ALMIGHTY AQUIFERS

People and the Planet
Lessons for a Sustainable Future

INTRODUCTION

All humans require freshwater to survive, but how humans find freshwater varies all over the world. Some places have access to water that can easily be found in streams, rivers or lakes (also known as **surface water)**. However, most humans rely on **groundwater**, which makes up 98 percent of all usable freshwater. **Aquifers** are underground deposits of water that feed wells and springs and can range in size and depth, spanning very small areas of land or areas as large as some countries.

One of the largest aquifers in the world is the Ogallala Aquifer (pronounced "o-gah-LA-la"), located in the High Plains region of the United States. This aquifer covers 174,000 square miles (or 450,000 square kilometers), can be up to 1,000 feet deep, and lies underneath eight U.S. states: South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico and Texas. The Ogallala Formation is thickest in West-central Nebraska, accounting for 37 percent of the total aquifer area, whereas South Dakota covers the least amount of the Ogallala, accounting for a mere 3 percent. Because the water in the Ogallala is the result of geological processes that took millions of years, it is essentially a **finite** resource. With use, the water level declines. Scientists say it would take natural processes 6,000 years to refill the reservoir.

While people have lived on the High Plains for centuries, it wasn't until the 1940s that we began using diesel-powered pumps to extract water from the Ogallala. Soon there were tens of thousands of irrigation wells on the prairie and the region became one of the wealthiest agricultural areas in the country. Groundwater withdrawals increased five-fold between 1949 and 1974 and the water table levels started to drop dramatically. Today the Ogallala Aquifer is being depleted at an annual volume equivalent to 18 Colorado Rivers! Although rain, snow and river systems are recharging a few parts of the aquifer, nature can't keep up with the demand.

CONCEPT

Throughout the U.S., aquifers have been depleted as population has increased and the demand for water has grown.

OBJECTIVES

Students will be able to:

- Identify the states that overlay the Ogallala Aquifer.
- Make connections between human population growth and the depletion of the Ogallala Aquifer.
- Name two human actions that can contribute to aquifer depletion.

SUBJECTS

Science (Earth and environmental), social studies (geography, history)

SKILLS

Critical thinking, observing, modeling natural systems, comparing and evaluating, identifying trends and patterns

METHODS

Students participate in a game that mimics the relationship between population growth and aquifer depletion.

Currently, the United States is the third most populated country in the world and as the population grows, we become increasingly dependent on having steady, large sources of freshwater – not only for municipal use, but also for industries such as agriculture and mining. Hydrologists believe that the Ogallala Aquifer may not be able to sustain the current demand for freshwater and could be drained in the next few decades, threatening the security and health of our country and future generations.

MATERIALS

For each group:

- Game Board (provided)
- Script Sheets 1 – 4 (provided)
- State Boards 1 – 4 (provided)
- Groundwater Tiles (provided)
- 6 sealable baggies

PROCEDURE

1. Before class, make a set of Groundwater Tiles for each group. The Tiles will need to be cut, separated by decade, and placed in sealable bags labeled with the appropriate dates. Print and cut out both pages of the Gameboard and tape together the two sides.

   Note: The game will work best if the Groundwater Tiles are printed in color.

2. Read aloud, or have students round-robin read, from the 'Introduction' above about the Ogallala Aquifer. You may also want to display images of the Ogallala, as found here: http://ne.water.usgs.gov/ogw/hpwlms/physsett.html.

3. Divide the class into groups of four and distribute a set of materials to each group. Explain that they will be playing a game to see how groundwater has been depleted from the Ogallala Aquifer over time. Groups should decide who will be Player 1, 2, 3, and 4 and give the appropriate State Board and Script Sheet to each player.

   Player 1 = Kansas and Colorado
   Player 2 = Nebraska and New Mexico
   Player 3 = Oklahoma and South Dakota
   Player 4 = Texas and Wyoming

4. Instruct students to place the Game Board in the center of the group and scatter all but one of the 1 km^3 of the Groundwater Tiles for 1950 on the Board, within the outline of the Ogallala, to represent the water stored in the aquifer at that time. This will be the only round that a tile remains in the bag.

5. Read aloud the following paragraph to the class:

"Imagine that you are a representative of your two states in 1950. At this point, the total amount of groundwater that has been withdrawn from the Ogallala Aquifer is 154 km^3, or cubic kilometers. (1 km^3 of water is equivalent to approximately 400,000 Olympic-sized swimming pools.) As we play this game, we will be moving forward in time from the year 1950 to the year 2000; each round will be a new decade. Every round, players will take turns reading aloud the Script Sheet for each of their states. Based on your scripts, you will draw the correct amount of Groundwater Tiles from the Ogallala and place them on your State Board, face up and within the outline of the appropriate state. This represents your state withdrawing water from the aquifer. Let's do the script for Player 1, round 1 together."

