PREPARING FOR HYDROGEOLOGY
This guide is written for students who will be participating in the Hydrogeology event for a Science Olympiad tournament.

Hydrogeology is a Division C event for Inquiry. This event will challenge your intellect and problem-solving skills by incorporating scientific research, computer simulation, and complex real-world problems.

During the competition, teams of up to two students work through the three part event by:
• Completing a written test
• Manipulating a groundwater computer simulation
• Evaluating the flow of groundwater and the risk of contamination in a given scenario, and completing a Remediation Techniques table

This guide includes what you need to know to be successful at the Hydrogeology event, including a general overview of the event, sample test questions for each portion of the event, and a step-by-step guide to running the Hydrogeology Challenge, the groundwater computer simulation used in the event.

The event Hydrogeology was designed by The Groundwater Foundation, a nonprofit organization that educates people and inspires action to ensure sustainable, clean groundwater for future generations. Learn more at www.groundwater.org.
GENERAL EVENT INFORMATION

PREPARING FOR COMPETITION

Hydrogeology is a three part event. You will be tested on your knowledge of groundwater, manipulate a groundwater computer simulation (called the Hydrogeology Challenge), and evaluate solutions, based on hydrogeological evidence, to reduce anthropogenic effects on groundwater.

RULES

Rules for Hydrogeology are available from your Tournament Director. This guide is meant to be used as a supplement to the rules. Be sure to check the rules for all event parameters.

NEEDED EQUIPMENT

- This event requires computers or tablets with access to the internet. Your event supervisor will supply a paper version of Hydrogeology in the event that you do not have access to computers, tablets, or internet access.
- Each team is allowed to bring a writing utensil, protractor and calculator.
- Each team is allowed to bring one 8.5” x 11” sheet of paper that may contain information on both sides.

PREPARING FOR COMPETITION

- There are three parts to the Hydrogeology competition. All three parts are individually described in this guide.
- All three parts must be completed within the 50-minute time period.
- Be prepared to answer multiple choice, matching, essay and fill in the blank questions.
- Be sure to show your work when calculations are required.
INSTRUCTIONS FOR USING THE HYDROGEOLOGY CHALLENGE

INTRODUCTION

The Hydrogeology Challenge is a learning tool that will introduce you to basic groundwater modeling concepts. It uses simple calculations and assumptions to present groundwater flow in a fun and easy to understand manner. Use the following instructions as a guide to get you started with The Hydrogeology Challenge. You'll be an expert in no time!

ABBREVIATIONS

G  Ground Elevation
S  Water Table Elevation in Static Conditions
P  Water Table Elevation in Pumping Conditions
i  Gradient
n  Porosity
K  Hydraulic Conductivity
ft  Feet
Elev X-Y  The difference between the water table elevation of well X and the water table elevation of well Y
Elevation X  The water table elevation of well X
Dist X to Y  The distance between well X and well Y
X-xy Dist  The distance between well X and the point (xy) between well X and Y that has a water table elevation equal to the water table elevation of the middle well
INSTRUCTIONS FOR USING THE HYDROGEOLOGY CHALLENGE (CONTINUED)

THE BASICS OF RUNNING THE HYDROGEOLOGY CHALLENGE:
• Go to http://groundwater.beehere.net/.
• Click the ‘Start the Challenge’ button.
• Select a scenario from the blue arrow drop down box (e.g. Event Guide Practice Exam).
• Prepare your model to determine groundwater flow direction, gradient, and horizontal velocity:
  - Select three wells (depending on your browser, you may have to single- or double-click)
  - You now have the option of turning well pumping on. We recommend you work through the model in static conditions first (well pumping off). If you wish to turn pumping on for a selected well, click on the white box that is labeled ‘Pumping On’ in the blue well pop-up box.

  Note: You may move the blue pop-up box to a new location on your screen by clicking and dragging.

FLOW DIRECTION
Now you are ready to calculate the flow direction. To determine the flow direction of groundwater between three wells you will need to work through the three basic steps.

• Step 1: Fill in the blank boxes with the necessary information. When filling in information about water table elevation, make sure to use the ‘Water table elevation in Static conditions (S)’ for wells that are not pumping and use the ‘Water table elevation in Pumping conditions (P)’ for wells that are pumping. You must fill in all of the boxes for Step 1 before you may move on to Step 2.

• Step 2: Fill in the blank boxes with the necessary information. Make sure to round your answers to the stated amount of decimal places. The distance between wells is shown on the map. You may use a calculator to help you answer the math questions. Upon completion of step 2, you will notice a grey line appears on your map. This is your water table contour line.

• Step 3: Select the direction of groundwater flow by clicking and dragging the blue dot around the compass. Groundwater flows from regions of higher elevation to regions of lower elevation.

  For helpful information about the assumptions of the Hydrogeology Challenge, you may click the reality check button for each section.

To check your answers select the ‘Check Answer’ button. Correct answers are highlighted in green, incorrect answers are highlighted in red. To view the correct answers, select the ‘Show Solution’ button.

GRADIENT
• Step 1: Click on ‘Reveal Distance Y’. Distance Y is the flow distance perpendicular to the water table contour (grey line) that you determined in Flow Direction. Distance Y will appear on your map.

