



Aquifer Depletion: Waukesha, Wisconsin, U.S.A. and Sana'a, Yemen

Grade Level: 6th-8th
Subject Areas: Science and Social Studies
Length of Unit: Up to three weeks

Summary

The following unit helps students critically examine the issues surrounding global water supply by investigating aquifer depletion in Waukesha, Wisconsin, USA, and Sana'a, Yemen. Sana'a, the capital of Yemen, is located in the Middle East, one of the most water-scarce regions of the world. In contrast, Waukesha is located near the Great Lakes, an area with abundant fresh water resources. Yet both regions risk losing their supply of fresh water through aquifer depletion. Using scientific and geographic data, students will compare these cases, observing how economic, social, cultural, and political context affects this global environmental issue. The unit begins with information and activities to help students gain a general understanding of world water supply and aquifer depletion. After the introductory activities, students study the Waukesha aquifer issue in depth. Students' understanding of this local environmental issue will help them connect with water supply issues in Sana'a, Yemen. In order to gain a global perspective of the issue, students conclude the unit by creating a list of international guidelines that encourage environmental, social, and economic sustainability.

Goals

- Increase students' awareness of environmental issues on a local and global scale.
- Foster understanding of students' citizenship in local and global communities.
- Increase students' awareness of world geography and global connections.

Wisconsin's Model Academic Standards Correlations

Social Studies

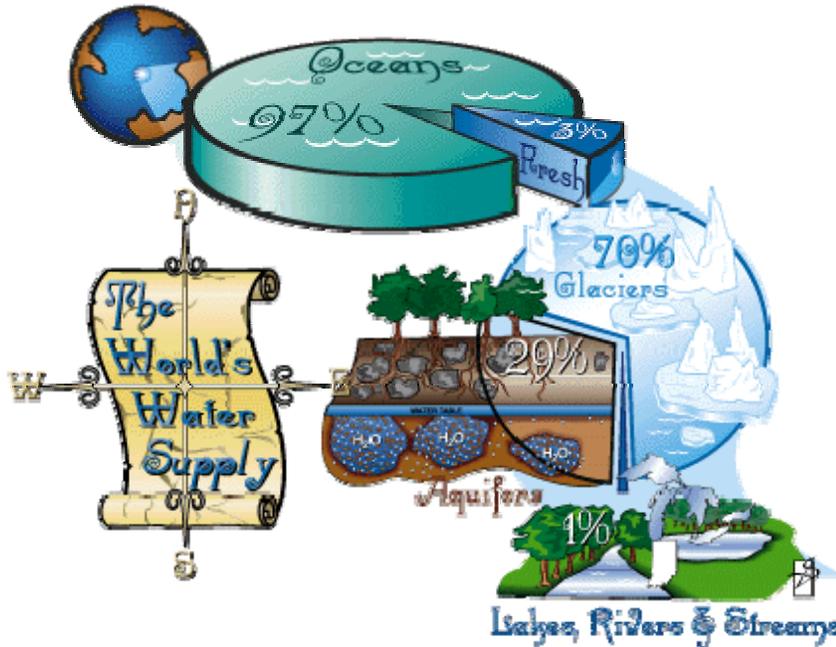
- Geography: A.8.1, A.8.3, A.8.4, A.8.5, A.8.7, A.8.8, A.8.11
- Political Science and Citizenship: C.8.7, C.8.8, C.8.9
- Economics: D.8.11
- Behavioral Sciences: E.8.4

Science

- Life and Environmental Science: F.8.8, F.8.9, F.8.10
- Science in Personal and Social Perspectives: H.8.1, H.8.2, H.8.3

