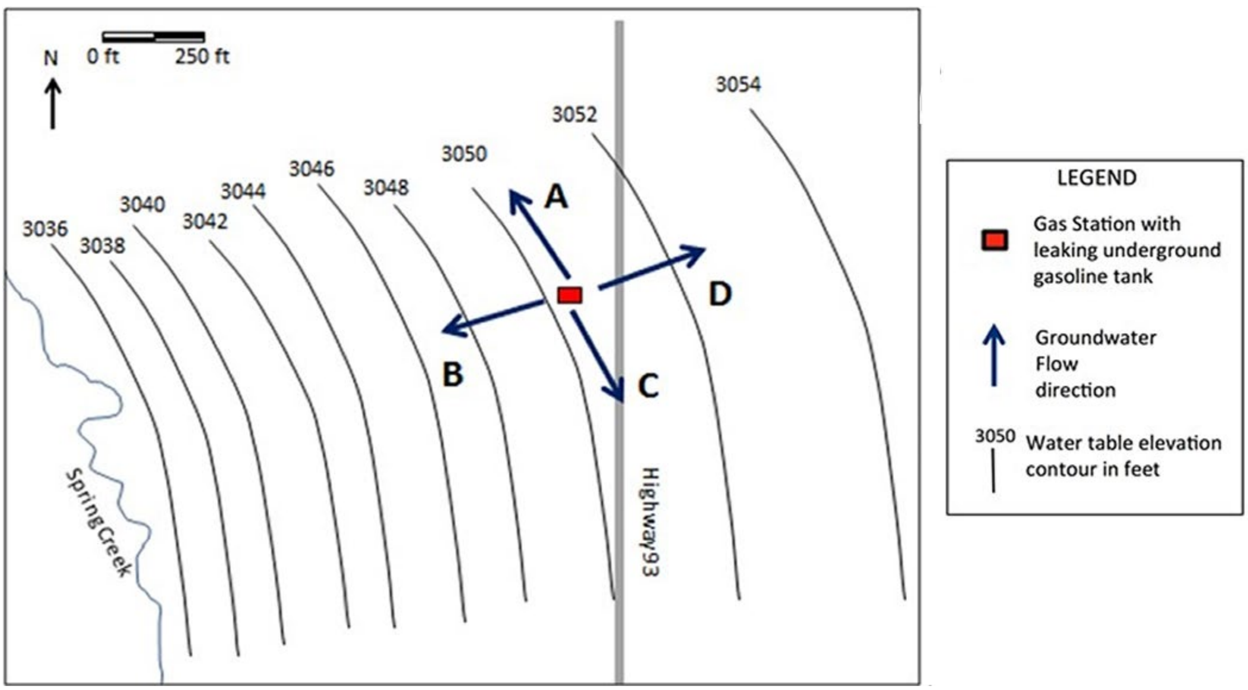
<u>Water Flow (Tracing groundwater and contamination, water table, potential energy - H)</u>

RONAN WATERFLOW ARROWS (Pre & Post)

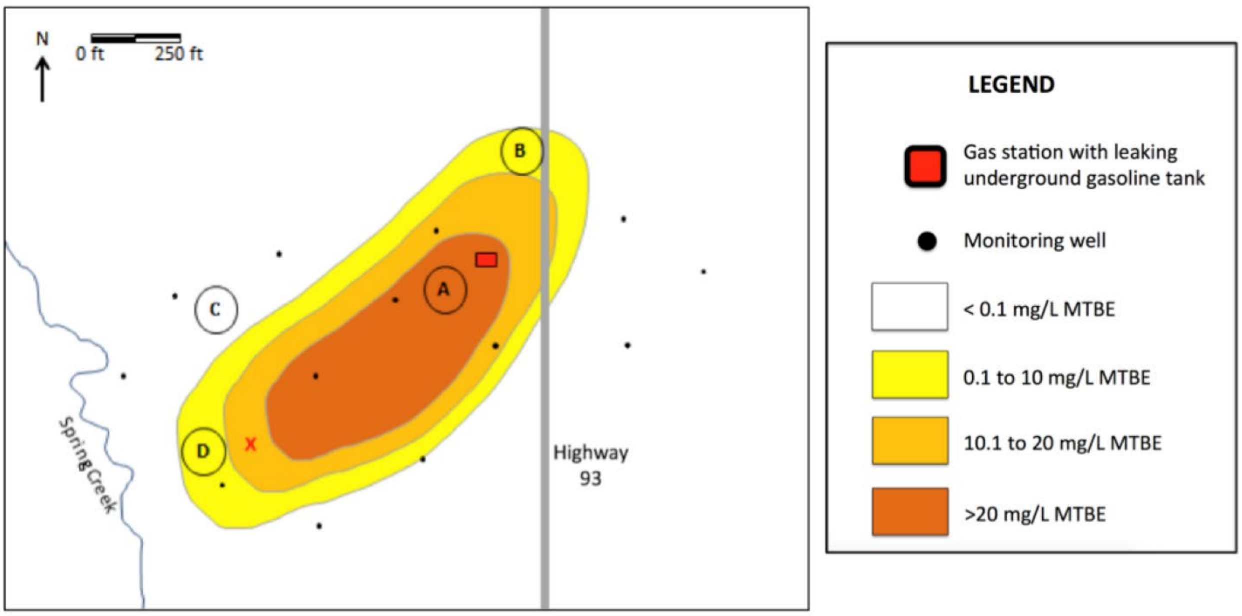
12. a. The map below shows the site of the gas station and the water table elevation contours. Which of the four arrows on the map best shows the direction contamination will flow from the leaking storage tank?

    A. Arrow A
    B. Arrow B
    C. Arrow C
    D. Arrow D

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



<u>Ronan Contamination Plume Map: (Interpolation & Uncertainty- D)</u>
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.



RONAN INTERPOLATION (Pre & Post)

13. a. What would be a reasonable estimate of the concentration of MTBE from a groundwater sample taken from a well at the X?

    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.