6. Player 1 will read the round 1 (1950) script for Colorado to the group and then collect 9 km^3 from the Ogallala (as indicated in the script) and place it within the Colorado outline on their State Card. They will repeat this for Kansas, round 1.

7. Players 2 – 4 should then repeat this process, reading their round 1 scripts for each state, collecting the appropriate amount of Groundwater Tiles, and displaying them face up in the appropriate state on their State Card.

8. After round 1 is complete, the group should add the Groundwater Tiles for 1960 to the Ogallala on the Game Board. Now that they have a good sense of how to play the game, ask students to keep in mind the following questions as they play the remaining rounds. (You may want to write these on the board.) Students can take notes on the back of their Script Sheets to record their thinking through the game.

    a. Do you see a relationship between population and groundwater withdrawal?
    b. What are some of the reasons that states use groundwater?

9. Each group can now continue to play the game for rounds 2 through 6.

10. After all of the rounds have been played, tell students to use their Script Sheets to determine the total population increase for each of their states, and the total aquifer withdrawal, in km^3.

11. Go over the Discussion Questions as a class. For some of the questions, students will need to discuss in their groups first.

<u>Answers to Script Sheets</u>
Total Population Increase: CO – 3,000,000; KS – 800,000; NE – 400,000; NM – 1,100,000; OK – 1,300,000; SD – 100,000; TX – 13,200,000; WY – 200,000

Total Aquifer Withdrawal: CO – 14 km^3; KS – 66 km^3; NE – -1 km^3 (recharge); NM – 11 km^3; OK – 13 km^3; SD – 0 km^3; TX – 176 km^3; WY – 0 km^3

DISCUSSION QUESTIONS

1. How much did population grow between 1950 and 2000 for all the states that draw from the Ogallala Aquifer?

   Population grew by 20,100,000 people.

2. Which state experienced the most population growth? Which state experienced the least?

   Texas experienced the most population growth. South Dakota experienced the least.

3. What did you notice about the relationship between population and groundwater withdrawal in your area? Were there any patterns?

   At times, there was a direct relationship between states' population growth and groundwater withdrawal. Texas, for instance, has the largest population of the states above the Ogallala, as well as the greatest amount of groundwater withdrawal. In contrast, Nebraska experiences population growth surges, but even though population increases, water depletion does not. It's important to remind students about the geographical and climate differences between the states that have access to the Ogallala.

4. Did each state's population always grow? Did every state always draw groundwater from the Ogallala?

   No, some states had static populations. For instance, Nebraska from 1980-1990. In addition, South Dakota experiences a static population from 1960-1990. This is because these population numbers are rounded to the nearest 100,000. Not every state drew from the Ogallala each decade. Wyoming and South Dakota are examples of this.

5. What is special about Nebraska's groundwater withdrawal?

   Nebraska is an example of a state that experiences negative withdrawal – in other words, the aquifer recharges (or refills) itself here. There are two primary natural sources for recharge in the Ogallala – snowmelt and precipitation. Not only does Nebraska contribute to the Ogallala, but it also has access to the largest percentage of the aquifer – 37 percent.

6. Considering that snowmelt and precipitation are main sources for aquifer recharge, how do you think aquifer withdrawal might change during times of extended drought?

   During periods of extended drought, there is not enough precipitation for aquifers to recharge at their normal rate. In addition, groundwater during drought is in higher demand. There is a smaller supply of surface water, meaning the groundwater gets tapped more frequently, and less natural precipitation means more groundwater is needed to water crops.

7. Which state drew the most from the Ogallala in the game? The least?

   Texas drew the most; Nebraska drew the least.

8. What were some of the reasons that groundwater was depleted in the High Plains?

   In the game, reasons for groundwater withdrawal included: livestock, agriculture and mining. In reality, the current land use in the High Plains area is 56 percent rangeland and 41 percent agricultural; mining operations have grown since 1950.

9. Historically, the Ogallala has been used as a water source for agricultural and livestock needs in the United States. As population increases, so does the demand for crops for food, and livestock for dairy and meat. What do you think will happen to groundwater?

   Answers may include: we will need more groundwater to support growth of crops and livestock, there will be less groundwater available for use, etc.

10. The Ogallala Aquifer is vast, but as we saw in our demonstration, it is used frequently as a resource. In the game, each state experienced a steady rate of withdrawal every ten years, but what would happen if a state started pulling more groundwater each succeeding decade? How might this affect other states, and the Ogallala?

