Teacher Introduction

This lesson sequence introduces students to groundwater as a critical freshwater resource and helps them build an evidence-based explanation for how contamination at one site can become a drinking-water problem for communities miles away. Across six lessons, students investigate aquifer structure, groundwater movement, wells, contamination pathways, and community risk, then apply their learning in a culminating scenario. It leverages Aquifer Lab materials and resources available through The Groundwater Foundation website.

Flexibility for Teachers: This lesson contains recommended activities, formats, and durations, as well as linked videos and articles. This plan is designed with the intent to support a diverse range of class requirements and educator needs. All activities, lesson structures, and resources are proposed as general recommendations. Teachers are encouraged to edit, adapt, replace, reorder, or combine materials to best fit the goals, pacing, and needs of their unique classrooms.

Unit Summary

- **Grade Levels:** 10–12
- **Key Topics:** groundwater, aquifers, porosity, permeability, hydraulic conductivity, wells, groundwater flow, contamination pathways, plume movement, drinking-water risk, and mitigation strategies
- **High-Level Objectives:** help students explain how groundwater systems work, analyze how contaminants move through those systems, interpret models and data related to groundwater flow, and apply evidence to evaluate risks and possible solutions for communities.
- **General Duration:** approximately 6 class periods, with most lessons designed for about 50 minutes and the culminating lesson designed for about 100 minutes across 2 periods.

Contents

LESSON 1 4
LESSON 2 7
LESSON 3 10
LESSON 4 14
LESSON 5 19
LESSON 6 22

Targeted NGSS Performance Expectation(s):			
HS-ESS2-2	**HS-ESS2-5**	**HS-ESS3-1**	**HS-ESS3-3**
HS-ESS3-4	**HS-ESS3-6**	**HS-ETS1-1/2/3**	

- **HS-ESS2-2** Analyze geoscience data to make the claim that one change to Earth's surface can create feedback that cause changes to other Earth systems.
- **HS-ESS2-5** Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
- **HS-ESS3-1** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- **HS-ESS3-3.** Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity.
- **HS-ESS3-4** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- **HS-ESS3-6** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- **HS-ETS1-1** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **HS-ETS1-2** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-ETS1-3** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Targeted Scientific & Engineering Practice(s)	Targeted DCI(s)	Targeted Cross-Cutting Concept(s)
Developing and Using Models • Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1), (HS-ESS2-3), (HS-ESS2-6) **Analyzing & Interpreting Data** • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-2) • Analyze data using computational models in order to make valid and reliable scientific claims. (HS-ESS3-5) **Using Mathematics & Computational Thinking** • Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-ESS3-3) • Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-ESS3-6) **Constructing Explanations & Designing Solutions** • Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-ESS3-1) • Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ESS3-4) • Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) • Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff	**ESS2.A: Earth Materials & Systems** • Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-1), (HS-ESS2-2) **ESS2.C: The Role of Water in Earth's Surface Processes** • The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties is central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-5) **ESS3.A: Natural Resources** • Resource availability has guided the development of human society. (HS-ESS3-1) **ESS3.C: Human Impacts of Earth's Systems** • The sustainability of human societies and the biodiversity that supports them require responsible management of natural resources. (HS-ESS3-3) • Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4) **ETS1.A: Defining & Delimiting Engineering Problems** • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B: Developing Possible Solutions** • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and	**Structure & Function** • The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (HS-ESS2-5) **Stability & Change** • Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS2-2), (HS-ESS3-4) • Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-3), (HS-ESS3-5) **Influence of Engineering, Technology, & Science on Society & the Natural World** • New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS2-2), (HS-ETS1-1) (HS-ETS1-3) • Modern civilization depends on major technological systems. (HS-ESS3-1), (HS-ESS3-3) • Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-ESS3-2), (HS-ESS3-4) • New technologies can have deep impacts on society and the environment, including some that were not anticipated. (HS-ESS3-3) **Cause & Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-1) **System & System Models** • When investigating or describing a system, the boundaries and initial conditions of the system

considerations. (HS-ETS1-3) **Asking Questions & Defining Problems** • Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)	aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	need to be defined, and their inputs and outputs analyzed and described using models. (HS-ESS3-6) **Science is a Human Endeavor** • Science is a result of human endeavors, imagination, and creativity. (HS-ESS3-3)

LESSON 1

Lesson Overview

Students are introduced to the unit problem by examining real-world cases of drinking-water contamination linked to groundwater and wells. They begin building an understanding of what groundwater is, why it matters to communities, where their own drinking water comes from, and how these ideas connect to the unit driving question.