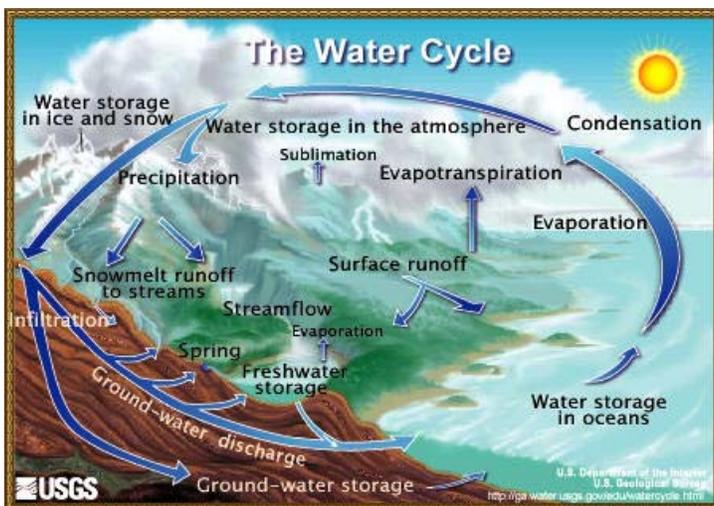
I: Introduction/Overview of Issue

A glance at the globe suggests an inexhaustible supply of water. However, over 97% of the earth's water is salt water in oceans. The remaining 3% is fresh water, most of which is frozen in glaciers, ice caps, and snow covered mountains. Only about 1% of the earth's water is liquid fresh water available for daily water supply needs. Liquid fresh water exists as surface water in lakes, rivers, and streams (about 22,300 cubic miles) and as groundwater (about 2,526,000 cubic miles).



From <http://www.purdue.edu/dp/envirosoft/groundwater/src/supply.htm>
More info: <http://www.theglobaleducationproject.org/fresh-water.php>

Groundwater accounts for 2/3 of the world's liquid freshwater supply. Groundwater is located within aquifers, underground layers of porous rock and soil. When water falls to the ground as rain, some flows into streams, rivers, and lakes, some evaporates into the atmosphere, and some seeps into the ground, eventually finding its way into aquifers where much of it is held. This underground water moves very slowly and may take a long time to recharge or refill.



From: <http://ga.water.usgs.gov/edu/watercycle.html>

People around the globe use the earth's supply of liquid fresh water for various purposes. Agriculture uses the most water (42%), followed by electricity generation (39%), homes/offices/hotels (11%), and manufacturing and mining (8%). The earth's freshwater supply is limited, but the world's population is growing at about 80 million people a year. Therefore, an additional 64 billion cubic meters of water need to be found each year. People around the world access groundwater through wells. Powerful diesel and electric pumps have allowed people to access water much more easily than by hand. The combination of population growth and easier access threatens water supplies. As the demand for water increases, increasingly deeper wells must be dug. Water that comes from deeper below the earth's surface is more likely to be contaminated with naturally occurring minerals, such as radium, because it has been in contact with rock formations for hundreds or thousands of years and minerals have dissolved into the water. Since aquifers recharge slowly, wells will eventually run dry.

This unit examines two examples of aquifer depletion: Waukesha, Wisconsin, USA, and Sana'a, Yemen. Sana'a, the capital of Yemen, is located in the Middle East, one of the most water-scarce regions of the world. In contrast, Waukesha is located near the Great Lakes, an area with abundant water resources. Yet both regions risk losing their supply of fresh water as their aquifers are depleted.

Sources:

http://www.epa.gov/NE/students/pdfs/ww_intro.pdf
<http://academic.evergreen.edu/g/grossmaz/WATER/>
<http://www.purdue.edu/dp/envirosoft/groundwater/src/intro.htm>
<http://dnr.wi.gov/org/water/dwg/gw/education/groundwaterguide/groundwaterguide.pdf>
<http://www.prb.org/>
<http://ga.water.usgs.gov/edu/earthwherewater.html>

II: Waukesha, Wisconsin

Background Information

Wisconsin has a great wealth of fresh water. On the surface, Wisconsin has 1 million acres of lakes, 5 million acres of wetlands, and 32,000 miles of streams, as well as 6.4 million acres of Lakes Michigan and Superior. Underground, Wisconsin has 1.5 quadrillion gallons of groundwater, from which 70% of the state's residents get their drinking water.

This immense amount of water seems inexhaustible. However, there has been growing concern as certain regions in the state begin to deplete the aquifers on which they depend for water. Waukesha, a city located about 15 miles west of Milwaukee in Southeastern Wisconsin, has been the center of a controversy which illustrates some issues with water use today.

