How many people can the aquifer support?
Teacher Lesson Plans

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Groundwater, Drought, and Natural Resource Management

Task 1: Introduction to the Groundwater Model

Task Overview
In this first lesson of the unit, students are introduced to the Groundwater Education simulation (http://groundwater.cee.illinois.edu/) to explore the relationship between groundwater and surface water. Students begin to ask questions about indicators of aquifer sustainability. This lesson provides the foundation for the rest of the unit in which students will develop a computational model for data that they collect within the simulation.

Lesson NGSS Practices, Crosscutting Concepts, Disciplinary Core Ideas
Disciplinary Core Ideas:
ESS3.A: Resource availability has guided the development of human society.
ESS3.C: The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

Science & Engineering Practices:
Developing and using models
Analyzing and interpreting data

Crosscutting Concepts:
Patterns
Cause and effect

Materials:
Aquifer model or diagram
Access to computers and the Internet
Student Handout: *Aquifer Exploration*

Safety Concerns:
None

I. Opening Activity: The Dust Bowl Video
Watch PBS' *The Dust Bowl* Intro video (http://www.pbs.org/kenburns/dustbowl/watch-videos/#2284398428) (5 minutes, 9 seconds)

Note: Because this unit is centered around an online simulation, this video clips serves as the initial *phenomena* for which the students will refer back to as the unit progresses. The clip

provides context (both historically and for current events) to aid in the development of their understanding. This is also a good topic for collaboration across departments/disciplines.

II. Discussion

After watching the video, engage the class in a discussion about the ***causes and effects*** of the dust bowl.

Record student observations and questions on the board.
Answers may include ideas such as:
- Drought caused fields and crops to dry up and die. Effects: Livestock also died. Farmers could not provide for their families, mass exodus of people leaving Oklahoma.
- Government encouraged moving to Oklahoma and farming. Effects: Coupled with the drought, the land was overworked, and the ecosystem ruined.
- Heavy winds across the barren fields caused constant dirt storms. Effects: Made the air unbreathable, livestock died, people got sick and died.

Ask students these questions to make connections between the Dust Bowl and water: *From where does the water for farming come? During the Dust Bowl, where do you think people got their water for drinking and household needs?*

Record their answers, ideas, and questions. Make connections between student responses that indicate drought, water, or groundwater.

III. Introduction to the Aquifer

Using a physical model or diagram of an aquifer, point out key features of the landscape and aquifer. You can find many diagrams of aquifers online, or build a simple physical representation as a demo similar to this one: http://sciencelearn.org.nz/Contexts/H2O-On-the-Go/Teaching-and-Learning-Approaches/Constructing-an-aquifer-model

(*Note:* it is not recommended that you have students build the "models" themselves, as it does not further the learning goals of the lesson. A quick demo or discussion of where the aquifer is located should suffice.)

Define the term *water table* as the depth below the surface that water is found.

Discuss:
What is the difference between surface and groundwater?
What water do we use for drinking?
How do we extract the groundwater in order to use it?
How does water get into an aquifer?

Now ask the same questions but in the context of the Dust Bowl.

IV: Explore the Predetermined Conditions in Simulation

Introduce the groundwater education website to students and explain that the tool will help us understand groundwater, and the causes and effects of human and environmental activity on aquifers and water supplies. Students should use their handout, *Aquifer Exploration*, as they familiarize themselves with the simulation.

Students open a web browser and navigate to the Groundwater Simulation (http://groundwater.cee.illinois.edu). Instruct students to choose the *No Development* option from the dropdown menu, and to click *Begin*.

Students explore the features of the simulation by following the prompts in the handout. When students are familiar with the site, instruct them click *End* to return to the main page.

Students now load the *City* scenario and watch the animation as it cycles through five years. Students uncheck the Animation box, as directed in Part I on their handouts, and step through the animations as needed. Students record observations and write down questions they have throughout the animation.

Students then load the *City + Farm* scenario and repeat the observations as described above (also detailed on the student handout).

Discuss:
Discuss the students' observations and add to the list of the questions that the class made during the video at the beginning of the lesson.