RONAN UNCERTAINTY (Pre & Post)

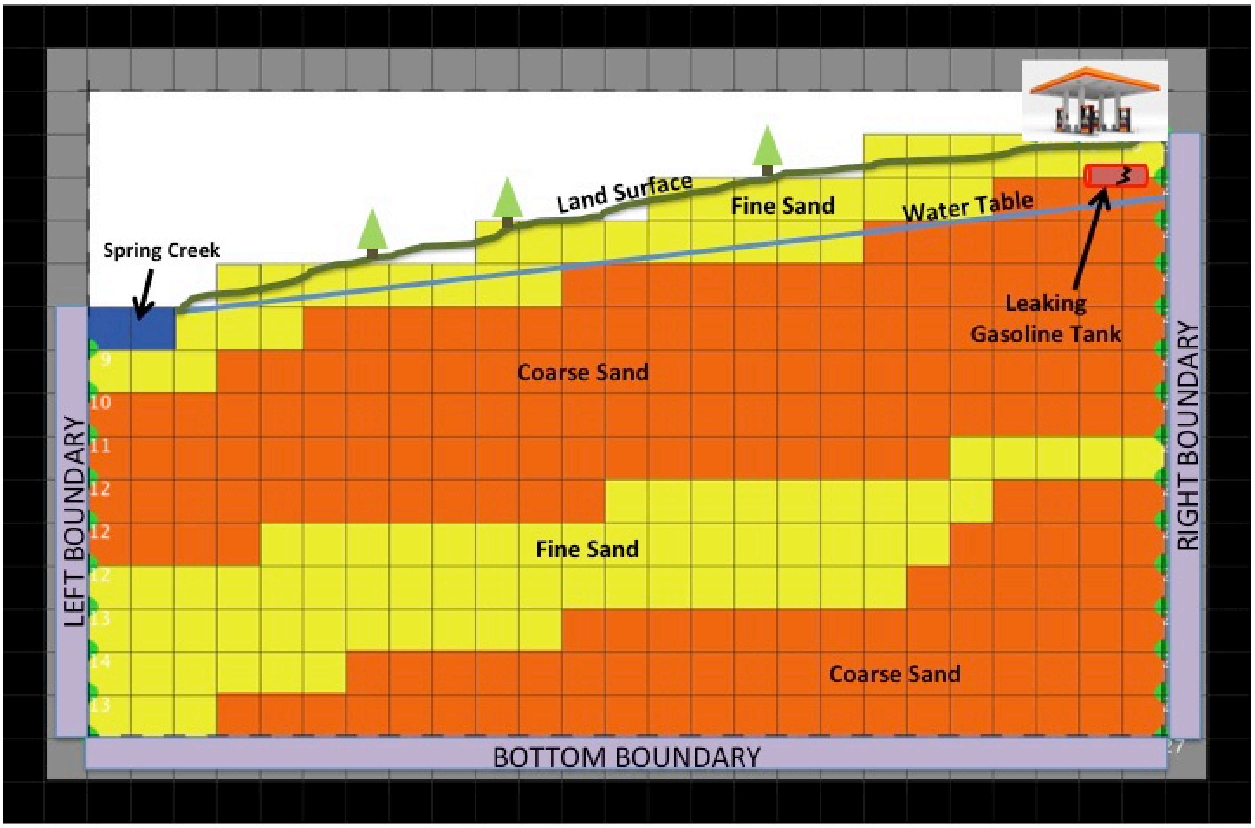
14. a. At which location would you be most uncertain about the concentration of MTBE modeled by the computer?

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

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

Ronan Model Parameterization (Parameterization – C)

The image below shows a cross-section of the area where the underground gasoline tank is leaking. A grid has been applied over the cross-section to begin making a computer model of the gasoline spill.

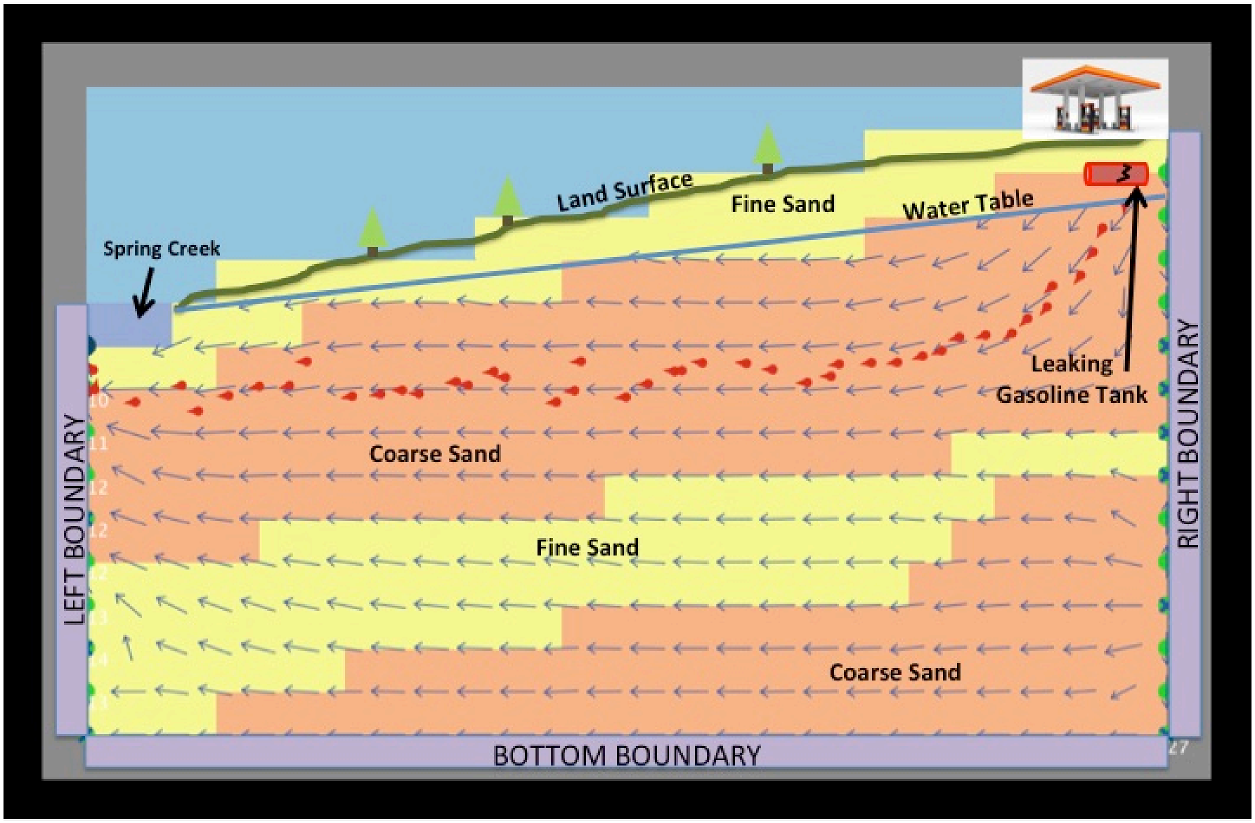


RONAN PARAMETERS (POST ONLY)

15. a. What information about each cell in the grid would be needed to compute and predict the flow of water and MTBE through the system?

    b. Please explain why each type of information (parameter) you listed is important.