NGSS Learning Goals

- **Ask questions about** where drinking water comes from and its **role in the hydrologic cycle**.
- **Obtain and communicate scientific information** from multiple sources to draw conclusions about the **interactions between groundwater and human societies** and **the effects of one on the other**.
- **Develop an initial explanation based on evidence** from multiple sources to explain how **pollutants contaminate drinking water** through groundwater **as a result of** human actions.

Lesson Question

How can contamination at a site become a drinking-water problem for people several miles away?

Time: 50 minutes (1 period)

Building Toward: HS-ESS2-2, HS-ESS2-5, HS-ESS3-1

Supplies

- Projector/Smartboard Tools - to watch online video clips as a class
- Computer(s) / Internet Access - to read online articles, interact with the EPA CCR search tool, and access other online resources
- Whiteboard / Large Paper / Poster Board - supplies for students to create a driving question board that will be referenced throughout all lessons

Resources

- [1]Students watch short video clips showing communities facing drinking-water contamination challenges. Options:
  - The Hanford Story
  - Duke Energy & Wilmington, NC
  - Denver, CO
  - Navy Contamination in Hawaii
  - Williston Basin
- [2]Supplies for students to create a driving question board, recommended questions available below.
- [3]Students watch a short video and read an article about what groundwater is, how it works, and its role in communities. [Alternate article for printing: EPA - What is Groundwater]
- [4]Students research where their own water comes from using the EPA's CCR search tool.
- Notable examples of groundwater contamination events in the United States include Flint, MI; Love Canal; Hinkley, CA; Camp Lejeune.
- Additional groundwater resources:
  - Information on Earth's Water
  - Groundwater Facts
  - CDC Drinking Water Sources: An Overview
  - Groundwater in the United States (USGS)

Lesson Flow & Student Experience

- Students begin the unit by examining real-world cases[1] of drinking-water contamination that appear to be connected to groundwater and wells. The teacher can use these opening video clips to help students notice recurring patterns across communities, including references to contaminated wells, groundwater pollution, and pollutants that were buried, stored, or released onto the ground rather than directly into a lake or river.
- Next, students discuss the patterns they noticed and use those observations to develop an initial explanation that contaminants coming into contact with the ground may move into groundwater and affect drinking-water supplies. This discussion helps the teacher establish the unit problem and gives students a reason to investigate groundwater more closely.
- Students then begin a driving question board[2] to organize what they still need to learn. The teacher can use this step to capture student questions about what groundwater is, where it is found, how it moves underground, how people access it, how it is

recharged, whether it can run out, how it is monitored, where contaminants come from, and whether contamination can be predicted.

- To build foundational understanding, students watch a short video and read[3] introductory resources about what groundwater is, how it works, and why it matters to communities. Teachers may also have students investigate where their own drinking water comes from using the EPA's CCR search tool[4] so they can determine whether local water systems rely on groundwater, surface water, or both.

This introductory lesson establishes the unit problem, surfaces students' initial ideas, and launches the questions that will guide the rest of the sequence. With those questions in place, students are ready to investigate how groundwater is stored underground, how aquifers are structured, and what factors influence groundwater movement.

What Students Figure Out

- Groundwater accounts for a major portion of Earth's freshwater, while only a very small amount is found in surface water.
- Nearly half of people in the U.S. rely directly on groundwater for drinking water or irrigation, making it an essential community resource.
- Groundwater is recharged by water that soaks into the ground, connecting precipitation, surface processes, and subsurface water storage.
- Groundwater interacts directly with surface water bodies, so impacts to one part of the system can affect another.
- Pollution released into soil or onto the ground surface can move into groundwater resources and potentially affect wells and drinking-water supplies farther away.
- Because groundwater moves underground over time, contamination is not always limited to the place where it began.