V: Explore the No Development Scenario

Students load the *No Development* scenario in the simulation. In this scenario, the students add wells to the farm and/or city and observe the effect that pumping water has on the aquifer.

VI: Closing

Discuss with the students, or have them write reflections, about how the simulation helped them understand the *causes and effects* of the Dust Bowl as discussed earlier in the lesson.

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Task 2: Indicators of Aquifer Sustainability

Task Overview
In this lesson students begin their investigation into the ways groundwater and surface water are connected. Students will observe the effect of adding wells to an area and will begin constructing a computational model that predicts the health of the aquifer.

Lesson NGSS Practices, Crosscutting Concepts, Disciplinary Core Ideas
Disciplinary Core Ideas:
ESS2.A: Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
ESS3.A: Resource availability has guided the development of human society.
ESS3.C: The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

Science & Engineering Practices:
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data

Crosscutting Concepts:
Patterns
Cause and effect
Stability and change

Materials:
Access to computers and the Internet
Student Handouts, *Aquifer Exploration* and
Poster paper, markers

Safety Concerns:
None

I. Opening Activity: Irrigation - The Dust Bowl's Legacy
Ask students what they believe to be the historical lessons learned from the Dust Bowl after watching yesterday's video and after their initial exploration of the simulation.

Answers will vary but may include suggestions such as *improved farming techniques*, *a change in farming practices especially during times of drought, etc.*

Show students the following clip from Ken Burns' *The Dust Bowl* series (1 minute, 19 seconds). This clip makes the point that irrigation, a practice that became popular and over-used during the 1930s, is still a conventional farming practice throughout America.
https://www.youtube.com/watch?v=SdbHx4TFGjU

Use this video as a way to build upon yesterday's observations. Students will be adding wells to the online simulation today, choosing how much water the farm can pump and how much the city can pump. They will begin to investigate the qualifications of a sustainable aquifer, by examining the causes and effects of pumping water from a well.

II: Indicators of Aquifer Sustainability

Students begin working on Task 2 Handout in which students identify the characteristics of aquifer sustainability. Students will identify four potential indicators of sustainability and use a Claim-Evidence-Reasoning chart in order to support their claims with evidence.

III: Class Discussion

After students have completed their Claim-Evidence-Reasoning chart, each student group should share their identified indicators of aquifer sustainability with the class. Student responses, including the evidence for their claims, should be recorded for all students to see as the discussion progresses. Students should discuss the merits of each idea listed by their classmates.

Possible indicators of aquifer sustainability may include: the area of the wetlands, water table depth for a single/group/cross-section of wetland cells, water table depth for farm or city wells, or river outflow.

After discussing the indicators and their merits, allow student groups the opportunity to make revisions or changes to their own identified indicators of aquifer.

Students groups should then *choose two* of their indicators for use in developing their computational model.

## IV: Data Collection and Computational Models

Before students get started on data collection, it is important to review with them the proper ways of collecting data in order to compare variables. Review *independent* and *dependent variables* and what that may look like in the context of the simulation. Do the following example, or similar, with the students.

- Load the *City* pre-determined scenario
- Select a wetland cell such as (19, 25)
- Ask students to identify the independent and dependent variables for this graph.
- Observe the graph with the students, and discuss what type of data could be taken from this graph. For instance, The Month of June could be the independent variable, and depth below the surface the dependent variable. (*Note: reading the graph itself may not be accurate. By moving the animation slider within the simulation, the data bar under the map will display the correct information while highlighting the desired spot on the graph.*)
- Walk students through constructing a data table (in lab notebooks or in a spreadsheet)

Graph: Cell (19, 25)
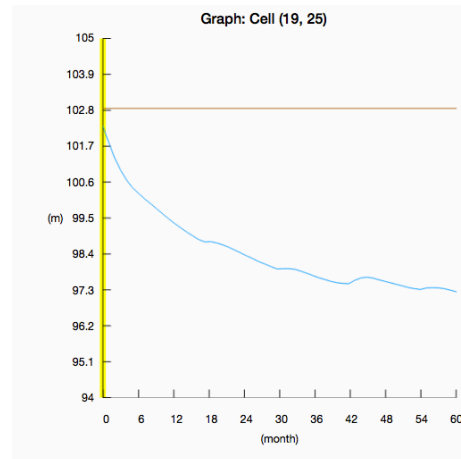
Month	6	18	30	42	54
Water Table depth below surface (m)	102.84 m – 100.43 m = 2.410	4.083	4.906	5.360	5.535