    Answers may include: the Ogallala would become depleted since it does not have time to recharge, the remaining states would not have as much access to freshwater, etc.

ASSESSMENT

Students create a newspaper headline about the Ogallala Aquifer. The headline should communicate one of the main ideas from the game.

FOLLOW-UP ACTIVITIES

1. Analyze a groundwater depletion map like the one found here: http://water.usgs.gov/edu/graphics/gwdepletion-map-2008.png. Students could also investigate the state of the world's aquifers, http://www.vox.com/2015/6/17/8790939/map-heres-where-the-world-is-running-out-of-groundwater, or research to find the closest aquifer to their local area.

2. Have students research techniques that farmers can employ to lessen their impact on aquifers (e.g. using robotic irrigation systems that apply water only when needed, developing drought-tolerant corn, etc.).

Sources: Scientific American, The Ogallala Aquifer: Saving a Vital U.S. Water Source; United States Census Bureau; United States Geological Survey.

ALMIGHTY AQUIFERS

PLAYER 1 SCRIPT SHEET

Name: ______________________________ Date: ______________

Round 1	**Colorado: 1950** It is 1950 in Colorado, and population is currently 1,300,000 people. To date, my state has withdrawn 9 km^3 of groundwater from the Ogallala.	**Kansas: 1950** It is 1950 in Kansas, and population is currently 1,900,000 people. To date, my state has withdrawn 36 km^3 of groundwater from the Ogallala.
Round 2	**Colorado: 1960** It is 1960 in Colorado, and population has grown by 500,000 people. Increased livestock operations in my state has withdrawn 1 km^3 of groundwater from the Ogallala.	**Kansas: 1960** It is 1960 in Kansas, and population has grown by 300,000 people. Corn farming in my state has withdrawn 6 km^3 of groundwater from the Ogallala.
Round 3	**Colorado: 1970** It is 1970 in Colorado, and population has grown by 400,000 people. Increased wheat production in my area has withdrawn 1 km^3 of groundwater from the Ogallala.	**Kansas: 1970** It is 1970 in Kansas, and population has not grown. Nevertheless, increased corn production has withdrawn 6 km^3 of groundwater from the Ogallala.
Round 4	**Colorado: 1980** It is 1980 in Colorado, and population has grown by 700,000 people. Increased beef production has withdrawn 1 km^3 of groundwater from the Ogallala.	**Kansas: 1980** It is 1980 in Kansas, and population has grown by 200,000 people. Increased dairy farming has withdrawn 6 km^3 of groundwater from the Ogallala.
Round 5	**Colorado: 1990** It is 1990 in Colorado, and population has grown by 400,000 people. Recent wheat farming has withdrawn 1 km^3 of groundwater from the Ogallala.	**Kansas: 1990** It is 1990, and population has grown by 100,000 people. Increased livestock production has withdrawn 6 km^3 of groundwater from the Ogallala.
Round 6	**Colorado: 2000** It is 2000 in Colorado, and population has grown by 1,000,000 people. Increased agricultural production has withdrawn 1 km^3 of groundwater from the Ogallala.	**Kansas: 2000** It is 2000 in Kansas, and population has grown by 200,000 people. Increased cattle farming has withdrawn 6 km^3 of groundwater from the Ogallala.
Total Population Increase		
Total Groundwater Withdrawal	______________ km^3	______________ km^3