In the late 19th century, Waukesha was a resort town known for the healing properties of its mineral-rich water. Lake Michigan was polluted, leading officials in Chicago and Milwaukee to look to Waukesha as a water source. In one incident in 1892, the people of Waukesha used pistols, pitchforks, and fire hoses to protect their water supply from speculators. Today, Waukesha is depleting its aquifer and Waukesha city officials are looking to Lake Michigan as a potential water source.

Today Waukesha is a city of 67,658. The population of Waukesha continues to grow, increasing 4.4% between 2000 and 2005. This increase in population has led to an increased demand for water. In fact, southeastern Wisconsin has the deepest groundwater drawdown (a lowering of groundwater due to pumping) in the state. The drawdown in Waukesha started slowly in the 1880s, but sped up in the late

1980s and throughout the next 15 years. Currently, the water level has dropped more than 600 feet below its original level. As the demand for water increases, deeper and deeper wells must be dug. Water that comes from deeper below the earth's surface is more likely to be contaminated with naturally occurring minerals, such as radium, because it has been in contact with rock formations for hundreds or thousands of years and minerals have dissolved into the water. The radium content of Waukesha's water is more than double the acceptable level set by the EPA in 2000. Radium exposure over a lifetime has been linked to higher risk of cancer.

One solution proposed by City of Waukesha officials is to build a pipeline to access Lake Michigan water. However, in 2001, a water protection plan entitled "Annex 2001" was developed. In December 2005, the plan was signed by governors and premiers of 8 US states & 2 Canadian provinces. The plan's goal is to protect the region from export and diversion of Great Lakes water. The plan bans new diversions of water outside the Great Lakes natural basin. Waukesha is 5 miles west of the subcontinental divide which is the western boundary of the Great Lakes basin. Water west of the subcontinental divide goes into the Mississippi River system and water east of the divide goes into the Great Lakes, so Waukesha's water goes into the Mississippi system. According to the plan, treated wastewater is supposed to be returned to the Great Lakes so it remains in the Great Lakes water system. However, the Waukesha officials propose dumping treated wastewater into the Mississippi system (Fox River) because they say it would be too expensive to send it back to Lake Michigan. The water would be permanently removed from the Great Lakes water system. In spite of Annex 2001, city officials hope their proposal will be approved by U.S. and Canadian officials. Supporters of this proposal state that the amount of water Waukesha would take would not stress the Great Lakes' water supply. Critics of Waukesha's plan say that the problem is not that the amount of water used by Waukesha would damage the Great Lakes, but that a precedent will be set. Perhaps states in the West that are desperate for water, such as Arizona, Nevada, and California, would look to the Great Lakes as a potential water source. Another suggested solution for Waukesha's water supply issues is water conservation. A third proposed solution is to obtain water from west of Waukesha which would cost twice as much.

Sources:

<http://www.madison.com/archives/read.php?ref=/tct/2006/06/05/0606050373.php>

<http://wri.wisc.edu/GroundwaterDrawdown.pdf>

<http://select.nytimes.com/gst/abstract.html?res=F10713F73F5A0C718DDDA10894DD404482>

<http://www.jsonline.com/story/index.aspx?id=469909>

http://www.greatlakesdirectory.org/wi/013106_great_lakes.htm

<http://www.madison.com/archives/read.php?ref=/wsj/2005/12/05/0512050058.php>

III: Sana'a, Yemen

Background Information

Sana'a, the capital of Yemen, is located at 7223 feet (2200 meters) above sea level, on a plateau surrounded by several mountains. The old part of the city has been inhabited for more than 2500 years and was designated a UNESCO World Heritage city. It is a generally dry place with low rainfall and limited surface water (few rivers or streams). The main source of water in the region is groundwater.