Driving Question Board

By the end of this lesson, students have generated and organized initial questions, including:

Groundwater

- What is it?
- Where is it?
- How many people get drinking water from groundwater?
- How does water move through the ground?
- What ways do we access groundwater?
- How is groundwater recharged?
- Can we run out of groundwater?

- How do we track groundwater if we cannot see it?

Contamination Questions

- What are the types of contaminants?
- Where do contaminants come from?
- What are the risks of different types of contaminants?
- Is there a way to predict when and where a contaminant will impact drinking water?

Next Step

Now that students have identified the key questions that will guide the unit, they are ready to build a stronger understanding of what groundwater is, how it moves underground, and how human actions can affect that movement.

Optional Homework / Graded Activity

- Aquifer Lab worksheet "***What Is Groundwater?***"

LESSON 2

Lesson Overview

Students learn the basic elements of an aquifer and the key properties of Earth materials—especially porosity and permeability—that affect how groundwater is stored and moves. Through two short e-learning exercises, they examine aquifer structure, analyze how different materials influence groundwater flow, and connect these ideas to questions from the driving question board.

NGSS Learning Goals

- **Use a model to obtain, analyze, and communicate information** about **aquifer structure** and **Earth material properties (porosity and permeability)** that **affect groundwater movement and storage**.

Lesson Question

How does groundwater move, and how is it affected by geologic material?

Time: 50 minutes (1 period)

Building Toward: HS-ESS2-2, HS-ESS2-5

Supplies

- Computer(s) / Internet Access - for students to interact with and complete e-learning activities
- Headphones - for students to watch the "Porosity and Permeability" video embedded in the 2nd e-learning exercise
- Class-Specific Driving Question Board
- (Optional) Projector/Smartboard Tools - to watch the "Porosity and Permeability" video from the e-learning together as a class and to review visuals of aquifers during discussions
- (Optional) Worksheet Printouts - Aquifer Lab worksheet "***Porosity & Permeability***" printouts if assigning hard-copy to students

Resources

- **Educator Guide - Aquifer Lab E-Learning Exercises (PDF)** - this guide provides a high-level overview of the different e-learning activities.
- Students will complete two of the **Aquifer Lab e-learning exercises**:
    1. [1]**"Aquifer Activity" [5-10 minutes]** - focuses on a cross-section of geologic layers and the basic features of an aquifer.
    2. [2]**"Porosity vs. Permeability" [10 minutes]** - reviews porosity and permeability and asks students to examine how surrounding materials influence groundwater movement.
- Have the students' driving question board available for them to review and discuss what questions they've answered so far.
- (Optional) Watch the embedded "Porosity and Permeability" video from the 2nd e-learning exercise as a class

Lesson Flow & Student Experience

- Students begin by completing the Aquifer Lab "Aquifer Activity" [1] e-learning exercise. The teacher can use this opening task to help students identify the major structural features of an aquifer, including the unsaturated zone, water table, recharge areas, and confining layers. As students work with the cross-section model, they label these features and begin connecting them to questions from the driving question board about where groundwater is found, how it is stored, and how it moves underground.
- Next, students discuss what the model reveals about aquifer structure and how different parts of the system relate to one another. This gives the teacher an opportunity to reinforce that groundwater is stored within geologic materials and that aquifer structure shapes how groundwater can move through the subsurface.
- Students then complete the Aquifer Lab "Porosity vs. Permeability" [2] exercise. In this second task, they compare different soil and sediment types and examine how porosity and permeability describe geologic materials. As they work, students make predictions about which materials will transmit water more easily and use evidence from the model to justify those predictions.

- As the lesson progresses, students connect Earth-material properties to groundwater behavior by identifying where groundwater is likely to move more quickly or more slowly based on the surrounding materials. The teacher can use this step to help students link aquifer structure, porosity, and permeability to a more complete explanation of groundwater movement and storage.

