are they different? Compare personal costs, responsibility, solutions, etc.

6. Research and report on which governmental agencies (municipal, county, state, and federal) regulate and protect groundwater. How do these groups work together? Discuss roles that other groups play (for more information, see *Groundwater: Wisconsin's Buried Treasure*).

7. Research and report on how water resources have influenced the history of your community. How has water helped your community develop? Has groundwater played a special role? Many areas of Wisconsin are known for having "healthful" spring water. Is part of your community's history related to spring water? How does your community feel about protecting groundwater?

8. Groundwater is important in the production and processing of many Wisconsin products such as cheese, beer and paper. Investigate some of these products. How much water do they use? How clean should the water be? Are there laws or regulations that govern the quality of the water they use?

Trouble in Paradise

Learning Objectives: Students will: (1) determine the source of groundwater contamination in the mythical town of Paradise using knowledge gained from previous activities, (2) discuss the implications of groundwater contamination in Paradise and (3) recommend possible solutions to the groundwater contamination problem in Paradise.

Subjects: Environmental Education, Science, Health Education and Social Studies

WMASs: EE: A.8.4, A.8.5, B.8.10, B.8.15, B.8.17, B.8.21, B.8.23, C.8.2, D.8.1

SC: A.8.6, B.8.6, C.8.6, E.8.1

HE: A.8.2, G.8.3

SS: A.8.1, A.8.11, D.8.11

Grades: 7–9 (and up)

Materials:

- Trouble in Paradise handouts
- colored pencils—red, blue and green

Background: In this activity, wells in the mythical town of Paradise have been contaminated with volatile organic compounds (VOCs). VOCs are a group of commonly used chemicals that evaporate, or "volatilize" when exposed to air. Since they dissolve many other substances, VOCs are widely used as cleaning and liquifying agents in fuels, degreasers, solvents, cosmetics, polishes, drugs and dry cleaning solutions. VOCs are found at airports and service stations; machine, print and paint shops; electronics and chemical plants; dry cleaning establishments; and in household products. Two common VOCs—1,2-dichloroethylene and trichloroethylene—are referred to in this activity.

When VOCs are spilled or dumped, some will evaporate and some will soak into the ground. Once in the soil, VOCs can be carried deeper into the ground by percolating rainwater. If they reach the water table, VOCs can persist for years because the cool, dark, low-bacteria environment does not promote decomposition. If VOCs in groundwater migrate to nearby wells, they can end up in someone's drinking water.

At least one VOC has been detected in about 2,500 drinking water wells in Wisconsin. Over 80 different VOCs have been found in Wisconsin's groundwater, with trichloroethylene being the VOC most commonly found. Some 770 private or public water supply wells have had concentrations of at least one VOC above a Wisconsin groundwater standard.

Some VOCs can harm the central nervous system, liver and kidney. For these types of health effects, researchers can determine a "no-observable-effect level"— a maximum VOC dose that does not produce any effect in exposed experimental animals. This "no-observable-effect level" is further reduced by a safety factor, which ranges from one tenth to one ten thousandth (depending on the strength of scientific evidence). From this number state groundwater standards are established.

Some VOCs (such as trichloroethylene) are known or suspected carcinogens (cancer-causers). State groundwater standards for carcinogens in drinking water are conservatively set so that lifetime consumption of the water will cause no more than 1 to 10 additional cancers for every million persons exposed. Additional information on how Wisconsin groundwater quality standards are developed can be found in Wisconsin's groundwater law, chapter 160, Wis. Stats., at: **legis.state.wi.us/statutes/1993/93stat0160.pdf**. Chapter NR 140, Wis. Administrative Code, contains the groundwater quality standards that have been adopted in Wisconsin. NR 140 can be found online at: **legis.state.wi.us/rsb/code/nr/nr140.pdf.**

Federal drinking water standards (Maximum Contaminant Levels) are set in a similar manner by the U. S. Environmental Protection Agency. Check out **epa.gov/safewater/standards.html** for information on how federal drinking water standards are developed.

Several factors influence a well's vulnerability to VOC contamination. One factor is the distance between the well and the source or sources of contamination. Another factor is time. Groundwater usually moves very slowly and it can sometimes take years for a spilled contaminant to reach nearby wells. The time and distance contaminants must travel are extremely important because many wells which presently show no contamination may eventually become contaminated by spills that have already occurred. In other words, we may not know the full effects of contamination we already have caused for many years to come (For more information, see *Groundwater: Wisconsin's Buried Treasure*).

There are two options for dealing with VOC contamination. The well owner can either construct a new well or treat water from the contaminated one. Treatment of the well water has the benefit of removing contaminated water from the ground. Both options are expensive. Drilling a new municipal well can cost as much as $1 million or more; building a water treatment facility for a contaminated municipal well generally costs between $500,000 and $1 million.