ALMIGHTY AQUIFERS

PLAYER 2 SCRIPT SHEET

Name: ______________________________ Date: ______________

Round 1	**Nebraska: 1950.** It is 1950, in Nebraska, and population is currently 1,300,000 people. As a state, I have recharged 1 km^3 of groundwater into the Ogallala. Add the 1 km^3 tile of groundwater from the 1950 bag to the center of the Ogallala.	**New Mexico: 1950** It is 1950 in New Mexico, and population is currently 700,000 people. To date, my state has withdrawn 6 km^3 of groundwater from the Ogallala.
Round 2	**Nebraska: 1960** It is 1960 in Nebraska, and population has grown by 100,000 people. However, my state has not drawn any groundwater.	**New Mexico: 1960** It is 1960 in New Mexico, and the population has grown by 300,000 people. Cattle ranching in my area has drawn 1 km^3 of groundwater from the Ogallala.
Round 3	**Nebraska: 1970** It is 1970 in Nebraska, and population has grown by 100,000 people. However, my state has not drawn any groundwater.	**New Mexico: 1970** It is 1970 in New Mexico, and population has not grown. Mining in my state has withdrawn 1 km^3 of groundwater from the Ogallala.
Round 4	**Nebraska: 1980** It is 1980 in Nebraska, and population has grown by 100,000 people. My state still has not drawn any groundwater.	**New Mexico: 1980** It is 1980 in New Mexico, and population has grown by 300,000 people. Livestock production has increased, withdrawing 1 km^3 of groundwater from the Ogallala.
Round 5	**Nebraska: 1990** It is 1990 in Nebraska, and population has not grown. My state still has not drawn any groundwater.	**New Mexico: 1990** It is 1990 in New Mexico, and population has grown by 200,000 people. Livestock production has increased, withdrawing 1 km^3 of groundwater from the Ogallala.
Round 6	**Nebraska: 2000** It is 2000 in Nebraska, and population has grown by 100,000 people. My state still has not drawn any groundwater.	**New Mexico: 2000** It is 2000 in New Mexico, and population has grown by 300,000 people. Increased beef production has withdrawn 1 km^3 of groundwater from the Ogallala.
Total Population Increase		
Total Groundwater Withdrawal	____________________ km^3	____________________ km^3

ALMIGHTY AQUIFERS

PLAYER 3 SCRIPT SHEET

Name: ______________________________ Date: ______________

Round 1	**Oklahoma: 1950** It is 1950 in Oklahoma, and population is currently 2,200,000 people. To date, my state has withdrawn 8 km^3 of groundwater from the Ogallala.	**South Dakota: 1950** It is 1950 in South Dakota, and population is 700,000 people. My state has not withdrawn any groundwater from the Ogallala.
Round 2	**Oklahoma: 1960** It is 1960 in Oklahoma, and population has grown by 100,000 people. As a state, increased wheat production has withdrawn 1 km^3 of groundwater from the Ogallala.	**South Dakota: 1960** It is 1960 in South Dakota, and there has been no population growth or groundwater withdrawal in my state.
Round 3	**Oklahoma: 1970** It is 1970 in Oklahoma, and population has grown by 300,000 people. Increased beef production in my state has withdrawn 1 km^3 of groundwater from the Ogallala.	**South Dakota: 1970** It is 1970 in South Dakota, and there has been no population growth or groundwater withdrawal in my state.
Round 4	**Oklahoma: 1980** It is 1980 in Oklahoma, and population has grown by 400,000 people. Dairy farming has withdrawn 1 km^3 of groundwater from the Ogallala.	**South Dakota: 1980** It is 1980 in South Dakota, and there has been no population growth or groundwater withdrawal in my state.
Round 5	**Oklahoma: 1990** It is 1990 in Oklahoma, and population has grown by 100,000 people. Dairy farming has withdrawn 1 km^3 of groundwater from the Ogallala.	**South Dakota: 1990** It is 1990 in South Dakota, and there has been no population growth or groundwater withdrawal in my state.
Round 6	**Oklahoma: 2000** It is 2000 in Oklahoma, and population has grown by 400,000 people. Corn farming has withdrawn 1 km^3 of groundwater from the Ogallala.	**South Dakota: 2000** It is 2000 in South Dakota, and population has grown by 100,000 people. However, there has been no groundwater withdrawal in my state.
Total Population Increase		
Total Groundwater Withdrawal	____________________km^3	____________________km^3