This lesson moves students from a general introduction to groundwater into a more detailed model of how aquifers work. With that foundation in place, they are ready to investigate how humans access groundwater and how pumping can change groundwater conditions.

What Students Figure Out

- Aquifers are made up of several key features that scientists and engineers use to describe, monitor, and predict groundwater behavior.
- Important aquifer features include the unsaturated zone, the water table, recharge areas, and confining layers, all of which affect where groundwater is stored and how it moves.
- Groundwater movement depends in part on the characteristics of the surrounding Earth materials.
- Porosity describes how much open space a material has, while permeability describes how easily water can move through those spaces.
- Different soil and sediment types can have very different porosity and permeability, which significantly affects groundwater flow.
- By comparing Earth materials and using aquifer models, scientists can make evidence-based predictions about where groundwater will move more quickly or more slowly.

Driving Question Board Progress

By the end of this lesson, students have made progress on questions including:

Groundwater

- ***What is it?***
- ***Where is it?***
- ***How many people get drinking water from groundwater?***
- ***How does water move through the ground?***
- What ways do we access groundwater?
- ***How is groundwater recharged?***
- Can we run out of groundwater?
- How do we track groundwater if we cannot see it?

Contamination Questions

- What are the types of contaminants?

- Where do contaminants come from?
- What are the risks of different types of contaminants?
- Is there a way to predict when and where a contaminant will impact drinking water?

Next Step

Now that students understand the basic structure of aquifers and how Earth materials influence groundwater movement, they are ready to investigate how humans access groundwater and how human actions can affect groundwater flow and availability.

Optional Homework / Graded Activity

- Aquifer Lab worksheet "***Porosity & Permeability***"

LESSON 3

Lesson Overview

Students learn how people access groundwater using wells and how pumping and overuse can change groundwater availability and affect communities and ecosystems. They build vocabulary related to wells and groundwater withdrawal, analyze real-world examples of aquifer overdraft, and consider whether groundwater is a renewable resource.

NGSS Learning Goals

- **Obtain, analyze, and communicate information** about how **wells** access **groundwater** and the **cause-and-effect relationships** of how **pumping** can change **groundwater conditions** within an **aquifer**.
- **Analyze real-world examples of well use** to investigate **cause-and-effect relationships** between **human technology and actions** (well placement and pumping) and changes in **groundwater resources and the environment**.
- **Draw on scientific evidence to explain** how **stability and change** in groundwater systems can be disrupted by **aquifer overwithdrawal**, including **impacts** that extend beyond the immediate loss of **drinking water resources**.

Lesson Question

How is groundwater accessed using wells, and how can pumping and overuse affect groundwater resources?

Time: 50 minutes (1 period)

Building Toward: HS-ESS3-1, HS-ESS3-6, HS-ESS2-2

Supplies

- Projector/Smartboard Tools - to watch videos as a class and show list of terms for students to define
- Computer(s) / Internet Access - to read online articles, research case studies, and check official terms glossary
- Class-Specific Driving Question Board
- (Optional) Worksheet Printouts - Aquifer Lab worksheet ***"Is Groundwater a Renewable Resource?"*** printouts if assigning hard-copy to students

Resources

- [1]Students watch a short video about how water wells work.
- [2]Students collaborate to define key well-related terms, then check their definitions using The Groundwater Foundation's online glossary.
- Students discuss the question "*Is groundwater a renewable resource?*"
- [3]Students read articles about groundwater overdraft and depletion:
    - Groundwater Overdraft
    - Groundwater Decline & Depletion
    - Groundwater Overuse and Depletion
- [4]Students read about and compare real-world case studies such as:
    - Great Plains' Ogallala Aquifer Drying Out
    - The Hidden Costs of Groundwater Overdraft
- [5]Students research additional examples of aquifer overwithdrawal in the U.S. and around the world. Examples:
    - North China Plain Aquifer
    - Arabian Aquifer System - Saudi Arabia
    - Indus Basin Aquifer
    - Mexico City Aquifer
    - Northwestern Sahara Aquifer System
    - Murray-Darling Basin Aquifers