• Step 2: Complete the formula to determine the gradient (i). Once again, make sure to round your answers to stated amount of decimal places.
  - A visual of the gradient will appear as a yellow arrow under the Step 2 equation. You are now ready to proceed to the final portion: Horizontal Velocity.
INSTRUCTIONS FOR USING THE HYDROGEOLOGY CHALLENGE (CONTINUED)

HORIZONTAL VELOCITY

Horizontal Velocity is calculated using Darcy’s Law. Darcy’s Law requires the hydraulic conductivity (K) and porosity (n) of the soil through which the groundwater is moving. To find these values, open the Geology Table of the well with the highest water table elevation (this is the well the groundwater will be flowing from). The Geology Table shows the lithology (soil type) where the well is located. The depth is listed as feet below the surface. To select your K and n values, choose the layer of soil with the highest conductivity (K) in the saturated zone (area below the water table).

- **Step 1:** Determine your hydraulic conductivity (K) and porosity (n). Fill in the blank boxes with the necessary information. You may back track to Gradient if you forgot your gradient value. Remember, porosity is entered in as a decimal, so a porosity of 45% would be entered as 0.45.

- **Step 2:** Complete the equation (Darcy’s Law) to calculate Horizontal velocity.

FINISH

Congratulations! You have successfully calculated the speed and direction of groundwater flow. You may now click the ‘All Done’ button. A prompt will appear allowing you two choices:

- “Continue with Previous Selection,” to continue in the same scenario
- “Begin a New Scenario,” to choose a brand new scenario

If you “Begin a New Scenario,” don’t forget to try the Hydrogeology Challenge with well pumping ON!
PART 1: OVERVIEW AND PREPARATION

During Part 1 of the Hydrogeology event you will take a written test. There will be questions from each of the following areas:

- The fundamentals of groundwater and hydrogeology
- Surface-groundwater interactions
- The relation of groundwater flow to geologic structure
- The management of contaminated groundwater

Questions can be multiple choice, true/false, fill in the blank, or short answer. Part 1 is worth 30% of the total score.

There are lots of resources you can use to study for the event, examples of approved scientific sites to help you prepare are listed below.

THE GROUNDWATER FOUNDATION www.groundwater.org


USGS (UNITED STATES GEOLOGICAL SURVEY) www.usgs.gov


US EPA (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY) www.epa.gov

- All about Wetlands - http://water.epa.gov/type/wetlands/index.cfm
- Groundwater Fact Flash - http://www.epa.gov/superfund/students/clas_act/haz-ed/ff_05.htm

OTHER

PART 2: OVERVIEW AND PREPARATION

In Part 2 of Hydrogeology you will use the Hydrogeology Challenge to determine the flow of groundwater under static (non-pumping) conditions. You will be provided a unique Hydrogeology Challenge scenario URL. You will also be provided the three wells you must use during this portion of the event (e.g. wells A, B, and C). All answers are submitted online. Part 2 is worth 10% of the total score.

HYDROGEOLOGY CHALLENGE PRACTICE

You can practice running the Hydrogeology Challenge online at http://groundwater.beehere.net/. There are several differences between the practice version of the Hydrogeology Challenge and the testing version used in competition.

The practice version of the Hydrogeology Challenge:
- Is accessible by the general public
- Allows users to check their answers and show the solution
- Has access to the “Reality Check” – a special feature of the Hydrogeology Challenge that explains how the Hydrogeology Challenge works and under what assumptions it computes answers

The testing version of the Hydrogeology Challenge:
- Is not accessible by the general public
- Requires a unique URL
- Does not have the option of checking answers or showing the solution
- Does not have access to the “Reality Check”

For a written description on how to run the Hydrogeology Challenge, please see the Hydrogeology Challenge Instructions on page 3. A video tutorial is also available at http://www.groundwater.org/kids/getinvolved/so/hydro.html.

IMPORTANT NOTES FOR PART 2

You will receive zero points for Part 2 if:
- The wrong scenario is used
- The wrong wells are used
- Pumping is turned on for one or more wells
- Multiple attempts are submitted
PART 3: OVERVIEW AND PREPARATION

During Part 3 of Hydrogeology you will manipulate the groundwater challenge to determine the risk of contamination to wells. You will also be required to fill out a Remediation Techniques Table (see page 9). Part 3 is worth 60% of the total score.

EXAMPLE QUESTIONS FOR PART 3
Your event supervisor may ask additional questions about the scenario. These questions can be multiple choice, true/false, fill in the blank, or short answer. Below are some example topics event supervisors may use to create additional questions for Part 3:

• The limitations/assumptions of the Hydrogeology Challenge. Remember to read and understand the Reality Checks.
• If one of the given circumstances changed (for example, a well stopped pumping water), how would that affect the flow of groundwater and the risk of contamination?
• Facts about the pollutant, e.g. what are other sources of the pollutant, what type of pollutant it is, a DNAPL or LNAPL or neither, what it is commonly used for, etc.
• Other situations that impact groundwater quality or quantity not necessarily related to the introduced contaminant (i.e. saltwater intrusion, land subsidence, sinkholes, or groundwater interactions with surface water).