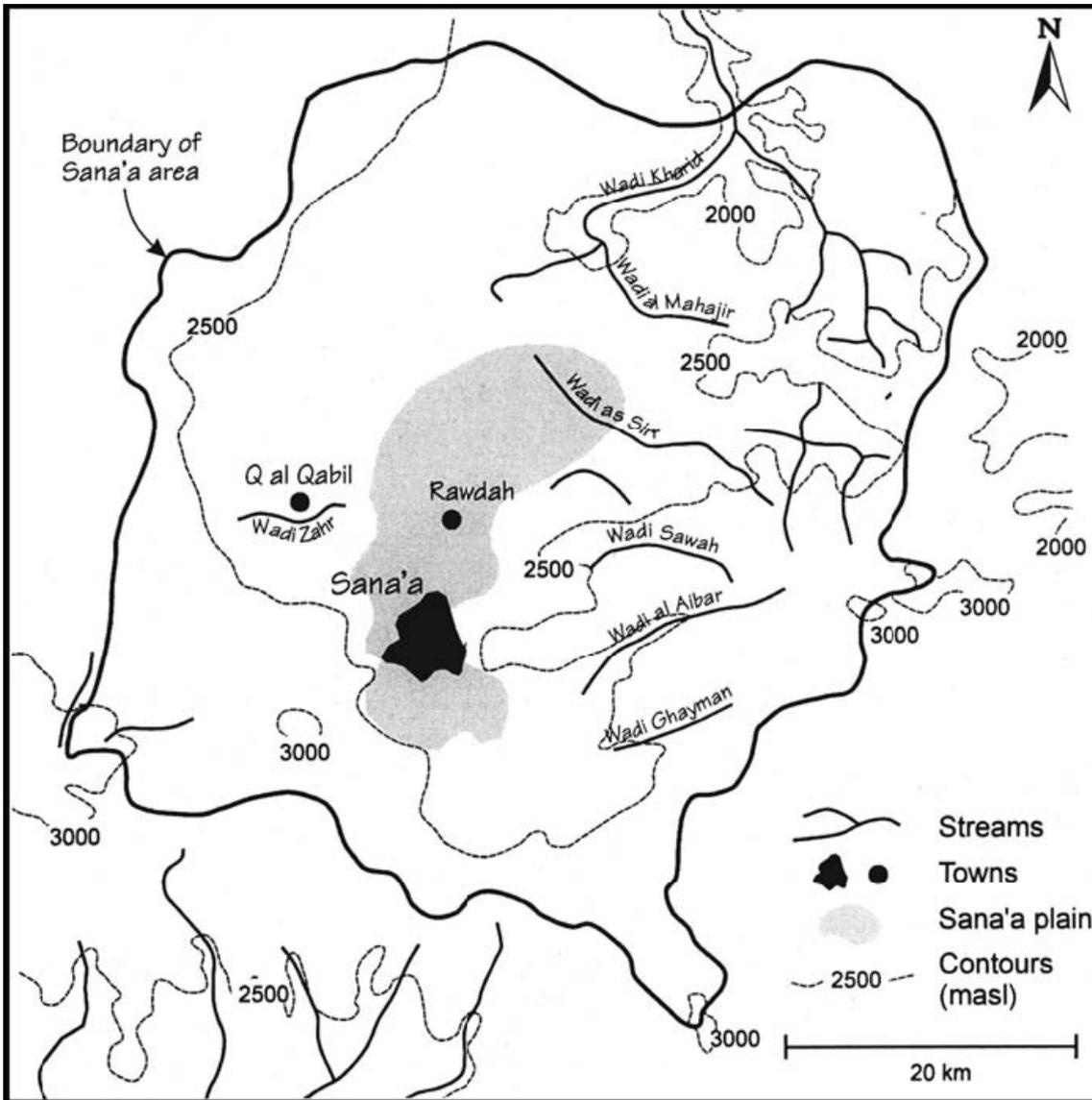
Yemen has one of the highest population growth rates in the world at 3.6% (in comparison the U.S. has a population growth rate of 0.91%). Sana'a, with a population of 1,747,627, is growing at an even higher rate as people move from the rural areas to the city. The population increase raises demand for water for drinking and growing food. Yemen is one of the world's poorest countries. 60% of the people work as

farmers. Agriculture in the Sana'a basin area accounts for 80% of water demand. Cultivation of qat (a tree that has leaves that are chewed as a stimulant in Yemen) and grapes (a cash crop) consume the majority of the water.