Lesson Flow & Student Experience

- Students begin by watching a short video[1] about how wells work. The teacher can use this opening to help students identify the different purposes of wells, including drinking water, irrigation, industry, and monitoring, and surface prior ideas about how pumping changes groundwater conditions. Next, students collaborate to define and check key well-related terms[2], so they have the vocabulary needed for the discussion and case-study work that follows. [See the recommended worksheet for this lesson for definitions of these terms.]
    - Cone of Depression
    - Depletion
    - Drawdown
    - Monitoring Well
    - Overwithdrawal
    - Safe Yield
    - Subsidence
    - Well
    - Well Closure
    - Well Siting
    - Wellhead Protection Area
- After students build this shared vocabulary, the lesson shifts to the question of whether groundwater is a renewable resource. Through discussion and short readings, students consider the conditions under which groundwater can be renewed and begin to recognize that renewal depends on whether withdrawals remain in balance with recharge.
- [3]To deepen that understanding, students read articles about groundwater overdraft and depletion and then compare real-world examples from the United States[4] and around the world[5]. As they analyze these cases, they identify common causes and effects of overuse and connect pumping decisions to falling water tables, dry wells, higher pumping costs, land subsidence, reduced water in springs, lakes, rivers, and wetlands, and broader ecosystem impacts.
- By comparing multiple case studies, students see how human technology and decision-making can change groundwater systems in ways that affect both communities and the environment. This gives teachers a chance to help students move beyond the idea of groundwater as only a water-supply issue and toward a systems view that includes long-term environmental and social consequences.

This lesson helps students move from understanding groundwater as a resource to recognizing how human technology and decision-making can change groundwater systems. With that foundation in place, students are ready to investigate how scientists and engineers track and predict groundwater movement.

What Students Figure Out

- Wells provide access to groundwater for drinking water, irrigation, and industry, and monitoring wells help scientists track groundwater conditions over time.
- Humans access groundwater through wells, which are drilled or constructed to extract or monitor water from aquifers.
- Groundwater is a renewable resource, but only if it is managed sustainably and withdrawals do not consistently exceed recharge.
- Surface water, recharge, discharge, pumping, and other human activities all influence groundwater behavior within an aquifer system.
- Overwithdrawal can lower the water table, require deeper wells, increase pumping costs, and cause some wells to run dry.
- Overuse can also lead to land subsidence, reduced water in springs, rivers, lakes, and wetlands, degraded ecosystems, and water-quality problems such as saltwater intrusion.
- When aquifer materials compact because of excessive groundwater removal, their ability to store water in the future can be permanently reduced.
- Human technology and decisions, especially well placement and pumping, can change groundwater conditions in ways that affect both communities and the environment.

Driving Question Board Progress

By the end of this lesson, students have made progress on questions including:

Groundwater

- ***What is it?***
- ***Where is it?***
- ***How many people get drinking water from groundwater?***
- ***How does water move through the ground?***
- ***What ways do we access groundwater?***
- ***How is groundwater recharged?***
- ***Can we run out of groundwater?***
- How do we track groundwater if we cannot see it?

Contamination Questions

- What are the types of contaminants?
- Where do contaminants come from?
- What are the risks of different types of contaminants?
- Is there a way to predict when and where a contaminant will impact drinking water?

Next Step

Now that students understand how wells provide access to groundwater and how pumping can change groundwater conditions, they are ready to investigate how scientists and engineers track and predict groundwater movement.

Optional Homework / Graded Activity

- Aquifer Lab worksheet *"**Is Groundwater a Renewable Resource?**"*

LESSON 4

Lesson Overview

Students investigate the tools and methods scientists and engineers use to monitor and predict groundwater movement. They use topographic maps, well data, and a simplified aquifer model to determine groundwater flow direction, gradient, and horizontal velocity, then apply those skills using the Aquifer Lab modeling application.

Note: it is highly recommended that educators review the **Educator Guide - Aquifer Lab Modeling Application (PDF)** in depth and explore the Aquifer Lab modeling application themselves prior to sharing with students.