INCORPORATING CONTAMINATION INTO THE HYDROGEOLOGY CHALLENGE
Part 3 of Hydrogeology introduces a contaminant to the original, unique scenario used in Part 2 of the event. Along with introducing a contaminant, other factors may be introduced as well, such as well pumping being turned on. These factors make up Part 3’s “situation.” The situation must include:

• Non-static conditions (at least one well must be pumping water)
• A contaminant (selected from the Contaminant Table on page 18)
• A contaminant source to be located at one well

The situation may also include:
• Well types
• Well uses
• Any other information deemed relevant to the scenario

Using the information from the given situation, you will manipulate the Hydrogeology Challenge scenario to determine which wells are at risk of contamination by the contaminant and approximately how long until the contamination may occur.
PART 3: OVERVIEW AND PREPARATION (CONTINUED)

You will also need to fill out a Remediation Techniques Table. The Remediation Table located on page 21 is a good place to study, but remember, it is a basic guide, and the test may use remediation techniques that are not listed in the table. Some good resources for additional remediation techniques are:

- Remediation Technologies - [http://www.epa.gov/superfund/remedtech/remed.htm](http://www.epa.gov/superfund/remedtech/remed.htm)

**SAMPLE REMEDIATION TECHNIQUES TABLE**

<table>
<thead>
<tr>
<th>Remediation Technique</th>
<th>Definition</th>
<th>In-situ or ex-situ</th>
<th>Type (Biological, Physical, or Chemical)</th>
<th>Cost (low, medium, high)</th>
<th>Applicable to [Given Pollutant] (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Stripping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phytoremediation</td>
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<td></td>
<td></td>
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<tr>
<td>Activated Carbon Treatment</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioremediation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART 1: SAMPLE TEST

This section is worth a total of 10 points. Possible points are labeled next to each question.

MULTIPLE CHOICE

1. In the image to the right, which location represents a gaining stream? (0.5 points)
   a. A
   b. B
   c. C

2. In the image to the right, which location represents a losing stream? (0.5 points)
   a. A
   b. B
   c. C

3. A DNAPL is a liquid that is __________ than water and __________ dissolve in water. (1 point)
   a. More dense, does
   b. Less dense, does
   c. More dense, does not
   d. Less dense, does not

4. A pollutant commonly associated with feedlots, fertilizer, and agriculture is: (1 point)
   a. Lead
   b. BTEX
   c. Arsenic
   d. Nitrate

5. An artesian system is one in which __________. (1 point)
   a. Water is unconfined
   b. There are no aquicludes
   c. Water can rise above the level of an aquifer when a well is drilled
   d. All of the above

6. An example of an organic groundwater contaminant would be ____________. (1 point)
   a. MTBE
   b. Cadmium
   c. Chlorides
   d. All of the above

7. An aquifer contains a great deal of water, but the water cannot be removed easily with an ordinary well. This is most likely due to sediment and rock characterized by: (1 point)
   a. Low porosity
   b. Poor sorting
   c. Low permeability
   d. High iron content
PART 1: SAMPLE TEST (CONTINUED)

TRUE/FALSE
8. Clay is more permeable than gravel. (0.5 points)
9. There is no soil moisture located in the unsaturated zone. (0.5 points)

SHORT ANSWER
10. Draw examples of rock formations in the boxes below that are (1 point):
   Permeable
   Impermeable

11. Define the following terms in one or two complete sentences (2 points):
   a. Permeability
   b. Porosity
   c. Transmissivity
   d. Aeration Zone

ANSWER KEY ON PAGE 26
PART 2: SAMPLE TEST

IMPORTANT: Please submit your answers online for this portion of the event.* It is a good idea to write down your calculated values as you work through the Hydrogeology Challenge just in case you need to refresh the page or have computer issues.

This section is worth a total of 10 points.

DIRECTIONS:


2. When submitting your answers:*  
   Name: [Team Number and School]  
   Location: [Location will be provided]

*Note: When completing the Event Guide Practice Exam scenario at http://groundwater.beehere.net/#practice, you will not need to submit your answers. The Event Guide Practice Exam scenario is meant for practice only as it contains the “Check Answer” and “Show Solution” buttons. During a Science Olympiad tournament, you will be required to submit answers as shown and will not have have access to the “Check Answer” and “Show Solution” buttons.
PART 3: SAMPLE TEST

This section is worth a total of 20 points.

THE SITUATION:
The small community of Event Guide Practice Exam has experienced an underground storage tank leak near well E. Due to the leak, BTEX has contaminated the groundwater of well E. Residents are now looking to your team to determine which wells are at risk of contamination and what options the community has for remediation of their groundwater.

*The Event Guide Practice Exam scenario can be found at: http://groundwater.beehere.net/#practice.*

THE FACTS:
• BTEX was found at well E
• Residents are currently pumping water from wells A, B, C, D, and G.
• Wells E and F are not currently pumping water.

YOUR MISSION:
Answer the following questions posed by Event Guide Practice Exam’s residents, and complete the Remediation Table by the residents’ request. You may use The Hydrogeology Challenge to help you complete your work.