Besides population growth, another reason for the increase in water use is the change from traditional farming and water management methods suitable for the region to modern farming techniques such as powerful water pumps which allow people to withdraw much more water.

Major Features of Sana'a Basin

From http://www.who.int/water_sanitation_health/resourcesquality/wpccasestudy13.pdf



(Sources: <http://www.earth-policy.org/Updates/Update15.htm> & http://www.who.int/water_sanitation_health/resourcesquality/wpccasestudy13.pdf)

Sana'a's aquifers are dropping at a rate of about 20 feet per year. If this rate continues they will be depleted by the end of decade. The groundwater is used in irrigated agriculture, industry, and households. Due to low rainfall, the groundwater does not recharge at a rate that can keep up with current demand and is therefore a (mostly) nonrenewable resource. In the Sana'a region farmers and the city are competing for water.

According to a 1997 report by the United Nations Environment Program (UNEP) and the World Health Organization(WHO), the reasons for overuse of groundwater are:

- Unclear water rights and thus unregulated extraction;
- Fuel subsidies and low import duties on agricultural equipment;
- High returns on cash crops;
- Inefficient irrigation practices.

In order to address water supply issues, the Yemeni government has prohibited the drilling of new wells without a permit and prohibited the establishment of new industries that consume large amounts of water. However, this has not been enough to stop depletion of the city's aquifers. Some other suggested solutions are to bring water from somewhere else, such as coastal desalination plants, or to relocate the capital. Some solutions suggested by UNEP/WHO report were to reuse wastewater in the city and to conserve agricultural water.

Sources:

http://www.who.int/water_sanitation_health/resourcesquality/wpccasestudy13.pdf

<http://www.earth-policy.org/Indicators/indicator7.htm>

<http://www.al-bab.com/bys/articles/ward01.htm>

IV. Activities

(Note: These activities have been aligned with Wisconsin's Model Academic Standards for Social Studies and Science. Specific standards are noted at the beginning or end of each activity in **bold**. SS = social studies standards, SC = science standards)

- Begin with basic information about groundwater. The Groundwater Study Guide produced by the Wisconsin Department of Natural Resources has excellent activities on the water cycle, how groundwater moves, wells, household water, and resource protection. Of particular use is the section on Wisconsin's Major Aquifers. The entire study guide is available at:
<http://dnr.wi.gov/org/water/dwg/gw/education/groundwaterguide/groundwaterguide.pdf>
- **SS A.8.1:** Have the students use a variety of geographic representations, such as political, physical, and topographic maps, a globe, aerial photographs, and satellite images, to gather and compare information about Waukesha, Sana'a, and their surrounding regions. On blank maps of the United States and Yemen have students locate Waukesha and Sana'a, labeling nearby political and physical features, and other relevant information.

Some suggested maps:

- Water Use in Wisconsin, 2000 from the USGS:
<http://wi.water.usgs.gov/pubs/ofr-02-356/ofr-02-356.pdf>
- Various maps of Yemen, including political, shaded relief, rainfall, population density, and land use: www.lib.utexas.edu/maps/yemen.html
- Map of San'a:
http://www.who.int/water_sanitation_health/resourcesquality/wpccasestudy13.pdf
- Maps of Waukesha: www.topozone.com
- Blank maps: <http://geography.about.com/library/blank/blxindex.htm?once=true&>