ALMIGHTY AQUIFERS

PLAYER 4 SCRIPT SHEET

Name: ____ Date: _____________________

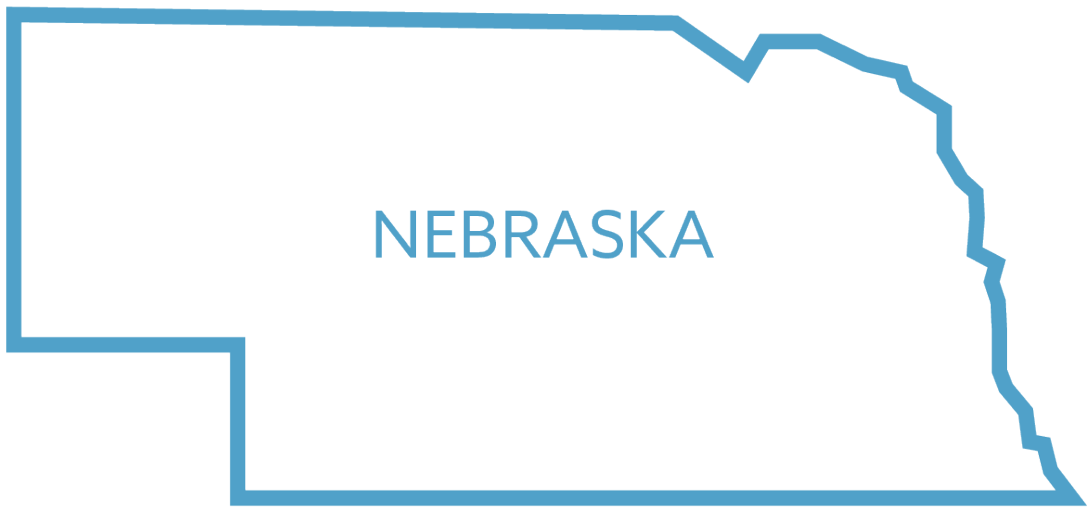
Round 1	**Texas: 1950** It is 1950 in Texas, and population is currently 7,700,000 people. To date, my state has withdrawn 96 km^3 of groundwater from the Ogallala.	**Wyoming: 1950** It is 1950 in Wyoming, and population is currently 300,000 people. My state has not withdrawn any groundwater from the Ogallala.
Round 2	**Texas: 1960** It is 1960 in Texas, and population has grown by 1,900,000 people. Increased cattle ranching in my state has withdrawn 16 km^3 of groundwater.	**Wyoming: 1960** It is 1960 in Wyoming, and population has not grown. My state has not drawn any additional groundwater.
Round 3	**Texas: 1970** It is 1970 in Texas, and population has grown by 1,600,000 people. Increased dairy farming in my state has withdrawn 16 km^3 of groundwater.	**Wyoming: 1970** It is 1970 in Wyoming, and population has not grown. My state has not drawn any additional groundwater.
Round 4	**Texas: 1980** It is 1980 in Texas, and population has grown by 3,000,000 people. Increased wheat production in my state has withdrawn 16 km^3 of groundwater.	**Wyoming: 1980** It is 1980 in Wyoming, and population has grown by 200,000. However, groundwater withdrawal has not increased.
Round 5	**Texas: 1990** It is 1990 in Texas, and population has grown by 2,800,000 people. Increased beef production in my state has withdrawn 16 km^3 of groundwater.	**Wyoming: 1990** It is 1990 in Wyoming, and population has not grown. My state has not drawn any additional groundwater.
Round 6	**Texas: 2000** It is 2000 in Texas, and population has grown by 3,900,000 people. Increased corn production in my state has withdrawn 16 km^3 of groundwater.	**Wyoming: 2000** It is 2000 in Wyoming, and population has not grown. My state has not drawn any additional groundwater.
Total Population Growth		
Total Groundwater Withdrawal	____________________km^3	____________________km^3