1. From well E, which direction(s) is the contaminant plume most likely going to go (North, Northeast, South, etc.)? (1 point)

2. Other than well E, which well(s) are at risk of contamination? (1 point)

3. Assuming the Hydrogeology Challenge’s assumptions are correct, if the residents start pumping water from well E, will that reduce the risk of contamination of any of the wells you listed in question 2? Explain your answer. (2 points)

4. Assuming the Hydrogeology Challenge’s assumptions are correct, if the residents start pumping water from well E, how will that affect the velocity of the contaminant plume? (2 points)

5. Approximately how long will it take for the BTEX to travel from the source (well E) to the nearest well in danger of being contaminated? (2 points)
   a. Less than one week
   b. About one year
   c. 2-4 years
   d. More than 5 years
### Remediaion Table

Complete the missing information in the table below. Each row is worth 3 points (12 points total).

<table>
<thead>
<tr>
<th>Remediation Technique</th>
<th>Definition (1 pt)</th>
<th>In-situ or ex-situ (0.5 pts)</th>
<th>Type (Biological, Physical, Chemical, Thermal, Containment Only, or Other) (0.5 pts)</th>
<th>Cost (low, medium, high) (0.5 pts)</th>
<th>Applicable to BTEX? (yes/no) (0.5 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Air Sparging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Air Stripping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Permeable Reactive Barrier</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Thermal Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Answer Key on Page 26*
THE PAPER VERSION

OVERVIEW

If there will not be access to internet, computers, or tablets the day of the tournament, you will receive a paper version. You may check with your coach or event supervisor to determine which version of the event will be run at the upcoming tournament.

The paper version of Hydrogeology is similar to the online version. The event rules are the same whether running the paper version or the online version of Hydrogeology. The paper version requires these additional materials to be supplied by event supervisors:

- Rulers (at least one for each team)
- Colored pencils – black, red, blue, and green

SAMPLE PAPER VERSION – DEFINITIONS

**WTE H-M:** The difference between the water table elevation of the well with the highest water table elevation and the water table elevation of the well with the middle water table elevation.

**WTE H-L:** The difference between the water table elevation of the well with the highest water table elevation and the water table elevation of the well with the lowest water table elevation.

**Distance H to L:** The distance in miles from the well with the highest water table elevation to the well with the lowest water table elevation.

**Distance H to P:** The distance in miles from the well with the highest water table elevation to the point P. Point P is located between the wells with the highest and lowest water table elevations, and it has the same water table elevation as the middle well.

**WTE H:** The water table elevation of the well with the highest water table elevation.

**WTE M:** The water table elevation of the well with the middle water table elevation.

**Distance Y:** The distance between the well with the highest water table elevation and the contour line (green line). Distance Y should be perpendicular to the contour line. In some instances, you may have to extend the contour line in order to measure distance Y perpendicular to the contour line.
The Groundwater Foundation Presents:
The Hydrogeology Challenge
Scenario: Sample Paper Version

To Begin: Pick three wells and complete steps 1 through 3 using the Well Log Look-Up Table

Answer Key for wells A, B, and C in static conditions on Page 32

Step 1: Flow Direction
1. Draw a black line from the well with the highest water table elevation (WTE) to the well with the lowest WTE.
2. Find the point (P) between the highest (H) and lowest (L) wells equal to the WTE of the middle (M) well using the equation below.
   \[
   \frac{WTE_H - M}{WTE_H - L} = \frac{\text{Distance} \ H \ \text{to} \ L}{\text{Distance} \ H \ \text{to} \ P} \text{ miles}
   \]
3. Mark the point between the highest and lowest wells equal to the WTE of the middle well (point P). Draw a green line from P to the middle well. You have just drawn a contour line.
4. The flow of groundwater will be perpendicular to the contour line. Draw a blue arrow representing the flow direction of groundwater. The arrow should point downhill gradient as groundwater flows from regions of higher elevation to regions of lower elevation.

Step 2: Gradient
1. In order to calculate the gradient, you must first find the distance (Y) from the highest well to the contour line. Draw this line in red. Remember this line should make a 90° angle with the contour line.
2. Measure the distance (Y) in feet (1 mi. = 5,280 ft.).
3. Calculate the gradient using the equation below.
   \[
   \frac{WTE_H - WTE_M}{\text{Distance} \ Y} = \text{ft/ft}
   \]