Ronan Cross-Section Model (Tracing water and contamination – H)
The image below is of a computer model showing the MTBE contamination plume from the leaking gasoline tank.



RONAN WATER FLOW (POST ONLY)

16. Explain why the MTBE contamination will flow through the ground as shown.

GROUNDWATER CARING (PRE & POST)

17. a. How important is it to you that groundwater is protected in your community?
    - 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.

MODELING IMPORTANCE (PRE & POST)

18. 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?
    - 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.

19. Pre & Post – 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.

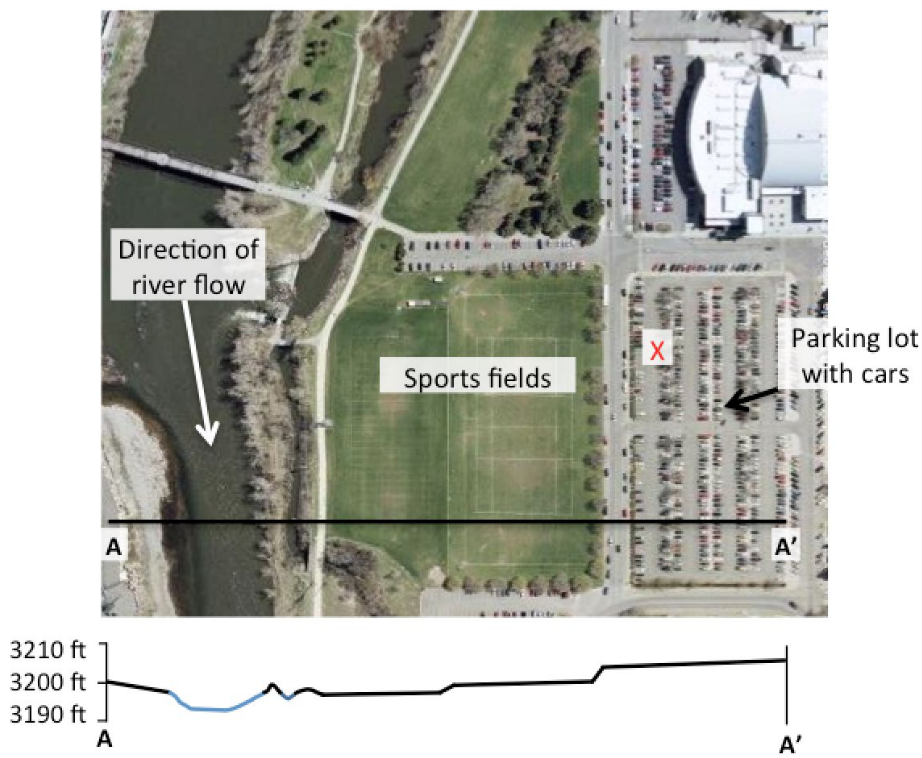
Comp Hydro Arizona Assessment and Teacher Guide

Note about this guide: This key provides 1) a description of purpose, 2) characteristics of model-based Goal model-based responses, and 3) examples of emergent scientific responses for each assessment question. The key is designed to help teachers examine students' ideas and how they change from pre to post assessment. While this is not explicitly a "grading key" with suggestions for points to award for different questions or responses, teachers are welcome to grade the assessments and provide points as best fits their own instructional grading systems.

Hydrology Items (H)

Purpose: These items assess students' how students trace and explain water moving through connected systems (surface and groundwater) using a combined map and cross section view representation.

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.



Surface profile along line A-A'

SPORTS FIELD (Pre & Post)

1. Could water falling on the sports fields as rain get into the river?
   a. (Choose 1) 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.

Goal model-based responses: Yes. Water that falls on the sports field could get into the river through a combination of surface runoff (because the river is at a lower elevation than the field) and groundwater infiltration and flow (because the soil below the grass is permeable – water could infiltrate through the grass and soil to the water table and flow into the river from underground). Students may also mention evaporation or evapotranspiration.

Look for mechanistic explanations that involve things like differences in elevation or potential energy, gravity, and permeability as governing water flow from surface, across or through ground, and into the river.

Examples of emergent scientific reasoning: Students may offer…

- proximity (nearness) as a reason why water could move from the field to the river
- improbable mechanisms for movement of water (wind, people)
- ideas about things that block the water from moving (e.g., surface features such as rocks or roads)

PARKING LOT (Pre & Post)

2. Could water falling on the parking lot as rain at the location marked with the X get into the river?

a. (Choose 1) 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.

Goal model-based responses: Yes. Water that falls on the parking could get into the river through a combination of surface runoff (because the river is at a lower elevation than the field) and/or engineered drainage. Parking lots are usually graded to drain in certain directions – for example to a grassy area where water can infiltrate or to a drain grate. Parking lot drainage grates often channel water to groundwater or to surface water features such as a detention pond, creek, or river. Students may also mention evaporation.

Look for mechanistic explanations that involve things like differences in elevation or potential energy, gravity, and permeability as governing water flow from surface, across or through ground, and into the river.

Examples of emergent scientific reasoning: Students may offer…

- proximity (nearness) as reason why water could move from the parking lot to river
- improbable mechanisms (wind)
- ideas about things that block the water from moving (e.g., surface features such as rocks). Note that human engineered structures (e.g., curbs) might be used to direct water movement. More sophisticated responses will tend to trace water across connected systems with reasonable mechanisms whereas emergent scientific responses might just leave water at a dead end.

Computer Modeling Items (Modeling-C)

The **purpose** of these questions is to find out how students conceptualize what a computational model is and how they are used.

MODELS QUESTIONS (Pre & Post)

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

Goal model-based responses: Some reasonable responses include:

- To define or better understand a system and how it works using a quantitative approach
- To test and/or predict what will happen in a system (using a "virtual" approach that is often more efficient/quick/cheap than conducting such tests in the real world. Sometimes it is not possible or feasible to conduct similar tests in the real world.)
- To develop and test solutions to problems (e.g., examine the computed effectiveness of different remediation methods for addressing groundwater contamination)
- To produce a visual representation of a computer output that can be used for communicating
- Issues of confidence, validity, accuracy, or uncertainty may come up – with students acknowledging that there is a need and are methods for judging these qualities of computer models

Examples of emergent scientific reasoning:
Many students indicate that computer models are used to see or visualize something. While this is not incorrect, it seems to be a more intuitive and often vaguely worded type of response that students provide when they have little detailed understanding of what a computer model is or what it does. Students may also use the word "simulate" without any explanation of what that means or involves when using a computer model.