- Set up a graph with axes and plot points – highlight proper labeling and title.
- Sketch a best fit line, reminding students that we never "connect the dots"
- *If appropriate to students' mathematical abilities, encourage them to add a trend line that best fits the data.*

- Ask students if they think that this point is representative of the entire aquifer? Select another point (near the farm, for instance) and observe the graph in the simulation.

Depth of Water Table every June

  - o Ask the students why they think this plot was so different. (*The wetlands are very close to the three city wells*)
  - o What does this point indicate for the aquifer? (*This wetland cell is no longer a wetland cell after a few years of pumping. This indicates that the wetlands are shrinking due to pumping in this scenario.*)
  - o What does this indicate to us about how we should collect data? (*Students should use at least two of their indicators of aquifer sustainability and check to make sure their results make sense across the aquifer. If they can't explain*
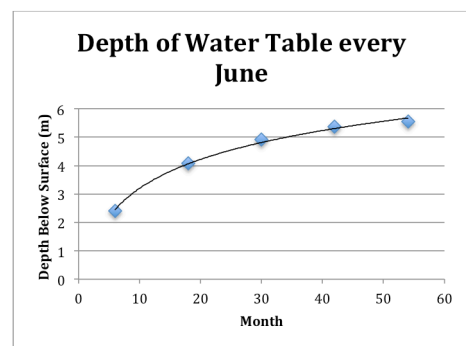
disparities in their data, they should consult with the teacher for next steps for further investigation.)

Students collect data for two Indicators of Aquifer Sustainability. Data should be recorded in a spreadsheet or in lab notebooks.

Note: While students collect data it is important to monitor the ways in which they are doing this. For instance, students should have a clear procedure for how often they are collecting data (e.g. water table depth for cell (12, 20) every January (months 1, 13, 25, etc.) rather than every month.

Students should graph their data. Remind students that they are looking for trends and patterns in their data that suggests a relationship.

Examples of Collected Data:
- Wetland Area vs. Month
- Water Table Depth (of a single cell) vs. Month
- Water Table Depth (of a single cell) vs. Different Total Pumping Rates
- Pumping Rates vs. Wetland Area
- Pumping Rates vs. Water Table Depth at a Well
- Pumping Rates vs. Water Table Depth (of a single cell)
- Pumping Rates vs. Average Water Table Depth of a Cross-Section

V: Gallery Walk

Student groups should sketch their graphs on to poster paper to share with the class in a gallery walk. Have students write questions or provide constructive feedback on post-it notes and stick them to other group's posters during the gallery walk. These comments should be constructive, provide feedback to that group in terms of their choices of Indicators of Aquifer Sustainability, and the merits or limits of the models, or questions about their work so far. The sentence frames below may help students deliver appropriate feedback:

Your model does a good job explaining _____.
Did you consider _____?
I suggest _____.
How does your model explain _____?

VI: Closing

Give students time to reflect on the comments and questions left on their posters. Either discuss common themes in the feedback as a class, or provide students time to write reflections about the feedback they received from their peers.

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Task 3: The Effects of a Drought on Your Groundwater Model

Task Overview

In this task, students continue using the Groundwater Education simulation (http://groundwater.cee.illinois.edu/) to explore the effects that drought and climate change have on an aquifer. In previous tasks, students learned how to use and collect data from the simulation. Students have selected indicators of aquifer sustainability and have started computational models. In this lesson, students will add to their models through the investigation of how a drought affects water resources available for human needs and activities.

Task Level NGSS Practices and Crosscutting Concepts

Disciplinary Core Ideas (DCI):

ESS3.A: Resource availability has guided the development of human society.