- **SS A.8.1:** Have students use EarthKAM (<http://www.earthkam.ucsd.edu/>) to view images of the Great Lakes region and the Middle East taken by the space shuttle and the international space station. Students can even take their own pictures of these regions.
- **SS A.8.3:** Have students use an atlas to identify the dominant patterns of land use in Waukesha County and the Sana'a region and make a hypothesis about the reason for aquifer depletion.
 - Land use map of Yemen:
http://www.lib.utexas.edu/maps/middle_east_and_asia/yemen_land_use_2002.jpg
 - Land use map of Waukesha:
<http://maps.waukeshacounty.gov/GISweb/waukco/waukco.asp>
 - Land use map of Wisconsin:
<http://www.pats.wisc.edu/landuse/rpcmaps.htm>
- **SS A.8.4:** Have students conduct a historical study of water use in Waukesha and explain the effect of this use on the environment. For example, have the students think about the following question: How has the groundwater drawdown affected the streams, rivers, lakes, and/or wetlands near Waukesha? Have students make a timeline of a brief history of both Waukesha and Sana'a with a focus on water.
 - Resources for history of Waukesha:
<http://www.wisconsinstories.org/2002season/water/journey.cfm>
<http://www.wisconsinstories.org/2002season/water/learn.cfm>
<http://www.waukeshacountymuseum.org/>
<http://www.waukeshacounty.gov/cm/History%20Waukesha.html>
<http://www.visitwaukesha.org/historytext.html>
 - Resources for history of Sana'a
<http://en.wikipedia.org/wiki/Sana%C3%A1>
http://www.arab.net/yemen/yn_sanaa.htm
<http://muslimheritage.com/topics/default.cfm?ArticleID=587>
- **SS A.8.5:** Using a statistical atlas, aerial photographs, satellite images, and computer databases, have the students identify and compare Wisconsin and Yemen's water supplies, including both surface and ground water. Have the students make charts that compare annual rainfall, total groundwater and surface water, and other statistics for each region.

Two helpful resources:
http://www.earthtrends.wri.org/pdf_library/country_profiles/wat_cou_887.pdf
<http://wi.water.usgs.gov/pubs/ofr-02-356/ofr-02-356.pdf>
- **SS A.8.7:** Have the students describe the movement of people throughout the world, using Waukesha and Sana'a as examples. Have the students examine the following questions: Why are people migrating to Waukesha? Why are they migrating to Sana'a? Then, have the students examine their own family histories for migration patterns. Why have their families migrated to different regions over time?
- Have students explore web sites, watch videos, read newspaper editorials, and listen to guest speakers that present different perspectives on world water supply issues. To help them keep track of the key players, use Student Handout #1. Some possible videos to use for this activity

are located at Wisconsin's Water Library:

<http://www.aqua.wisc.edu/waterlibrary/videoselections2.asp>

Helpful newspapers are: Milwaukee Journal Sentinel & Yemen Times.

- **SS A.8.11:** Have students examine the causes and consequences of aquifer depletion, a current global issue. Have the students brainstorm possible responses by various individuals, groups, and nations that would prevent aquifer depletion.
- **SC F.8.8, SC F.8.9:** Have the students show through investigations how organisms both depend on and contribute to the balance or imbalance of populations and/or ecosystems, which in turn contribute to the total system of life on the planet. Have the students answer the following questions: Does aquifer depletion affect the balance of ecosystems? If so, how? How does it affect the survival or population growth of certain species? If so, how?
- **SC F.8.10** Have the students project how current trends in water use and population growth will influence the natural environment, and show how current policies (Annex 2001 & Yemeni government policies, for example) affect those trends.
- Using Student Handout #3, have the students compare and contrast water issues in Waukesha and Sana'a.
- **Simulation:** Have students participate in a class simulation about what should be done about world water supply issues.
 - a. Before students start to do their research on the issue, have the students practice evaluating the scientific evidence used in various media (for example, television, radio, Internet, popular press, and scientific journals) using criteria of accuracy, logic, bias, relevance of data, and credibility of sources. (**SC H.8.1**)
 - b. Divide the students into small groups each representing the key players in the debate. Some key players include: international organizations, government officials, developers, farmers, city residents, environmentalists, etc.
 - c. Have the students locate, organize, and use relevant information to understand aquifer depletion. Students may refer to newspaper editorials, websites, and other sources of information about the issue. (**SS C.8.7**)
 - d. Have the students research their position and develop their arguments. As they develop their arguments have the students keep in mind that part of their solution should be scientific (**SC H.8.2**) and they should keep in mind the way their solution affects personal health and safety (**SC H.8.3**). Students should prepare to take a position and advocate the position in a debate (**SS C.8.7**).
 - e. Have the students present and discuss "in character" in an international summit style debate. During the debate have students fill in Student Handout #2. (**SS C.8.7**).
 - f. After the simulation have students step out of character and discuss which arguments they find most compelling. As a class make a list of possible solutions. Some suggestions that might improve the situation are: (**SS A.8.11, SC H.8.2**)