Step 3: Horizontal Velocity
1. Three variables are needed to calculate the horizontal velocity of groundwater. They are gradient (i), hydraulic conductivity of the soil (k), and porosity of the soil (n). You have already calculated the gradient. Use the look-up table to find the hydraulic conductivity and porosity by selecting the layer of soil in the well with the highest WTE that has the highest conductivity (k) in the saturated zone (area below the water table). Then, using Darcy’s equation below, calculate the horizontal velocity.
   \[
   \frac{k \ x \ i \ l}{n} = \text{ft/day}
   \]
<table>
<thead>
<tr>
<th>Well Location</th>
<th>Depth</th>
<th>Lithology</th>
<th>Conductivity</th>
<th>Porosity (%)</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>0-25</td>
<td>Clay</td>
<td>0.01</td>
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<td></td>
<td>25-55</td>
<td>Fine Sand</td>
<td>26.8</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>55-93</td>
<td>Silty Sand</td>
<td>6.7</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>93-140</td>
<td>Crs. Sand &amp; Gravel</td>
<td>160.8</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>0-15</td>
<td>Fine Sand</td>
<td>26.8</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>15-48</td>
<td>Silty Sand</td>
<td>6.7</td>
<td>44</td>
</tr>
<tr>
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<td>48-72</td>
<td>Sandstone</td>
<td>26.8</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>72-88</td>
<td>Crs. Sand &amp; Gravel</td>
<td>160.8</td>
<td>34</td>
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<tr>
<td></td>
<td>25-70</td>
<td>Medium Sand</td>
<td>67.0</td>
<td>39</td>
</tr>
<tr>
<td>B</td>
<td>95</td>
<td>Fine Sand</td>
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<td>Crs. Sand &amp; Gravel</td>
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<td>4.02</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>25-70</td>
<td>Silty Sand</td>
<td>6.7</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>70-165</td>
<td>Sandstone</td>
<td>26.8</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>165-185</td>
<td>Crs. Sand &amp; Gravel</td>
<td>160.8</td>
<td>34</td>
</tr>
<tr>
<td>Category</td>
<td>Sub-Category</td>
<td>Pollutant</td>
<td>About</td>
<td>DNAPL or LNAPL?*</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Volatile Organic Compounds (VOCs)**</td>
<td>Halogenated</td>
<td>Carbon Tetrachloride</td>
<td>A grain fumigant used to make refrigerants and propellants for aerosol cans as well as a solvent and dry cleaning agent.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chloroform</td>
<td>A chemical that was used as an extraction solvent and is now mainly used to make propellant and refrigerant.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perchloroethylene (PCE)</td>
<td>A solvent often used for dry cleaning and metal degreasing.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trichloroethylene (TCE)</td>
<td>An industrial solvent commonly used for metal degreasing, refrigerant manufacturing, and cleaning kerosene-fueled rocket engines.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluorotrichloromethane (Freon 11)</td>
<td>Prior to 1996 this compound was widely used as a refrigerant. Freon-11 was banned in 1996 for its ozone depletion potential.</td>
<td>DNAPL</td>
</tr>
<tr>
<td>Nonhalogenated</td>
<td></td>
<td>Acetone</td>
<td>A common solvent used for cleaning, nail polish remover, and paint thinner.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Methanol</td>
<td>A naturally occurring substance often used as a gasoline additive, paint stripper, propellant for aerosol cans, and cleaners.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)</td>
<td>A group of naturally-occurring chemicals that are typically found in petroleum products. They have a strong odor and are highly flammable.</td>
<td>LNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Methyl Tert-Butyl Ether (MTBE)</td>
<td>A manufactured chemical compound used as a fuel additive and solvent. It has an offensive taste and color.</td>
<td></td>
</tr>
<tr>
<td>Semivolatile Organic Compounds (SVOCs)</td>
<td>Halogenated</td>
<td>Pentachlorophenol (PCP)</td>
<td>A white solid that is used as a wood preservative and was used as a herbicide in the past. Herbicide use of PCP was banned in 1987.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polychlorinated Biphenyls (PCBs)</td>
<td>PCBs were banned in 1979, but before then they were used as coolants and lubricants. They can still be found in some products today such as fluorescent lighting and electrical devices that use PCB capacitors.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td>Nonhalogenated</td>
<td>Polycyclic Aromatic Hydrocarbons (PAHs)</td>
<td>A group of over 100 combinations of hydrocarbons that can be found naturally in the environment but can also be manmade. PAHs are used for research purposes as well as to make dyes, plastics, pesticides, and medicines.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pesticides</td>
<td>All chemicals that are used to kill or control pests.</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Sub-Category</td>
<td>Pollutant</td>
<td>About</td>
<td>DNAPL or LNAPL?*</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>----------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Petroleum Byproducts</td>
<td></td>
<td>Creosote</td>
<td>A wood preservative used for commercial purposes only. It is obtained from high temperature distillation of coal tar.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coal Tar</td>
<td>A by-product of carbonized coal. It is a brown or black liquid of extremely high viscosity.</td>
<td>DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crude Oil</td>
<td>A liquid petroleum that is highly viscous and has a higher density than light crude oil.</td>
<td>LNAPL/DNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diesel</td>
<td>A heavy distillant that is used as fuel.</td>
<td>LNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gasoline</td>
<td>A refined petroleum that is used as fuel in internal combustion engines.</td>
<td>LNAPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)</td>
<td>A group of naturally-occurring chemicals that are typically found in petroleum products. They have a strong odor and are highly flammable.</td>
<td>LNAPL</td>
</tr>
<tr>
<td></td>
<td>Metals</td>
<td>Methyl Tert-Butyl Ether (MTBE)</td>
<td>A manufactured chemical compound used as a fuel additive and solvent. It has an offensive taste and odor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cadmium</td>
<td>A metal used for metal plating and coating operations, solar batteries and pigments.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead</td>
<td>A metal used in roofing, plumbing, storage batteries, etc. It used to be used in paints.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nickel</td>
<td>A metal that is used for making stainless steel, coinage, rechargeable batteries, guitar strings, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Copper</td>
<td>A metal used to make electrical wiring and household plumbing materials. Copper compounds can be used as pesticide.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chromium</td>
<td>A metal often used as a surface coating. It has also been used for making dyes, wood preservatives, synthetic rubies, leather tanning, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iron</td>
<td>A metal used in making steel. The cheapest available metal and the most widely used metal.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aluminum</td>
<td>The second most used metal behind iron. Used in the manufacturing of transportation vehicles, packaging materials, a wide variety of household items, etc.</td>
<td></td>
</tr>
</tbody>
</table>
### CONTAMINANT TABLE (CONTINUED)