ALMIGHTY AQUIFERS

PLAYER 1 STATE BOARD

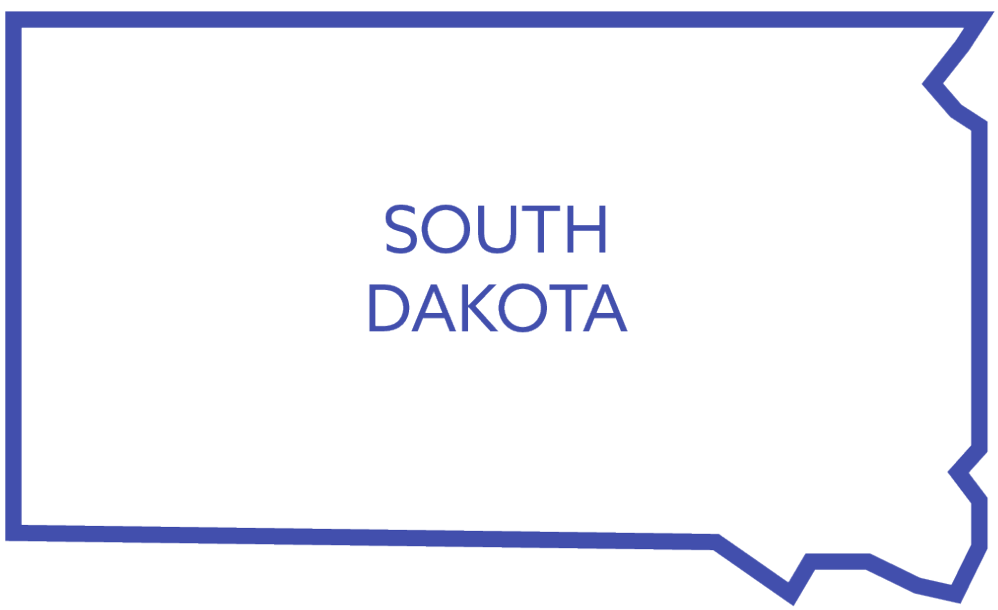
ALMIGHTY AQUIFERS

PLAYER 2 STATE BOARD



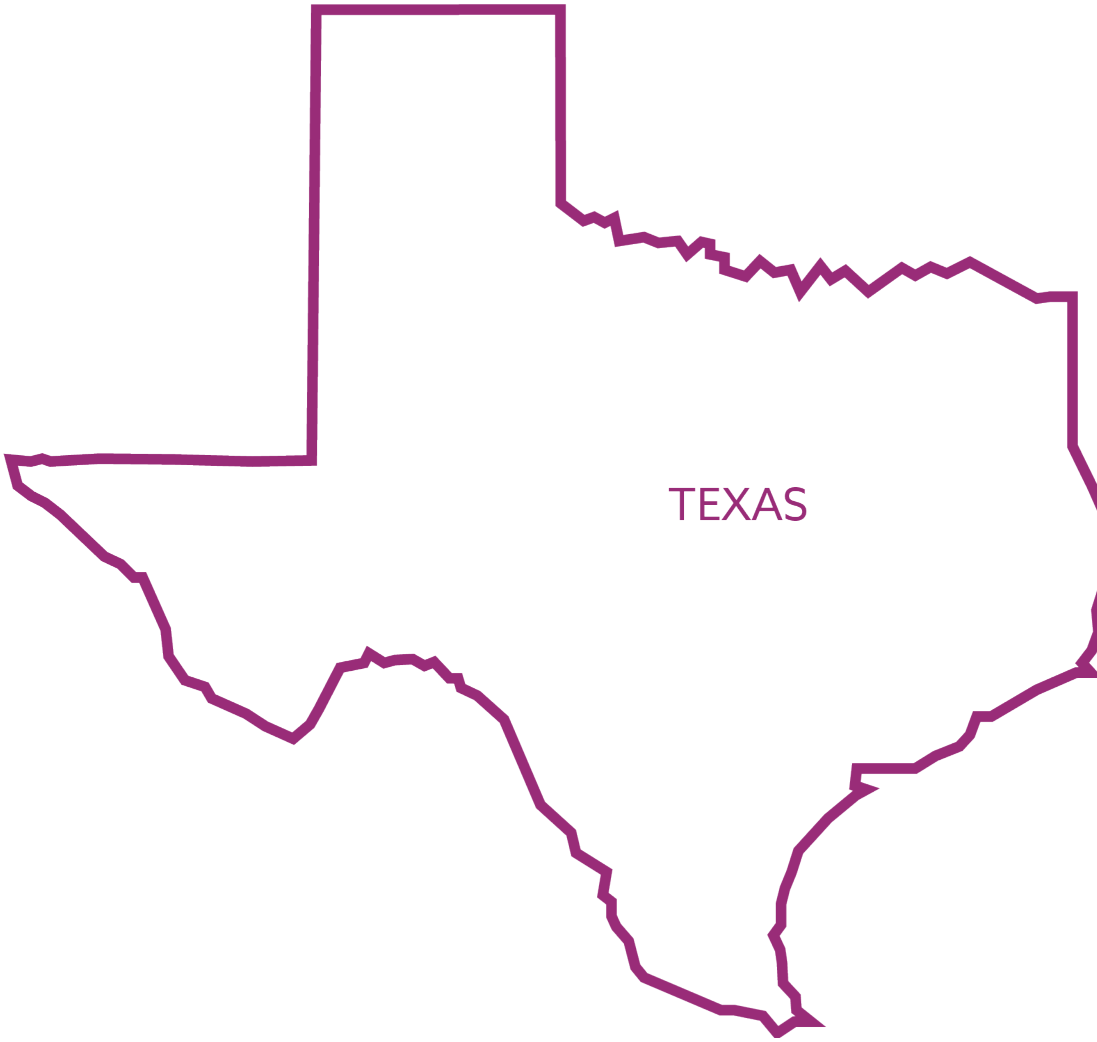
ALMIGHTY AQUIFERS

PLAYER 3 STATE BOARD



ALMIGHTY AQUIFERS

PLAYER 4 STATE BOARD



ALMIGHTY AQUIFERS

GROUNDWATER TILES

1950

			1 km^3 1950
1 km^3 1950	1 km^3 1950	1 km^3 1950	1 km^3 1950
1 km^3 1950	1 km^3 1950	1 km^3 1950	1 km^3 1950
5 km^3 1950	1 km^3 1950	1 km^3 1950	1 km^3 1950
5 km^3 1950	5 km^3 1950	5 km^3 1950	5 km^3 1950
10 km^3 1950	10 km^3 1950	10 km^3 1950	10 km^3 1950
10 km^3 1950	10 km^3 1950	10 km^3 1950	10 km^3 1950
10 km^3 1950	10 km^3 1950	10 km^3 1950	10 km^3 1950