Activity setting:

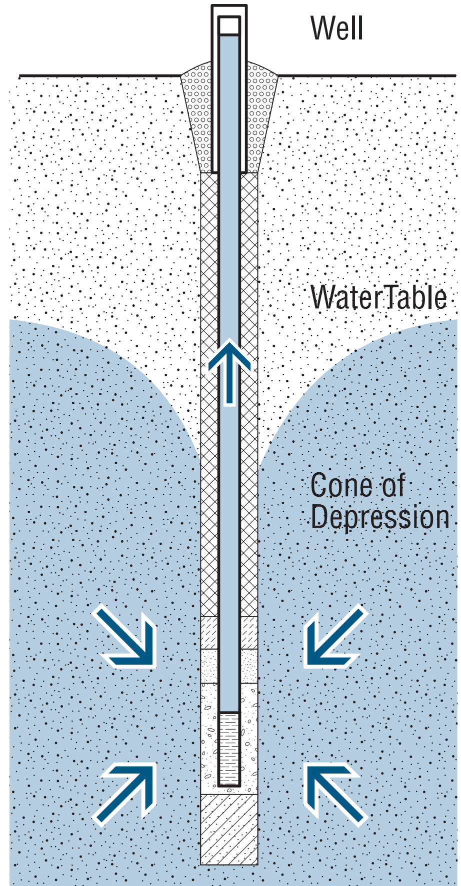
VOC contamination has occurred in "Paradise" and your students will be asked to determine where the VOCs came from and what should be done about the problem. The contamination was first noticed after the installation of a high capacity community well. Wells that draw a large volume of water can affect the direction and rate of groundwater flow by creating a "cone of depression." As groundwater is depleted under the well site, it is replaced by groundwater from soils surrounding the well. So even water that initially flowed away from the well can be drawn toward it as groundwater immediately under the well is removed.

The new municipal well in "Paradise" has created a cone of depression and is drawing water and the plume of VOC contamination toward itself. The source of contamination is the closed landfill at the Johnson farmsite which, while it operated, may have accepted wastes containing VOCs from local industries and households. This landfill was designed as a "natural attenuation" site, meaning that the landfill depended only on the characteristics of surrounding soils to contain and filter leachate from the waste deposited there. Today landfills must be lined with a layer of impermeable clay which helps to contain leachate. Modern waste disposal regulations also limit the type of wastes that can be deposited in a municipal landfill.

Note: The groundwater standard listed for 1,2-dichloroethylene (1,2-DCE) on the activity sheets is actually the groundwater standard for 1,2-dichloroethylene (cis), which is an isomer of 1,2-DCE. On the activity sheets, 1,2-DCE is considered to be one substance to simplify the exercise.

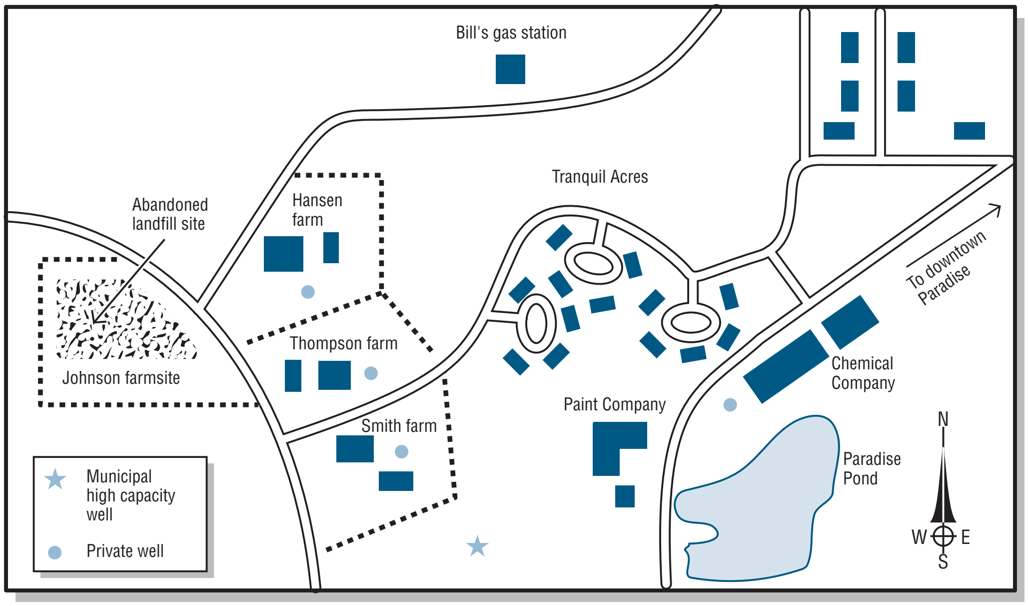
Procedure:

1. Using How Much is a Part per Billion? handout, discuss the idea of parts per trillion (ppt), parts per billion (ppb) and parts per million. Explain that drinking water standards and laboratory results are often stated in micrograms per liter (µg/L) which is equivalent to ppb. Because it's easier to understand the concept of ppb than µg/L, the Trouble in Paradise Activity Sheets use parts per billion.
2. Tell students that the mythical town they will be investigating is based on several Wisconsin communities that actually experienced groundwater contamination. Explain what VOCs are and their many sources. Briefly discuss how groundwater standards are set in Wisconsin.
3. Distribute "Trouble in Paradise" handouts. Have students read the case study.
4. Ask individual students to read aloud the problems on the activity sheet. Clarify any uncertainties about the problems.
5. Working in small groups, complete the activity sheet. Remind students that they will need to use the information given in the case study AND what they have learned in previous activities to answer the questions. It may be helpful to review the reading of topographic maps.
6. Using the completed worksheets, construct a master time line on the chalkboard. Discuss the time line and answers to activity sheet questions.
   - ❖ In what general direction does groundwater flow in Paradise?
   - ❖ What is the source of contamination? How do you know?
   - ❖ Where would you place test wells to confirm the source of contamination?
   - ❖ What is a plume of contamination?
   - ❖ How did the shape of the plume of VOC contamination change? What caused it to change?