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Pollutant</th>
<th>About</th>
<th>DNAPL or LNAPL?*</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganics</td>
<td>Radonuclides</td>
<td>Radium</td>
<td>A highly radioactive metal with a half-life of 1601 years. It decays into radon gas.</td>
<td></td>
<td>Natural deposits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radon</td>
<td>A radioactive gas that is the result of decaying Radium.</td>
<td></td>
<td>From natural deposits of radium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uranium</td>
<td>A weakly radioactive metal that is used to produce nuclear energy.</td>
<td></td>
<td>Natural deposits; Mining/milling waste</td>
</tr>
<tr>
<td>Other inorganics</td>
<td>Arsenic</td>
<td>Arsenic</td>
<td>A poisonous element that is used to strengthen alloys of copper and lead. It has also been used in the production of pesticides.</td>
<td></td>
<td>Natural deposits; Mining</td>
</tr>
<tr>
<td></td>
<td>Nitrate</td>
<td>Nitrate</td>
<td>(NO₃) Essential plant nutrient that in excess can accelerate eutrophication in aquatic plant growth and cause hypoxia (low levels of dissolved oxygen) to human and other warm-blooded animals.</td>
<td></td>
<td>Human/animal waste; Feedlots; Industrial waste from food processing; Septic tanks; Fertilizer and agriculture</td>
</tr>
<tr>
<td></td>
<td>Chlorides (Salts)</td>
<td>Chlorides (Salts)</td>
<td>A group of salts that are very soluble in water. They are found naturally in seawater, but it only takes a small amount of chlorides to contaminate freshwater.</td>
<td></td>
<td>Natural deposits; Road salts; Fertilizer; Human/animal waste; Water-softener; Naturally in soil</td>
</tr>
<tr>
<td>Explosives</td>
<td></td>
<td>2, 4, 6-trinitrotoluene (TNT)</td>
<td>An explosive compound commonly used for military and industrial applications. TNT-production ended in the mid-1980s.</td>
<td></td>
<td>Active and former U.S. Military installations; Army ammunition plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hexahydro- 1, 3, 5-triazine (RDX)</td>
<td>A highly explosive, synthetic product that has been used in the manufacture of explosives.</td>
<td></td>
<td>Active and former U.S. Military installations; Army ammunition plants</td>
</tr>
<tr>
<td>Pathogens</td>
<td></td>
<td>E. Coli</td>
<td>A type of coliform bacteria that live in water that may cause symptoms such as vomiting and diarrhea.</td>
<td></td>
<td>Bodily waste; Animal waste; Naturally in soil</td>
</tr>
</tbody>
</table>

*DNAPL stands for Dense Non-Aqueous Liquids and LNAPL stands for Light Non-Aqueous Phase Liquids.

**The various colors (Red, Blue, Green) represent the tournaments at which the pollutant or pollutant category may be used in competition. Red categories may be used at regional, state, and national tournaments. Blue pollutants may be used at state and national tournaments. Green pollutants may be used at national tournaments only.

---

### Contaminant Pool

<table>
<thead>
<tr>
<th>Regional (Red)</th>
<th>State (Blue and Red)</th>
<th>National (Green, Blue, and Red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOCs -- category only</td>
<td>Nitrate, Arsenic, Chlorides (Salts), DNAPL, LNAPL, Pesticides, Gasoline, Diesel, MTBE</td>
<td>Carbon Tetrachloride, Chloroform, Freon 11, Acetone, Methanol, PCP, PCE, PCBs, TCE, Creosote, Coal Tar, Extra Heavy Crude Oil, Radium, Radon, Uranium, TNT, RDX, E. Coli</td>
</tr>
<tr>
<td>SVOCs -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroleum Byproducts -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosives -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pathogens --category only</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Regional (Red)</th>
<th>State (Blue and Red)</th>
<th>National (Green, Blue, and Red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOCs -- category only</td>
<td>Nitrate, Arsenic, Chlorides (Salts), DNAPL, LNAPL, Pesticides, Gasoline, Diesel, MTBE</td>
<td>Carbon Tetrachloride, Chloroform, Freon 11, Acetone, Methanol, PCP, PCE, PCBs, TCE, Creosote, Coal Tar, Extra Heavy Crude Oil, Radium, Radon, Uranium, TNT, RDX, E. Coli</td>
</tr>
<tr>
<td>SVOCs -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroleum Byproducts -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosives -- category only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pathogens --category only</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## SUGGESTED REMEDIATION TECHNIQUES