1960

1 km^3 1960	1 km^3 1960	1 km^3 1960	1 km^3 1960
1 km^3 1960	5 km^3 1960	5 km^3 1960	10 km^3 1960

1970

1 km^3 1970	1 km^3 1970	1 km^3 1970	1 km^3 1970
	5 km^3 1970	5 km^3 1970	10 km^3 1970

1980

1 km^3 1980	1 km^3 1980	1 km^3 1980	1 km^3 1980
1 km^3 1980	5 km^3 1980	5 km^3 1980	10 km^3 1980

1990

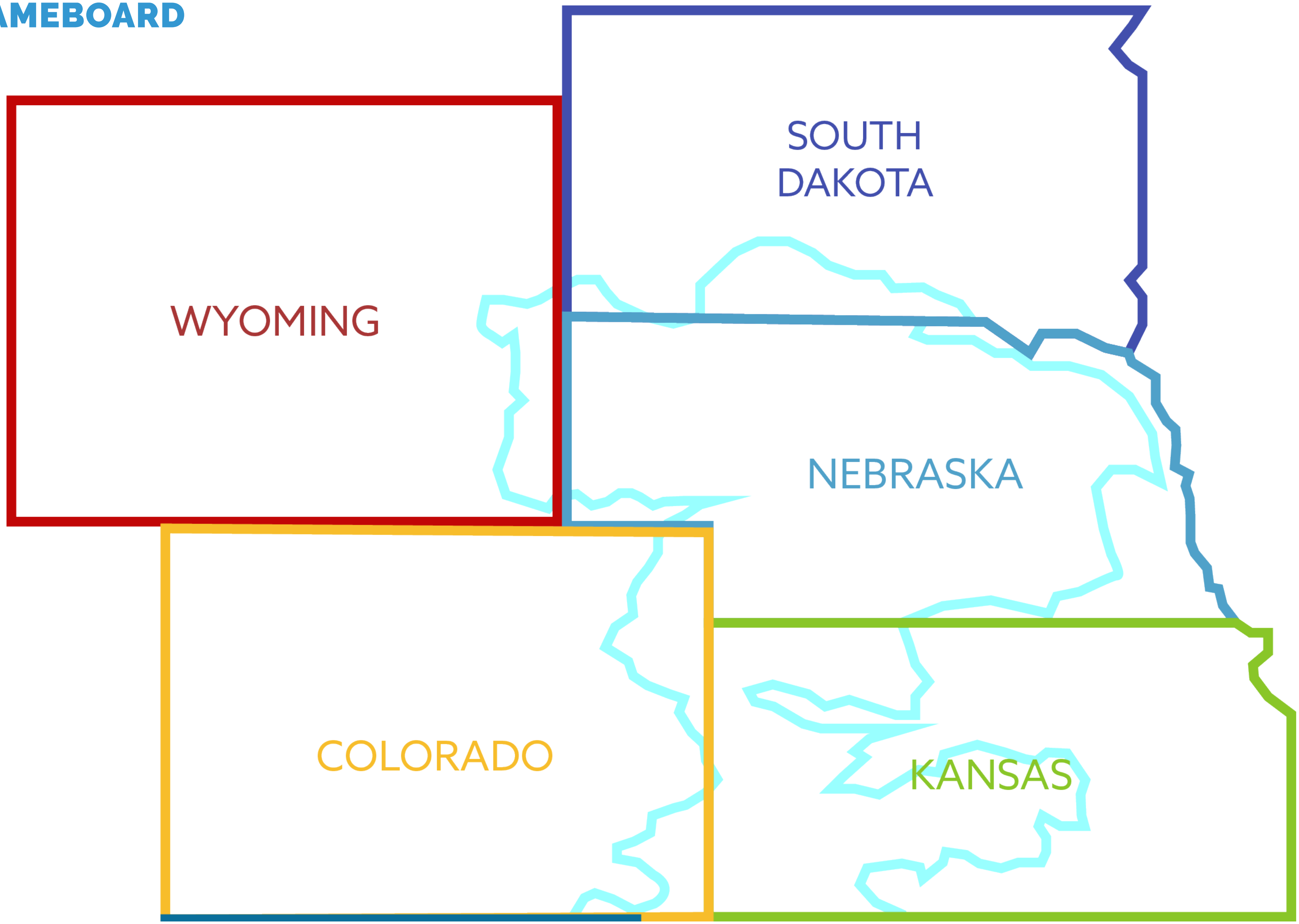
1 km^3 1990	1 km^3 1990	1 km^3 1990	1 km^3 1990
	5 km^3 1990	5 km^3 1990	10 km^3 1990