- g. Have the students deliberate and decide which solutions would work best. Students should consider how individuals, groups, and institutions could impact aquifer depletion at the local, state, national, & international levels while aiming to promote environmental, social, and economic sustainability. Have the students use Student Handout #2 to evaluate their solutions. **(SS E.8.4)**
- h. Have the students rank the solutions and discuss criteria that are guiding their choices. Have students come to a consensus for what they see as the best solutions and make a class list. **(SS A.8.11)**
- i. Have the students brainstorm ways they can take action to enact their solutions. (For more information on general environmental action strategies see Hungerford, H. et al. 2003. *Investigating and Evaluating Environmental Issues and Action: Skill Development Program*. Stipes Publishing.) Some ways of taking action might include: educating the school and community about the issue, promoting water conservation, or writing letters to government officials. **(SS A.8.11)**

Debriefing questions:

- How was the simulation similar and different from ways in which real advocates participate in public policy debates? **(SS C.8.8)**
- What role should/do international organizations play in this issue? **(SS C.8.9)**
- Describe how personal decisions can have a global impact on issues such as water use **(SS D.8.11)**.

V. Assessment

- Have the students create presentations for other classes or for a school assembly. The students should design a rubric for what would make a good presentation. Then, have them evaluate themselves and each other. The teacher should assess them as well.
- Have the students write a persuasive essay about world water issues.

VI. Resources

1. Articles/Guides

Amnesty International

<http://web.amnesty.org/pages/ec-water-eng>

Barringer, Felicity. NYT. Aug 12, 2005.

<http://select.nytimes.com/gst/abstract.html?res=F10713F73F5A0C718DDDA10894DD404482>

British-Yemeni Society

<http://www.al-bab.com/bys/articles/ward01.htm>

Earth Policy Institute

<http://www.earth-policy.org/Indicators/indicator7.htm>

http://www.earth-policy.org/Books/EPR_contents.htm
<http://www.earth-policy.org/Updates/Update15.htm>
http://www.greatlakesdirectory.org/zarticles/080902_water_shortages.htm
http://www.earth-policy.org/Books/Epr/Epr1_ss9.htm

Enriquez. Milwaukee Journal Sentinel. June 4, 2006

Flesher, John. Wisconsin State Journal. Dec. 5, 2005.
<http://www.madison.com/archives/read.php?ref=/wsj/2005/12/05/0512050058.php>

Food and Agriculture Organization of the United Nations
<http://www.fao.org/countryProfiles/water/default.asp?search=search&iso3=YEM>

Groundwater Resources of Southeastern Wisconsin
Southeastern Wisconsin Regional Planning Commission/Wisconsin Geological and Natural
History Survey
http://www.sewrpc.org/publications/techrep/tr-037_groundwater_resources.pdf

Milwaukee Journal Sentinel Article, unknown author,
http://www.greatlakesdirectory.org/wi/013106_great_lakes.htm

People and the Planet
<http://www.peopleandplanet.net/doc.php?id=1901>

Rowen, James. The Capital Times. June 5, 2006
<http://www.madison.com/archives/read.php?ref=/tct/2006/06/05/0606050373.php>

Wisconsin Natural Resources Magazine
<http://www.wnrmag.com/supps/2006/apr06/using.htm#sub3>

World Resources Institute
http://www.earthtrends.wri.org/pdf_library/country_profiles/wat_cou_887.pdf
<http://wri.wisc.edu/GroundwaterDrawdown.pdf>

2. Curriculum

Wisconsin Department of Natural Resources
The Groundwater Study Guide
<http://dnr.wi.gov/org/water/dwg/gw/education/groundwaterguide/groundwaterguide.pdf>