<table>
<thead>
<tr>
<th>Regional (Red)</th>
<th>State (Blue and Red)</th>
<th>National (Green, Blue, and Red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air stripping</td>
<td>All of the categories from Regional plus the following:</td>
<td>All of the categories and pollutants from Regional and State plus any other techniques found in the Remediation Technologies Screening Matrix.</td>
</tr>
<tr>
<td>Bioremediation</td>
<td>Permeable Reactive Barrier (PRB)</td>
<td></td>
</tr>
<tr>
<td>Activated Carbon Treatment (Assuming Pumping)</td>
<td>Chemical Reduction Oxidation</td>
<td></td>
</tr>
<tr>
<td>Phytoremediation</td>
<td>Air Sparging</td>
<td></td>
</tr>
<tr>
<td>Monitored Natural Attenuation</td>
<td>Bioslurping or Dual Phase Extraction</td>
<td></td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>Precipitation/Coagulation/Flocculation</td>
<td></td>
</tr>
<tr>
<td>Vertical Engineered Barriers (VEB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incineration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The cost of a remediation technique can vary greatly and depends upon many factors. This table is meant to be an estimated cost based on data from the Remediation Technologies Screening Matrix and Reference Guide (1994) as well as professional opinion.*
GLOSSARY

**Aeration zone:** The zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. Plant roots can capture the moisture passing through this zone, but it cannot provide water for wells. Also known as the unsaturated zone or vadose zone.

**Aquifer:** An underground geological formation able to store and yield water.

**Cone of depression:** The zone around a well in an unconfined aquifer that is normally saturated, but becomes unsaturated as a well is pumped, leaving an area where the water table dips down to form a cone shape. The shape of the cone is influenced by porosity and the water yield or pumping rate of the well.

**Confining layer:** Geologic material with little or no permeability or hydraulic conductivity. Water does not pass through this layer or the rate of movement is extremely slow.

**Darcy’s Law:** Describes the flow of a fluid through a porous medium. There are several different ways of expressing Darcy’s basic equation, but the Hydrogeology Challenge uses \( V = K i / n \) where \( V \) is the seepage velocity of groundwater, \( K \) is the hydraulic conductivity, \( i \) is the gradient of the water table, and \( n \) is the porosity.

**Dense Non-Aqueous Phase Liquid (DNAPL):** A liquid that is both denser than water and does not dissolve in water.

**Depletion:** The loss of water from surface water reservoirs or groundwater aquifers at a rate greater than that of recharge.

**Discharge:** An outflow of water from a stream, pipe, groundwater aquifer, or watershed; the opposite of recharge.

**Drawdown:** A lowering of the groundwater level caused by pumping.

**Ex-Situ:** Not in the natural or original position or place, off-site. Ex-situ remediation techniques involve removing the contaminated groundwater from underground and treating at an aboveground facility.

**Flow rate:** The time required for a volume of groundwater to move between points. Typically groundwater moves very slowly—sometimes only inches per year.

**Groundwater:** Water found in the spaces between soil (gravel, sand, silt, and clay) particles and cracks in rocks underground (located in the saturation zone). Groundwater is a natural resource that is used for drinking, recreation, industry, and growing crops.

**Halogenated SVOCs:** An SVOC containing one of the halogen elements located in the seventh column of the periodic table (e.g. fluorine, chlorine, bromine, or iodine).

**Halogenated VOCs:** A VOC containing one of the halogen elements located in the seventh column of the periodic table (e.g. fluorine, chlorine, bromine, or iodine).

**Hydraulic Conductivity:** A measure of the aquifer’s ability to transmit water through pore spaces and fractures when submitted to a hydraulic gradient.

**Hydrologic cycle:** (also known as the water cycle) The paths water takes through its various states—vapor, liquid, solid—as it moves throughout the oceans, atmosphere, groundwater, streams, etc.
GLOSSARY

Hydrogeology: The study of interrelationships of geologic materials and processes with water, especially groundwater.

Impermeable layer: A layer of material (such as clay) in an aquifer through which water does not pass.

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

Infiltration rate: The quantity of water that enters the soil surface in a specified time interval. Often expressed in volume of water per unit of soil surface area per unit of time.

In-Situ: In the natural or original position or place. In-situ remediation techniques take place underground where the contaminated groundwater is located.

Light Non-Aqueous Phase Liquid (LNAPL): A liquid that is does not dissolve in water and has a lower density than water.

Lithology: The physical characteristics of a rock or stratigraphic unit.

Monitoring well: A non-pumping well, generally of small diameter, that is used to measure the elevation of a water table or water quality.

Nonhalogenated SVOCs: An SVOC that does not contain one of the halogen elements located in the seventh column of the periodic table (e.g. fluorine, chlorine, bromine, or iodine).

Nonhalogenated VOCs: A VOC that does not contain one of the halogen elements located in the seventh column of the periodic table (e.g. fluorine, chlorine, bromine, or iodine).

Overwithdrawal: Withdrawal of groundwater over a period of time that exceeds the recharge rate of the supply aquifer. Also referred to as overdraft or mining the aquifer.

Permeable/Permeability: Capable of transmitting water (porous rock, sediment, or soil); the rate at which water moves through rocks or soil.