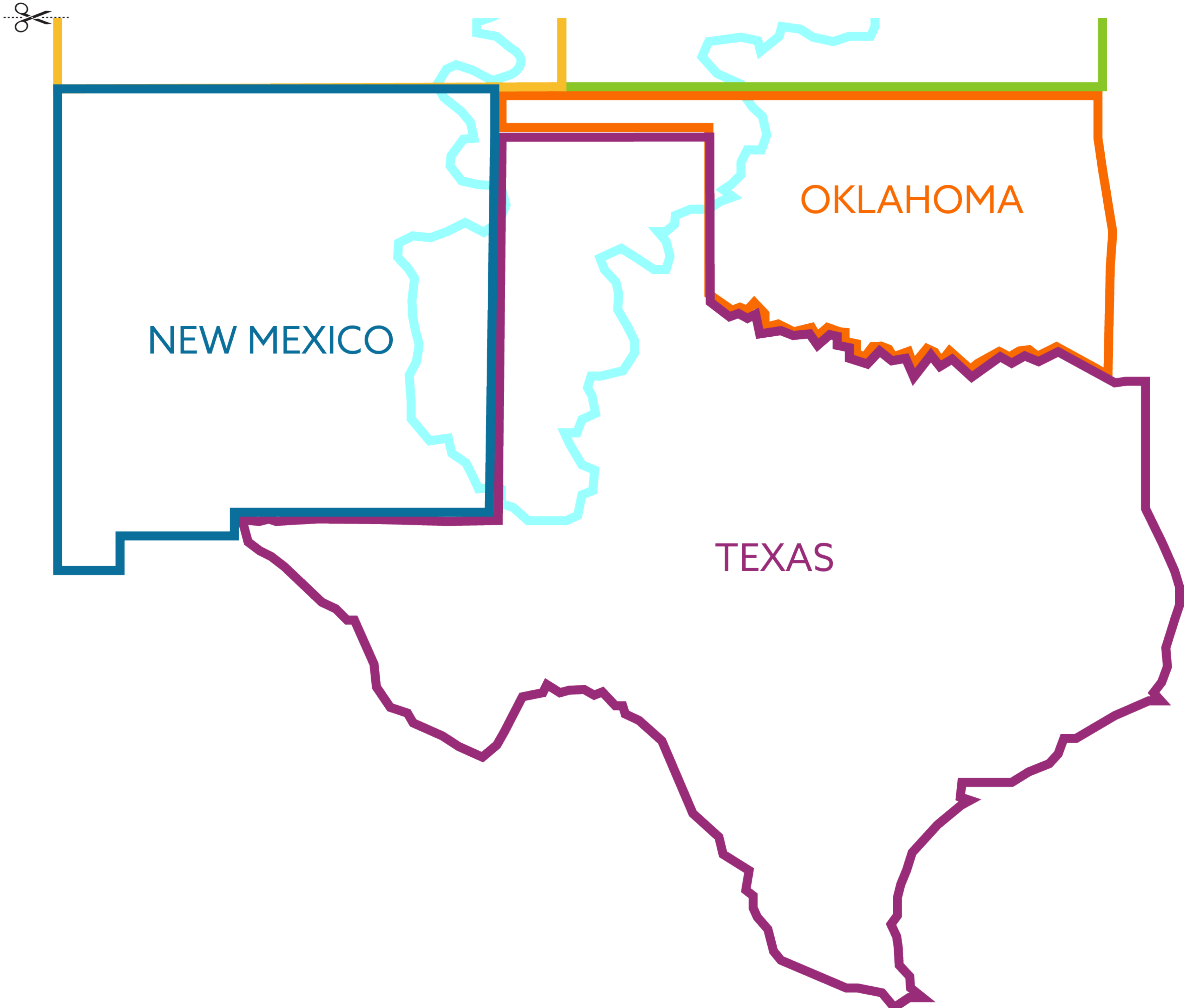
2000

1 km^3 2000	1 km^3 2000	1 km^3 2000	1 km^3 2000
1 km^3 2000	5 km^3 2000	5 km^3 2000	10 km^3 2000

ALMIGHTY AQUIFERS

GAMEBOARD




OKLAHOMA
NEW MEXICO
TEXAS