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.

Goal model-based responses: More sophisticated responses will address finding solutions to a problem by using computer models to do things like make predictions and test hypotheses. They may also identify a problem that requires quantification and calculations to solve.

Examples of emergent scientific reasoning: Emergent scientific responses may name problems without elaboration as to how a computer model would be useful in addressing it. Mid-level responses may describe a real-life problem or pose a how or why question that is answered by a visualization or a simulation rather than a computational model.

MODELS PROBLEMS (Pre & Post)

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

Goal model-based responses: More sophisticated responses may indicate that computer models rely on data and that not all relevant or sufficient data may be included in the model or that the data may be incorrect or incomplete. Other potential problems could include that the model is missing important variables (parameters) or is not sufficiently calibrated.

Examples of emergent scientific reasoning: Emergent scientific responses may explain that computers can crash, have 'bugs,' or be wrong or inaccurate (without an underlying cause such as insufficient data or missing parameters). Sometimes students mention that computer models can be difficult to understand.

MODELS EVALUATION (Pre & Post)

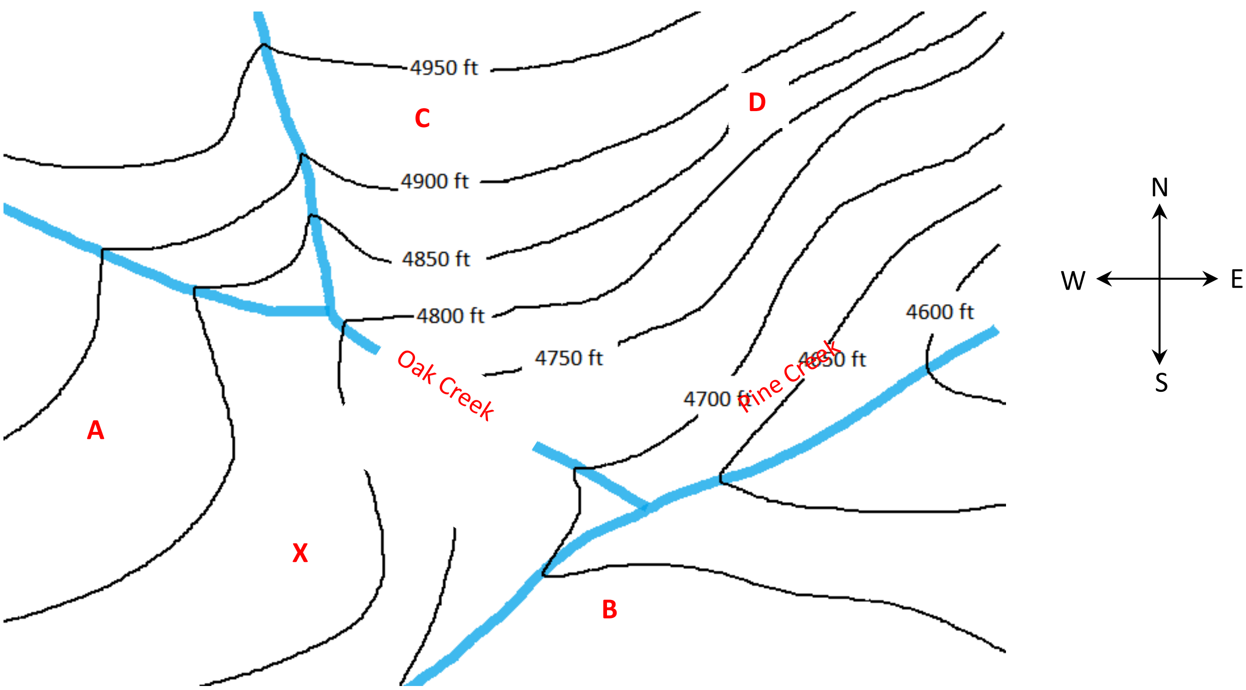
5. How can a scientist judge if a computer model is accurate?

Goal model-based responses: More sophisticated responses may indicate that to judge if a computer model is accurate the output from the model should be compared to or calibrated against real-world data and observations from the field. Calibration is a key method addressed in the unit; however, students may also mention approaches such as comparing with previous studies and findings from other scientists.

Examples of emergent scientific reasoning: Emergent scientific responses may suggest a scientist can judge if a computer model is accurate by using common sense, doing the math, getting a second opinion, or making a real (physical) model and comparing it to the computer model.

<u>Surface Elevations (Map interpretation and Data Interpolation –D)</u>

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



TOPO INTERPOLATION (Pre & Post)

6. a. What would be a reasonable estimate for the elevation of the land surface at the X on the map?
   A. 4800 ft
   B. 4850 ft
   C. 4815 ft
   D. 4765 ft

   b. Please explain why you chose that answer.

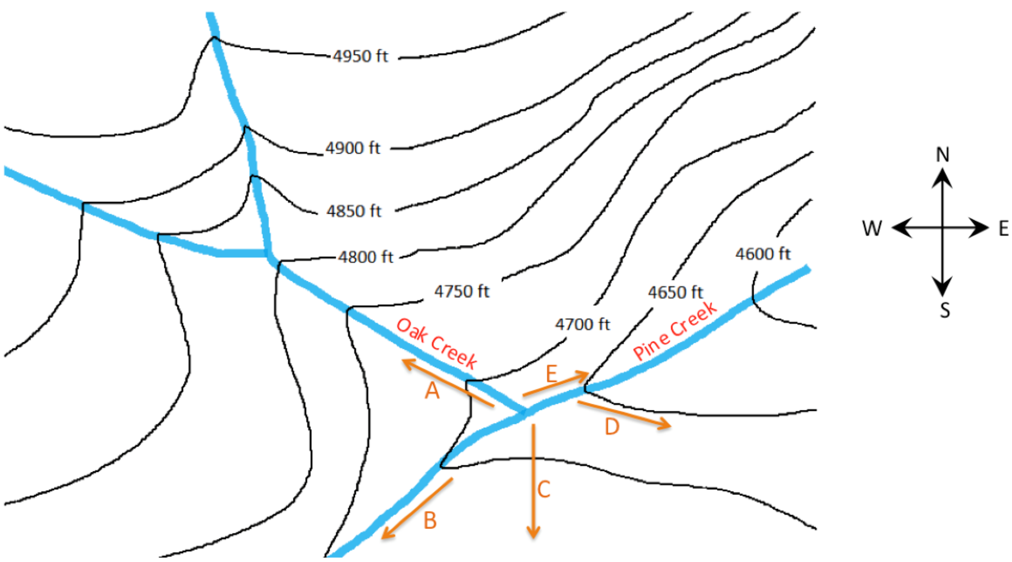
Purpose: This question assesses student understanding of contours and interpolation of data.