ESS3.B: Natural hazards and other geologic events have shaped the course of human history; they have significantly altered the sizes of human populations, and have driven human migrations.

Science & Engineering Practices:

Planning and carrying out investigations

Analyzing and interpreting data

Developing and using models

Crosscutting Concepts:

Patterns

Cause and effect

Materials:
Copies of National Geographic and Scientific American articles
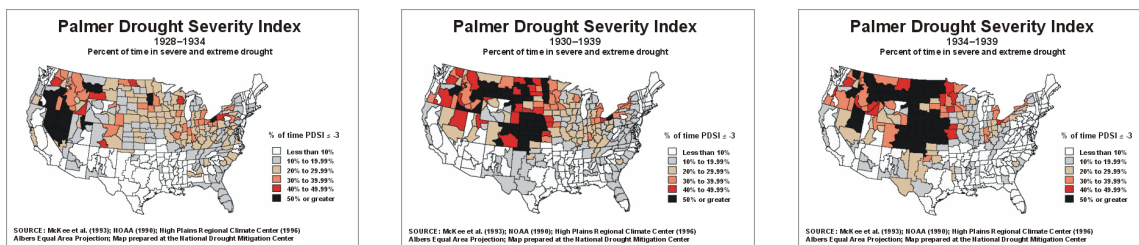Access to computers and Internet

Safety Concerns:
None

I. Opening Activity: Map Comparisons
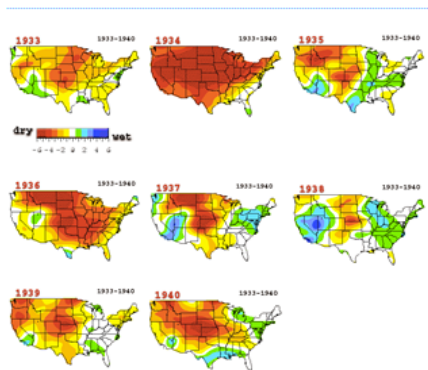Share one or both sets of the following maps with your students.

These images are taken from the National Drought Mitigation Center:
http://drought.unl.edu/planning/monitoring/historicalpdsimaps.aspx

These images are edited from The National Climatic Data Center:
https://www.ncdc.noaa.gov/paleo/drought/drght_history.html

Ask students for observations about these images. Students may point out that the Dust Bowl drought came in three waves (peaks in 1934, 1936, and 1939-40), that Nebraska and Oklahoma were in severe drought the entire seven years, or that at times, the drought spread to most of the country.

After the Dust Bowl maps, share the California drought map images with students:

- 6-second animation: http://www.latimes.com/la-me-g-california-drought-map-gif-htmlstory.html
- Images only: http://www.latimes.com/science/la-me-g-california-drought-map-htmlstory.html

Spend 2-3 minutes sharing ideas about the similarities between these droughts, time scale, and possible causes of drought. Spend an additional 2-3 minutes having student groups brainstorm what they perceive the effects of a drought to be, and potential solutions for coping with a drought.

II. Current Event Articles
Students read one or both of the articles:
National Geographic: *They've Seen Lots of Droughts, But This One's Different*
Scientific American: *Drought Takes $2.7-Billion Toll on California Agriculture*

Note: Rather than having every student read both articles, assign one article per student group. Half of the groups read the National Geographic article, which focuses on residential water consumption. The other half of the class reads the Scientific American article, which focuses on the economic toll drought takes on agriculture. The perspective of each article may influence the outcomes of the groups' computational models and become the basis for rich class discussion in regards to how many people this particular aquifer could support in a drought scenario.

Allow students time to discuss the article with their group members.

III. Revisit Graphs and Computational Models
Each groups' graphs should be posted on poster paper around the classroom from the previous task. Ask students what data they might need to collect in order to revise or change their models in the event of a drought. Whiteboard student responses.

IV. Drought Scenario in Simulation and Computational Model Revision

Students should observe what the drought looks like in the *No Development, City,* and *City + Farm* scenarios. Ask students what changes in patterns they observed as a result of adding a drought, as compared to the first time they used the simulation.

Note: For comparison, students could record their observations on their *Aquifer Exploration* handout.