NGSS Learning Goals

- **Develop and use models** (topographic maps and simplified aquifer/well data) to determine groundwater **flow direction, gradient, and horizontal velocity** and to make predictions about where groundwater will move over time.
- **Analyze and interpret data** from wells and maps to explain how **systems and system models** and **cause-and-effect relationships** help hydrogeologists predict the movement of **groundwater**.
- **Use mathematics and computational thinking** to apply a simplified form of **Darcy's Law** and quantify how changes in **hydraulic conductivity, porosity, and water-table gradient** change groundwater velocity.

Lesson Question

How do scientists and engineers track and predict groundwater movement?

Time: 100 minutes (2 periods)

Building Toward: HS-ESS2-2, HS-ESS2-5, HS-ESS3-3, HS-ESS3-6

Supplies

- Projector/Smartboard Tools - to watch videos as a class, review Darcy's Law equation together, and to share/review the student modeling application guide together (if needed)
- Computer(s) / Internet Access - for students to interact with and complete e-learning activities and to use the practice version of the Aquifer Lab modeling activity
- Calculators - basic calculators for students to use with the e-learning exercise and modeling application
- Class-Specific Driving Question Board

Resources

- **Educator Guide - Aquifer Lab E-Learning Exercises (PDF)** - this guide provides a high-level overview of the different e-learning activities.
- **Educator Guide - Aquifer Lab Modeling Application (PDF)** - this guide provides an overview of the Aquifer Lab modeling application, it's general use, and the Teacher Portal.
- [1]Students watch a short video about topographic maps and discuss how elevation and water-table information can help predict groundwater movement.
- [2]White board/visual tool to see and review Darcy's Law and its variables. [Details on Darcy's Law and variables can be found in the Aquifer Lab Modeling Application Educator's Guide]
    - The e-learning for this lesson also reviews Darcy's Law and its variables to help affirm student learning.
- [3]Students will complete the third Aquifer Lab e-learning exercise:
    - "Darcy's Law & Groundwater Modeling" [10-15 minutes] - students learn how to calculate flow direction, gradient, and horizontal velocity. This exercise prepares them to then practice with the Aquifer Lab modeling application.
- [4]The practice version of the Aquifer Lab Modeling Application via the Aquifer Lab website.
    - Link for students: AquiferLab.com
    - **Student Guide - Aquifer Lab Modeling Application (PDF)** - this guide provides an overview of the Aquifer Lab modeling application and how to complete the activity for students.
- (Optional) Read the article USGS "How do Hydrologists Locate Groundwater?"
- (Optional) Use The National Map Viewer to explore topographic maps for their local community

Lesson Flow & Student Experience

- Students begin by watching a short video[1] about topographic maps and discussing how elevation and water-table information can help predict groundwater movement. This introduction helps them connect visible surface features to the underground movement of water and prepares them to think about how hydrogeologists infer groundwater flow from indirect evidence.
- Students then learn that scientists and engineers use data and models to monitor and predict groundwater movement. As a class, they examine a simplified form of Darcy's Law[2] and break down what each variable represents:

$$V = \frac{K \times i}{n}$$

V = horizontal velocity of groundwater

K = hydraulic conductivity

i = gradient of the water table

n = porosity

- They discuss how some of these values come from geologic materials while others must be determined from map and well data.
- Using the Aquifer Lab e-learning exercise[3], students analyze a simplified aquifer model with topographic maps and monitoring well data. They determine groundwater flow direction by using water-level data from wells, calculate the gradient of the water table, and gather hydraulic conductivity and porosity values from the model's soil and layer data. As they work, students see how each piece of information contributes to a groundwater-flow prediction.
- Students also learn that hydraulic conductivity describes how easily water moves through a material, while porosity describes how much open space that material contains. They compare fine-grained and coarse-grained materials and consider how differences in these properties influence groundwater velocity. In the simplified model, they also consider the assumptions built into groundwater-flow predictions and why models are useful even when they do not capture every detail of a real aquifer system.