Goal model-based responses: Responses correctly identifies 4815 as the most reasonable answer and describes a process for interpolating between 4800 ft. and 4850 ft. Ideally, responses include an indication that the contour lines connect points of equal elevation.

Examples of emergent scientific Reasoning: Least sophisticated responses may be quite vague with no reference to elevations. More sophisticated responses indicate that the contour lines dip down, point down or slope downwards. They may read across the map directly rather than following a contour line. Answers may suggest that contours are like steps and the area between the contours is the same elevation as the closest contour line.

PINE CREEK FLOW (Pre & Post)

Purpose: These questions assess data visualization and student ability to interpret 3D space from 2D representation.



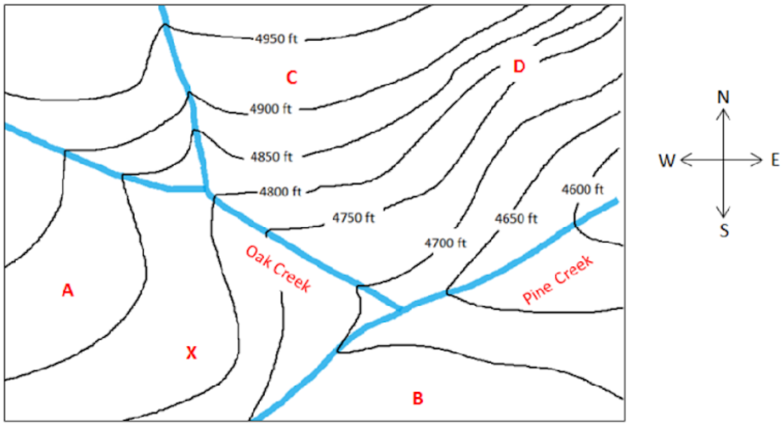
7. a. Which arrow or arrows show the direction that Pine Creek is flowing? (Choose one or more arrows.)

   b. Explain why the arrow or arrows you chose show the direction Pine Creek flows.

Goal model-based responses: Indicates that water flows northeast or north or east, with an explanation that recognizes that the land slopes down in elevation in that direction or references water flowing downhill and/or gravity.

Examples of emergent scientific Reasoning: Least sophisticated answers provide indicate that water flows south or down the page. May provide a reference to the compass rose. More emergent responses refer to school rules like the rule of Vs.

TOPO GRADIENT (Pre & Post)



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.

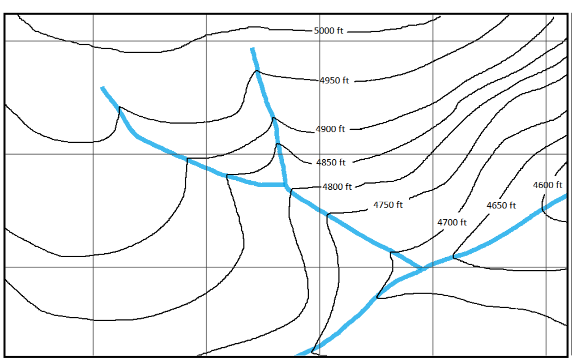
Goal model-based responses: Answer D with an explanation that identifies that the contour lines are closest together, ideally indicating that this is the shortest rise over run.

Examples of emergent scientific Reasoning: Emergent scientific answers state that the land is going down, refers to the contour lines as pointing downwards, or references contour lines that are curvier.

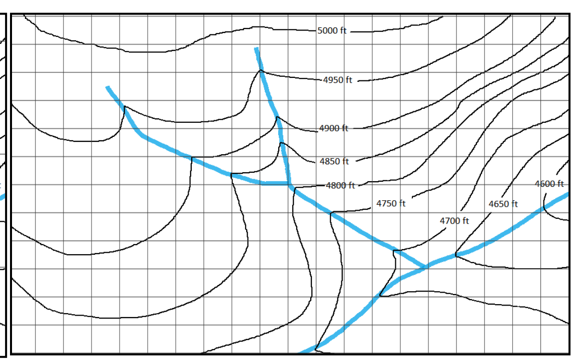
<u>Map Discretization/Sampling (C)</u>

Purpose: These items are computational thinking principles related to discretization.

The diagram below shows two different grids to divide the map into cells to develop a computer model of water flow. Use this diagram for the questions below.



Grid A



Grid B

TOPO GRIDS (POST ONLY)

9. What is the purpose of dividing the area into cells?

Goal model-based responses: Indicate that the cells are useful for modeling data, entering data into a model, or organizing data.

Examples of emergent scientific Reasoning: States that the cells contain information or are used to pinpoint locations. Least sophisticated responses refer to the cells as enabling one to "see" something on the map.

GRID B (POST ONLY)

10. Give at least one advantage and one disadvantage of using Grid B (smaller cells) for your computer model.
    a. Advantage:
    b. Disadvantage:

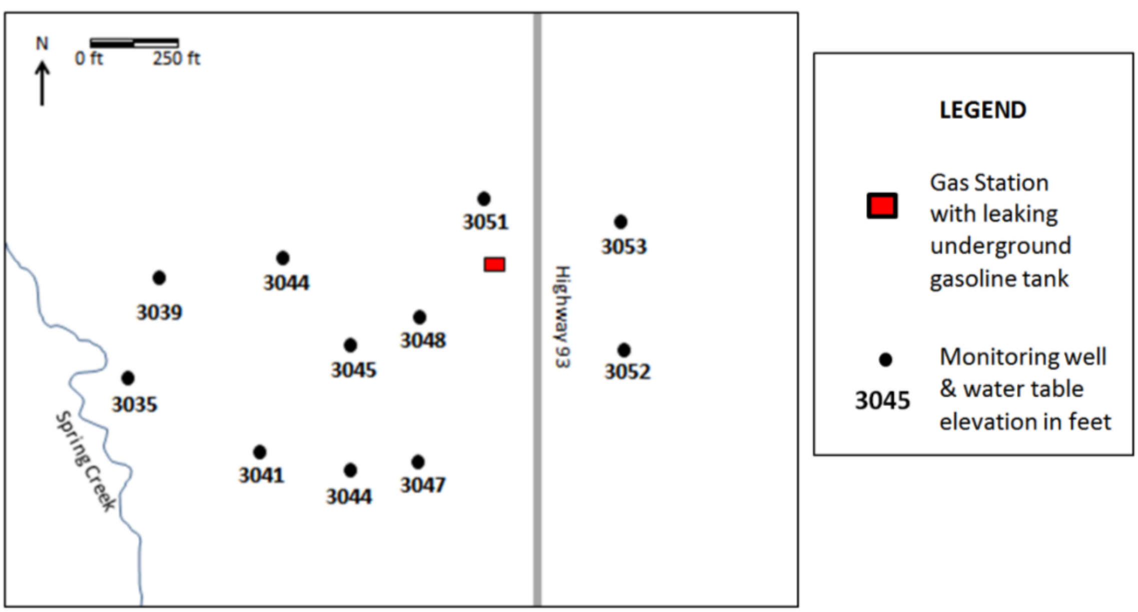
Goal model-based responses: Ideal responses include indication that discretization is about breaking up a continuous surface or continuous data into chunks for the computer to work with. They also suggest that large cells might have too much information and it is harder to decide what information to include in each cell but also that small cells require more data to work with and that more data requires more effort on the part of the computer model.