3. Historical Information

Waukesha:
<http://www.wisconsinstories.org/2002season/water/journey.cfm>
<http://www.wisconsinstories.org/2002season/water/learn.cfm>
<http://www.waukeshacountymuseum.org/>
<http://www.waukeshacounty.gov/cm/History%20Waukesha.html>
<http://www.visitwaukesha.org/historytext.html>

Sana'a
<http://en.wikipedia.org/wiki/Sana%C3%A1>
http://www.arab.net/yemen/yn_sanaa.htm

<http://muslimheritage.com/topics/default.cfm?ArticleID=587>

4. Websites

Amnesty International

<http://www.amnesty.org/>

CIA: The World Factbook

<http://www.cia.gov/cia/publications/factbook/index.html>

Clean Water Action Council

<http://www.cwac.net/groundwater/index.html>

Earth Policy Institute

<http://www.earth-policy.org>

EPA

<http://www.epa.gov/ebtpages/wategroundwater.html>

Food and Agriculture Organization of the United Nations

<http://www.fao.org>

Groundwater Guardian Program.

<http://www.uwsp.edu/cnr/gwguardian/>

People and the Planet

<http://www.peopleandplanet.net>

USGS

<http://wi.water.usgs.gov/>

<http://wi.water.usgs.gov/glpf/>

UW-Eau Claire class website

<http://academic.evergreen.edu/g/grossmaz/WATER/>

Water Resources Institute

<http://www.wri.wisc.edu/>

Wisconsin Department of Natural Resources

<http://www.dnr.state.wi.us/>

Wisconsin Historical Society

<http://www.wisconsinhistory.org/turningpoints/>

Wisconsin Resources Protection Council

<http://www.wrpc.net/home.html>

Wisconsin Stewardship Network

<http://www.wsn.org/mining.html>

World Resources Institute

<http://www.earthtrends.wri.org>

5. Newspapers

The Capital Times and Wisconsin State Journal Archives
<http://www.madison.com/archives/>

Milwaukee Journal Sentinel
<http://www.jsonline.com/>

Yemen Times
<http://yementimes.com/index.shtml>

6. Video/Audio

Great videos on Wisconsin's groundwater at Wisconsin's Water Library
<http://www.aqua.wisc.edu/waterlibrary/videoselections2.asp>

7. Maps

USGS Maps Water Use in Wisconsin, 2000
<http://wi.water.usgs.gov/pubs/ofr-02-356/ofr-02-356.pdf>

Various maps of Yemen, including political, shaded relief, rainfall, population density, and land use: www.lib.utexas.edu/maps/yemen.html

Map of San'a: http://www.who.int/water_sanitation_health/resourcesquality/wpccasestudy13.pdf

Maps of Waukesha: www.topozone.com

Blank maps: <http://geography.about.com/library/blank/blxindex.htm?once=true&>

8. Groundwater Glossaries

<http://www.groundwater.org/gi/gwglossary.html>

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Created: September 2006
Last updated: September 2006

Players	How are they affected?	How do they perceive the issue?	What are their values?	What are their needs & desires?

Based on a handout by Pennock, M. & L. Bardwell. 1994. *Approaching Environmental Issues in the Classroom*. University of Michigan. p. 35. For more information on defining the issue and environmental beliefs and values see: Hungerford, H. et al. 2003. *Investigating and Evaluating Environmental Issues and Actions*. Illinois: Stipes Publishing.

1. What is the solution?

2. What values are served? (fairness, efficiency, productivity, etc.)

3. Whose needs are met? (Are there trade-offs? Can one solution work for all?)

4. What are the positive effects? (for the interested parties; for the environment)

5. What are the negative effects?

6. What groups are needed for implementation?

7. What are barriers to the solution? (political/economic/cultural/practical)

8. What other solutions can you think of?

Student Handout #3

Aquifer Depletion in Waukesha, Wisconsin, USA and Sana'a, Yemen: Compare and Contrast

Directions: In the first circle list ideas that are true for water issues in Waukesha **only**. In the second circle list ideas that are true for water issues in Sana'a **only**. In the space where the circles overlap, list ideas that are true of **both** the Waukesha and Sana'a.