Students should repeat the data collection procedures that they developed in Task 2, selecting the drought option in the simulation. Students add another column of data to their computational models in their spreadsheets or in lab notebooks, and plot the new data on the same graphs from Task 2, if possible.

Students should extrapolate their best-fit line for the drought for another two years (using dotted lines for extrapolation), modeling the effects of a prolonged drought.

Students update their posters to reflect the drought data.

IV. Closing

Student groups write a summary comparing and contrasting their no-drought and drought data in lab notebooks or on posters.

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Task 4: Final Models and Justification

Task Overview

In this last task, students are using their data to draw conclusions in order to answer the unit's essential question: How many people can the aquifer support? Students will justify their conclusions with evidence, and communicate their findings to the class.

Task Level NGSS Practices and Crosscutting Concepts

Disciplinary Core Ideas:
ESS2.A, ESS3.A, ESS3.B, ESS3.C

Science & Engineering Practices:
Analyzing and interpreting data
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

Crosscutting Concepts:
Cause and effect

Materials:
Access to computers and Internet
Poster Paper
Printer (optional)

Safety Concerns:
None

I. How Many People Can the Aquifer Support?

Using their data from previous class periods, students make claims as to how many people they believe the aquifer can support. They can use their own collected data to make this claim, or other data they observed within the simulation.

Note: There are several ways the students can come to a conclusion about how many people the aquifer can support. Look for justifications that include data and evidence.

For instance, if there are 5 city wells pumping at their maximum rate and 3 farm wells when the aquifer is in drought, we see red appear on the map as early as Month 14. This indicates that too much water is being removed and that the aquifer is not stable. Students could conclude that the city is removing 75,000 gallons of water each day (5 wells each pumping 15,000 gallons daily), and that the average American household of four needs 400 gallons of water a day. This works out 187.5 households of four, or 750 people. This population is too big for this aquifer.

Students can make a rough estimate of a stable population by determining the maximum water they believe the aquifer can sustainably have pumped out each day. Dividing that by 400 gallons will the number of four person households that the aquifer can support.

Student groups finalize their posters that explain the population that they believe the aquifer can support. Posters should include graphs and a written explanation that support their reasoning. Evidence should be cited on the posters (e.g. data collected in the simulation, facts given in the readings such as the amount of water an American household uses each day, etc). Groups must make recommendations for how to best manage an aquifer.

II. Presentations

Student groups present their findings and posters to the class. When all groups have presented, allow time for gallery walk and class discussion to synthesize results. Discuss similarities and differences. How did the groups differ in their approach to this task? Ask students how very large discrepancies in population size can be accounted for between the models.

Discuss the farm with students. Ask students who addressed the farm in their data collection or in their final presentation to share more about how they viewed the farm compared to the city. Ask all students their thoughts about the farm as the city population grows. During a drought,

what farming practices should be considered? Students should address the farm, numerically or in words, as to how they believe it affects their model.

Ask students if they see similarities to the Dust Bowl of the 1930s in the trends in their data, or in current event news articles.

Discuss with students the limitations of models, even those based on data. At best, models accurately predict phenomena or generate data to support explanations. At worst, they provide inaccurate information. Ask students how they can evaluate their models (answers may include: compare outcomes with other models from other student groups, observe if predictions are correct, collect more data).

III. Revisions

Allow student groups to meet and review their findings in light of what they know about their classmates' findings. Students should make any changes to their models based on feedback from peers and class discussion. Allow student groups to use information presented by another group, so long as they cite that group's work when writing their final project for submission.

IV. Final Written Response

Student groups should submit a copy of their group's final computational model (spreadsheet with labeled columns and rows, relevant graphs for drought and no-drought with extrapolations if appropriate, and final poster).

Each student should independently submit their handouts and the final written response that includes:
- A brief explanation and justification for their chosen Indicators of Aquifer Sustainability
- A description of the method they used for collecting data
- Conclusions based on their finalized computational model
- Recommendations or an explanation for responsible aquifer management based on their collected data and observations, and historical knowledge
- An explanation of the merits and limits of their model