Examples of emergent scientific Reasoning: Emergent scientific responses focus on advantages and disadvantages for seeing better or more clearly or are related to accuracy.

Groundwater Items

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.

<u>Water Table Elevation Contour Interval: (Discretization – C)</u>



RONAN CONTOUR INTERVAL (Post only)

11. a. The map above shows the location of the gas station and some monitoring wells. The numbers next to the wells show the elevation of the water table. What groundwater elevation contour interval would be the best choice for making a contour map of the water table?

    A. 0.2 foot
    B. 2 feet
    C. 20 feet
    D. 200 feet

    b. Please explain why your choice is best for showing groundwater elevation on this map.

Purpose: This question examines how students make sense of a data representation – in particular, how do you choose a scale (i.e., contour interval) that is appropriate to effectively communicate information about a system in a visual representation.

Goal model-based responses: More sophisticated student reasoning generally indicates that 2 ft. is the best choice based on the scale of the data shown. Students may note that using a 0.2 foot interval would give more contour lines than are needed to understand the data and the 20 and 200 ft. levels would give too few contour lines.

Examples of emergent scientific reasoning: Emergent scientific responses may be guesses or not provide a reason for their choice that takes into account the scale of the water table elevation values.

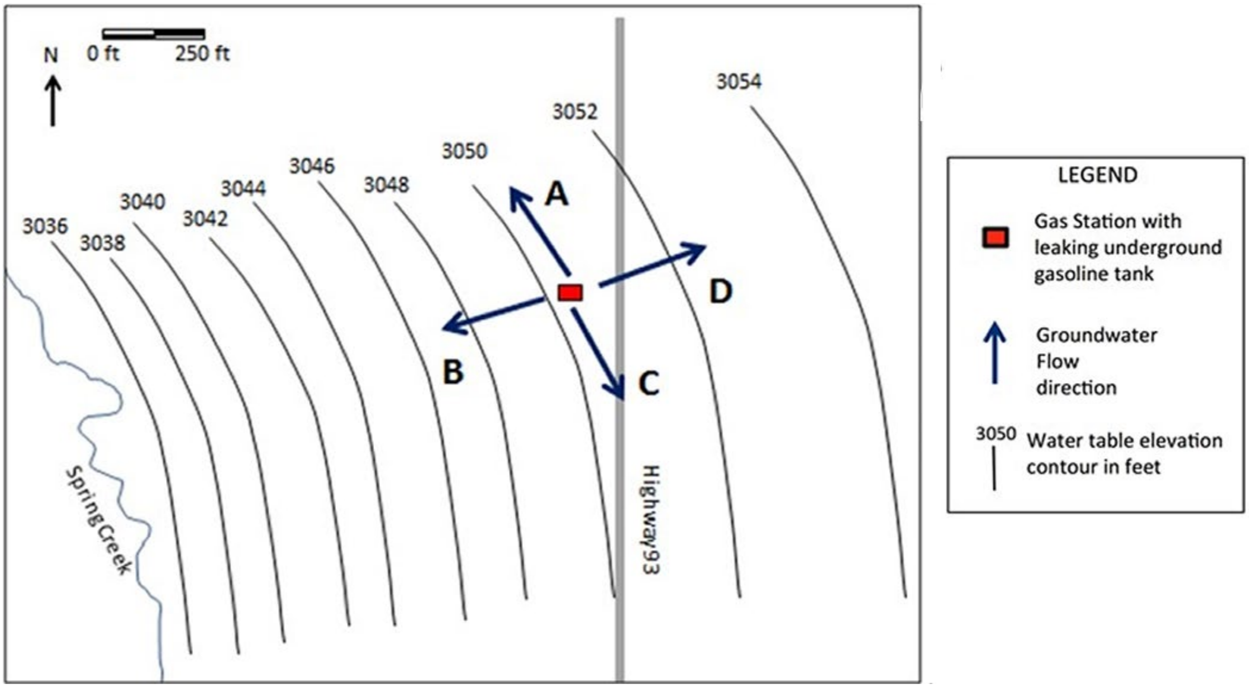
<u>Water Flow (Tracing groundwater and contamination, water table, potential energy - H)</u>

RONAN WATERFLOW ARROWS (Pre & Post)

12. a. The map below 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?

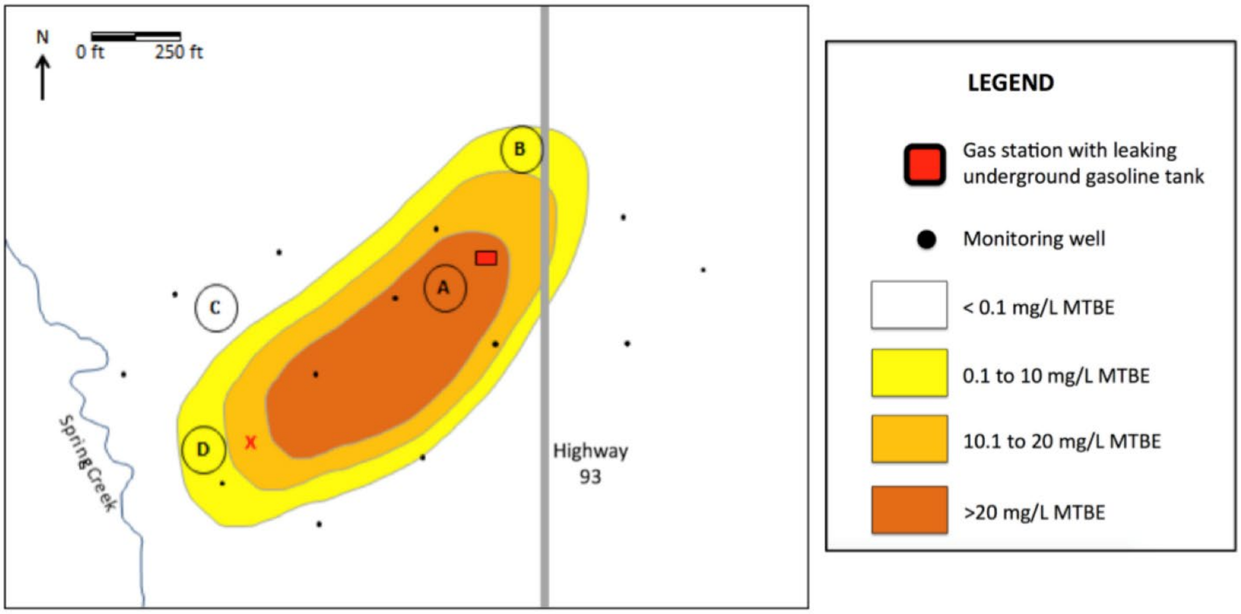
    A. Arrow A
    B. Arrow B
    C. Arrow C
    D. Arrow D