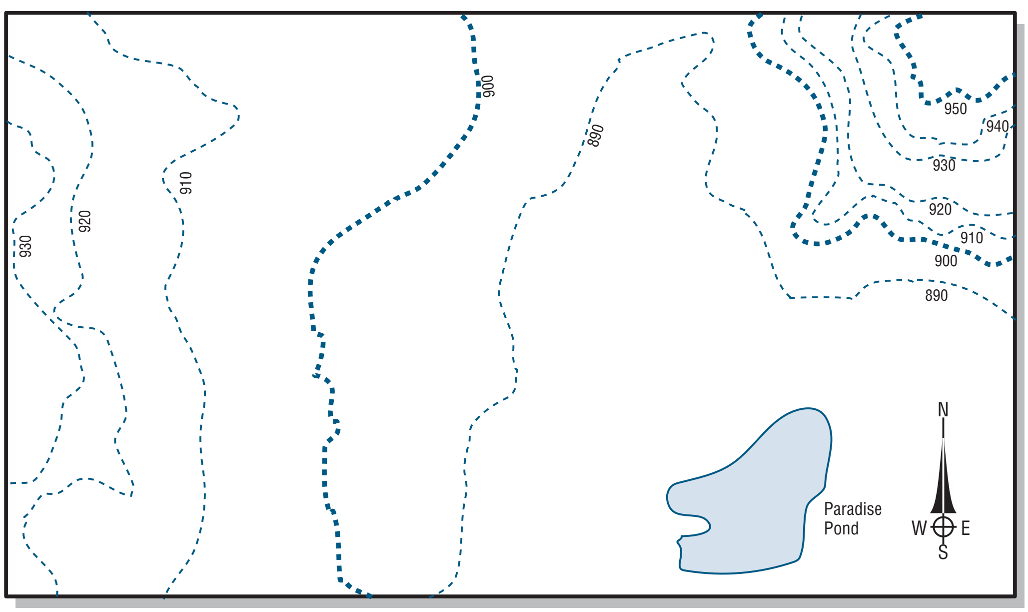


   - ❖ Why did it take so long for the VOCs to move from their source into surrounding wells?
   - ❖ Why did the contamination appear in the Hansens' well then seem to disappear?
   - ❖ Why was there such a delay between the time that VOCs were first discovered in the Hansens' well and when city officials decided to take action?
7. Discuss the implications of groundwater contamination in Paradise.
   - ❖ What are VOCs used for?
   - ❖ Who might have put materials containing VOCs in the landfill?
   - ❖ When is groundwater "contaminated"? Is water that contains 200 ppb 1,2-dichloroethylene considered contaminated? Is 200 ppb 1,2-dichloroethylene considered unhealthy?
   - ❖ Does contaminated necessarily mean unhealthy?

- ❖ Why do you think the groundwater standard for 1,2-DCE is so much higher than the MCL for trichloroethylene (TCE)?
- ❖ Who's to blame for the contamination?
- ❖ Who should pay to solve the problem?
- ❖ How did the citizens react to the contamination? Were their demands reasonable? What else could citizens do?
- ❖ How did the contamination affect private well owners?
- ❖ Should the Smiths' and Thompsons' well water be restored (either by construction of a new well or by treating water from existing wells)? If so, who should pay?
- ❖ Could the contamination affect the new community well?
- ❖ How long can Paradise's problem continue?
- ❖ If hazardous materials are removed from the landfill in Paradise, they may have to be moved to a hazardous waste landfill in another state. Is that fair? Who should pay to maintain and operate the disposal site?
- ❖ Could the contamination have been avoided? If so, how?
- ❖ What can Paradise do about the contamination now?
- ❖ Could your community have problems like this?
- ❖ How can your community help prevent groundwater contamination problems?



Map A



Map B

Going Beyond:

Going Beyond:

1. Using selected discussion questions as an outline, research and report on a groundwater contamination issue in your area.
2. Use the websites listed in this exercise as a starting point to learn how Wisconsin groundwater standards and federal Maximum Contaminant Levels are established. Look at the similarities and differences in how health standards are set and in which substances have standards at the state and federal level.
3. Have your students do calculations to understand the concepts of 1 part per million, 1 part per billion and 1 part per trillion. For example, how long is 1 million seconds? How long is 1 billion feet?

Adapted from: *Discovering Groundwater: A Supplementary Activities Guide for Upper Elementary Social Studies and Science Classes,* 1984, Wisconsin Department of Natural Resources, Western District (out of print).