Permeable layer: A layer of porous material (rock, soil, unconsolidated sediment); in an aquifer, the layer through which water freely passes as it moves through the ground.

Plume: In groundwater a plume is an underground pattern of contaminant concentrations created by the movement of groundwater beneath a contaminant source. Contaminants spread mostly laterally in the direction of groundwater movement. The source site has the highest concentration, and the concentration decreases away from the source.

Pore space: Openings between geologic material found underground. Also referred to as void space or interstices.

Porosity: The ratio of the volume of void or air spaces in a rock or sediment to the total volume of the rock or sediment. The capacity of rock or soil to hold water varies with the material. For example, saturated sand contains about 20% water; gravel, 25%; and clay, 48%.

Recharge: Water added to an aquifer. For example, when rainwater seeps into the ground. Recharge may occur artificially through injection wells or by spreading water over recharge basins.
GLOSSARY

**Recharge rate:** The quantity of water per unit of time that replenishes or refills an aquifer.

**Recharge zone or area:** An area where permeable soil or rock allows water to seep into the ground to replenish an aquifer.

**Remediation:** Containment, treatment or removal of contaminated groundwater. May also include containment, treatment or removal of contaminated soil above the water table.

**Residence time:** Period of time that groundwater remains in an aquifer.

**Safe yield:** The annual amount of water that can be taken from a source of supply over a period of years without depleting that source beyond its ability to be replenished naturally in “wet years.” Also called sustainable yield.

**Salt water intrusion:** Process by which an aquifer is overdrafted creating a flow imbalance within an area that results in salt water encroaching into a fresh water aquifer.

**Saturation zone:** The portion below the earth’s surface that is saturated with water is called the zone of saturation. The upper surface of this zone, open to atmospheric pressure, is known as the water table.

**Semi-Volatile Organic Compounds (SVOCs):** Organic compounds that have a boiling point higher than water and may vaporize when exposed to temperatures above room temperature.

**Subsidence:** A depression of the land surface as a result of groundwater being pumped. Cracks and fissures can appear in the land. Subsidence is virtually an irreversible process.

**Surface water:** Water above the surface of the land, including lakes, rivers, streams, ponds, floodwater, and runoff.

**Transmissivity:** A measure of the capability of the entire thickness of an aquifer to transmit water. Also known as coefficient of transmissivity.

**Volatile Organic Compounds (VOCs):** Organic compounds that have high vapor pressure and low water solubility.

**Water table:** The top of an unconfined aquifer; indicates the level below which soil and rock are saturated with water. The upper surface of the saturation zone.

**Well:** A bored, drilled or driven shaft, or a dug hole whose depth is greater than the largest surface dimension and whose purpose is to reach underground water supplies to inject, extract or monitor water.

**Well closure:** The process of sealing a well that is no longer being used to prevent groundwater contamination and harm to people and animals.

**Well siting:** Location of a well placed to best protect water quality, access adequate water quantity, and allow for inspection and maintenance of the well.

**Wellhead protection area:** A protected surface and subsurface zone surrounding a well or well field supplying a public water system to keep contaminants from reaching the well water.
Important Notes:
- Answers are for wells A, B, and C in static conditions (no pumping)
- Assumes 1 mi = 0.75 in
- All lines are measured from center of well
- All answers are approximate. Answers may slightly vary depending on measuring technique.
SAMPLE TEST ANSWER KEY: PARTS 1 AND 3

PART 1


10. Permeable  Impermeable

11. a. **Permeability**: Capable of transmitting water (porous rock, sediment, or soil); the rate at which water moves through rocks or soil.

b. **Porosity**: The ratio of the volume of void or air spaces in a rock or sediment to the total volume of the rock or sediment. The capacity of rock or soil to hold water varies with the material. For example, saturated small grain sand contains less water than coarse gravel.

c. **Transmissivity**: A measure of the capability of the entire thickness of an aquifer to transmit water. Also known as coefficient of transmissivity.

d. **Aeration Zone**: The zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. Plant roots can capture the moisture passing through this zone, but it cannot provide water for wells. Also known as the unsaturated zone or vadose zone.

PART 3

1. South. However, the plume could disperse from west to southeast/east since all of the wells located in those areas have lower water table elevations (WTEs).

2. Wells F and G and possibly D since those three wells have lower WTEs.

3. Yes, pumping water from well E will lower the WTE to 2,460 ft. This will remove the risk of well D becoming contaminated because well D’s WTE is 2,467 ft.

4. Pumping water will lower the WTE and the gradient, slowing the velocity of the contaminant plume.

5. D) More than 5 years

6.-9. See Remediation Table on page 27
SCIENCE OLYMPIAD
Science Olympiad is a nonprofit organization devoted to improving the quality of science education, increasing student interest in science and providing recognition for outstanding achievement in science education by both students and teachers.

These goals are accomplished through classroom activities, research, training workshops, and the encouragement of intramural, district, regional, state, and national tournaments.

Science Olympiad tournaments are academic competitions that consist of a series of individual and team events which students prepare for during the school year. These competitions are balanced among the various science disciplines of biology, earth science, chemistry, physics, computers, and technology.

For more information about Science Olympiad, visit their official website at www.soinc.org.

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