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



Purpose: This question probes students' abilities to interpret data in the form of contour lines and to apply principles of groundwater flow (high to low potential energy) to interpret a map.
Goal model-based responses: More sophisticated responses indicate arrow B because this is the direction from high to low potential energy (or water table elevation). Students may also recall that water flow lines are perpendicular to elevation contour lines. At an intermediate level of sophistication, sometimes students choose B and suggest that direction is "downhill" not specifying that the contours represent groundwater rather than surface water.

Examples of emergent scientific responses: Lower-level responses may indicate contamination will flow in the direction indicated by arrow C because of an assumption that 'down the page' is the same as the downhill direction. Arrow A may be selected as the arrow closest to pointing in the same direction as the arrow on the map key. Other responses may indicate the direction of arrow B because that is the direction of the river (school-rule reasoning of all water flowing into streams).
<u>Ronan Contamination Plume Map: (Interpolation & Uncertainty- D)</u>
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.



RONAN INTERPOLATION (Pre & Post)

13. a. What would be a reasonable estimate of the concentration of MTBE from a groundwater sample taken from a well at the X?

    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.

Purpose: This question examines how students infer contamination concentration estimates from a contamination plume contour map.

Goal model-based responses: 14 mg/L is a reasonable estimate for the concentration of MTBE at the X. The most common reasoning given by students is that this value lies within the range indicated by the key for the color of the area corresponding to the X. More sophisticated responses indicate interpolation or estimation between the range of values specified in the key.

Examples of emergent scientific responses: Emergent scientific student responses may guess, provide unclear reasoning, or misinterpret the map and key.

RONAN UNCERTAINTY (Pre & Post)

14. a. At which location would you be most uncertain about the concentration of MTBE modeled by the computer?

    A. A
    B. B

C. C
D. D

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

Purpose: This question probes students' understanding of confidence in model outputs and how models are connected to real world data and decision-making. Students' reasoning should involve their understanding of linear interpolation and extrapolation, as well as their understanding of how model outputs are generated. This question can be used to examine how students make sense of missing data contributing to uncertainty associated with model outputs. The question also provides insight into students' understanding of how contamination moves in a groundwater system.

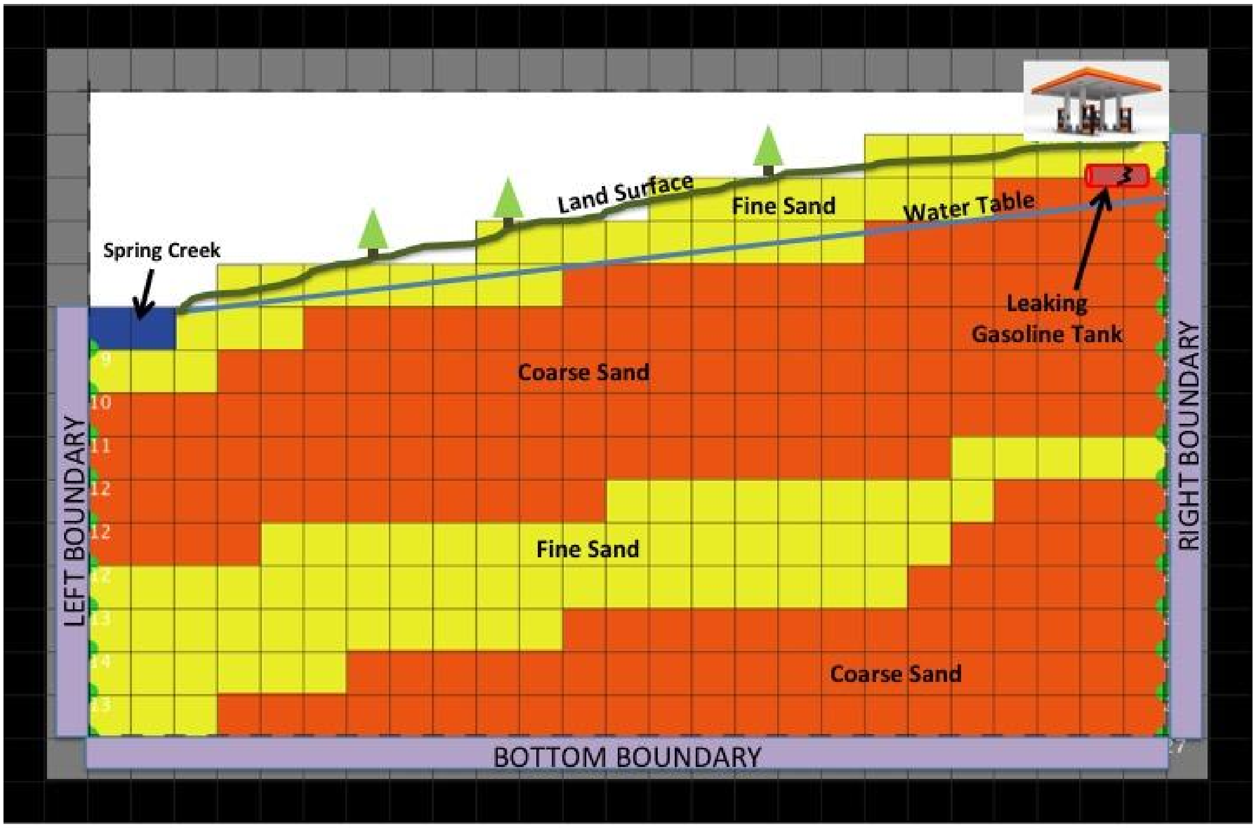
Goal model-based responses: Students who answer B may have more sophisticated reasoning that they'd be most uncertain at this location because there are not any monitoring wells close to or around this location so the model has insufficient data for estimating a concentration at this location. In general, more sophisticated responses acknowledge that uncertainty relates to sufficiency of data.

Other students may answer B and provide the reason that this location is up gradient from the source. This reflects a relatively sophisticated hydrology understanding-based strategy of using knowledge of groundwater systems to question the modeled estimation of contamination – reasoning that contaminant would not travel up the water table gradient from the source. For these students, uncertainty is not related to data but rather to a model output that is inconsistent with a reasonable prediction based on the map and understanding of how the system works.

Examples of emergent scientific reasoning: Some who answer A or C may reason that these points are in areas with an unbounded range (<0.1 mg/L or >20 mg/L) so the value could be anything less than or greater than the value indicated in the map key. This relates to (im)precision rather than (un)certainty – both are important issues for judging models and model outputs, but they are not the same. Students may also reason that they are less uncertain in areas of highest or lowest concentration and/or closest or farthest proximity from the source.

Ronan Model Parameterization (Parameterization – C)

The image below shows a cross-section of the area where the underground gasoline tank is leaking. A grid has been applied over the cross-section to begin making a computer model of the gasoline spill.



RONAN PARAMETERS (POST ONLY)

15. a. What information about each cell in the grid would be needed to compute and predict the flow of water and MTBE through the system?

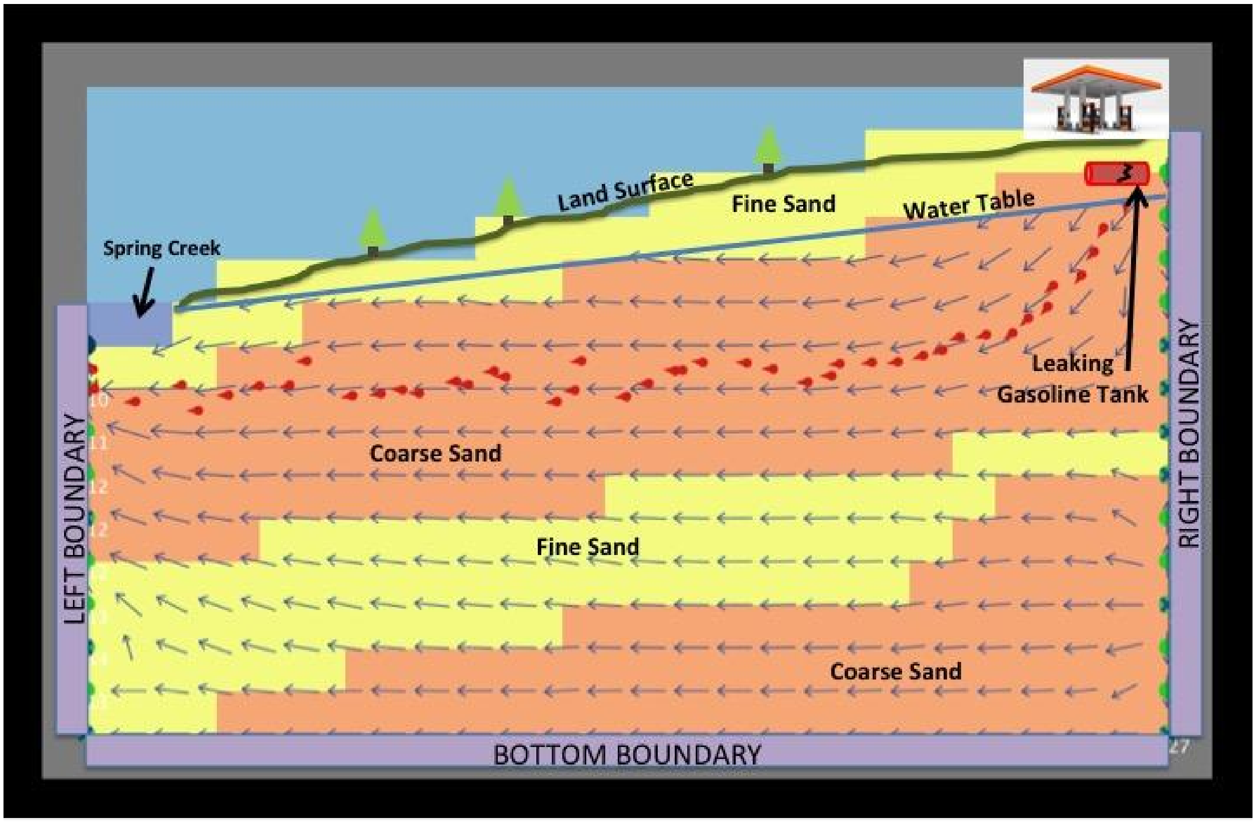
    b. Please explain why each type of information (parameter) you listed is important.

Purpose: This question probes students' understanding of factors (parameters) affecting the flow of groundwater and contamination that would need to be included in a computational model of a real world groundwater system. Students' responses may focus on data and/or rules for determining groundwater and contaminant flow.

Goal model-based responses: More sophisticated responses may include: gravitational potential energy or potential energy, pressure, hydraulic head, permeability, porosity, infiltration rates, and/or location of recharge and discharge. Responses may include an explanation of why parameters are important in determining flow of groundwater and contaminants (rules governing system/model).

Examples of emergent scientific reasoning: Emergent scientific answers may include: depth (location), type of sediment, direction of flow, or amount of contamination. These answers may mention vocabulary, but lack connection to associated principles or explanation of how this information would be used in a computational model.

Ronan Cross-Section Model (Tracing water and contamination – H)
The image below is of a computer model showing the MTBE contamination plume from the leaking gasoline tank.



RONAN WATER FLOW (POST ONLY)

16. Explain why the MTBE contamination will flow through the ground as shown.

GROUNDWATER CARING (PRE & POST)

17. a. How important is it to you that groundwater is protected in your community?
    - 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.

Purpose: This question examines how students explain contamination movement depicted in a cross-section representation.

Goal model-based responses: Sophisticated responses indicate that contamination flows as shown because it is flowing with the groundwater and groundwater is flowing from an area of higher potential energy (or hydraulic head) to an area of lower potential energy- as shown by the flow arrows.

Examples of emergent scientific reasoning: Emergent scientific responses may describe contamination as moving in the direction of the arrows without referencing any of the physical principles responsible for the flow.

MODELING IMPORTANCE (PRE & POST)

18. 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?
    - 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.

19. 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.