By the end of the lesson, students have used maps, well data, and a simplified groundwater equation to estimate where groundwater will move and how fast it may travel. The e-learning exercise prepares students to use the Aquifer Lab Modeling Application[4] to practice groundwater-flow prediction. With that foundation in place, they are ready to investigate how groundwater becomes contaminated and how contamination can spread through groundwater systems.

Modeling Practice Activity

To strengthen student understanding of how models can be used to predict groundwater flow, students complete practice scenarios in the publicly available Aquifer Lab Modeling Application. These practice tasks prepare them for the final culminating activity, which uses the test version of the application. The section below describes one possible approach, but teachers are encouraged to adapt it to fit their classroom needs. At a minimum, students should complete 3–4 different scenarios.

Note: In this activity, a "scenario" consists of one selected map and three selected wells in the modeling application. Each new combination counts as a different scenario. For example, if a student uses the same map but completes the activity with four different sets of three wells, that student has completed four scenarios.

Throughout the activity, teachers may use general prompt questions such as: Where is groundwater flowing? How fast is it moving? Which wells or locations seem most connected? Which areas appear most or least at risk from contamination? What evidence supports your conclusion? Teachers may also remind students that the modeling application is a simplified representation of a real groundwater system, so conclusions should be based on available evidence while recognizing that real systems are often more complex.

Activity Flow

1. **Part 1: Acclimating to the Application** - Students review the "Student Guide - Aquifer Lab Modeling Application (PDF)" before opening the application. They then explore the site, navigation, and controls to become familiar with how it works. Teachers may also encourage students to revisit the modeling e-learning exercise for extra support.
2. **Part 2: Practicing Static Conditions** - Students complete at least two practice scenarios with all selected wells not pumping, using water-table data under static conditions. Teachers may use simple contextual questions to connect the modeling work to real-world situations, such as:
    - Stardew City is located northeast of Well C. Based on the model, do groundwater and any possible contaminants from Wells A, B, and C appear to flow toward the city or away from it? How quickly is the groundwater moving?

    Teachers may also prompt students to explain their reasoning using stems such as:

    - *The model suggests groundwater is flowing toward _____ because _____.*
    - *This area appears most at risk because _____.*
3. **Part 3: Practicing Pumping Conditions** - Students complete two practice scenarios in which at least one selected well is pumping. Ideally, one scenario repeats a previous setup so students can compare how pumping changes the results. After completing both static and pumping scenarios, teachers may ask students to compare how the groundwater flow pattern, speed, and areas of greatest risk changed under different conditions.

Notes Tracker

Teachers may also encourage students to track their work using the following categories for consistency: scenario, static or pumping, groundwater flow direction, estimated speed, most at-risk location, evidence / notes.

What Students Figure Out

- Scientists and engineers rely on wells, especially monitoring wells, to gather the data needed to determine and predict groundwater movement.
- Topographic maps and water-level data can be used together to infer groundwater flow direction because groundwater tends to move from higher hydraulic head to lower hydraulic head.
- Darcy's Law is used to estimate the horizontal velocity of groundwater, which describes how fast groundwater moves underground.
- To use Darcy's Law in this lesson's model, students must determine flow direction, water-table gradient, hydraulic conductivity, and porosity.
- Hydraulic conductivity describes how easily water moves through a material, while porosity describes how much open space the material contains.
- Different Earth materials affect groundwater movement differently, so geologic properties are essential for making evidence-based predictions.
- Even though groundwater often moves slowly, it is constantly moving and can travel significant distances over time.
- Because groundwater can move contaminants from one location to another, understanding flow direction and velocity helps explain how contamination can spread and which areas may be at risk.
- Models are useful tools, but they depend on assumptions and simplified conditions, so predictions are strongest when supported by data from wells and repeated observations.

Driving Question Board Progress

By the end of this lesson, students have made progress on questions including:

Groundwater

- ***What is it?***
- ***Where is it?***
- ***How many people get drinking water from groundwater?***
- ***How does water move through the ground?***
- ***What ways do we access groundwater?***
- ***How is groundwater recharged?***
- ***Can we run out of groundwater?***
- ***How do we track groundwater if we cannot see it?***

Contamination Questions

- What are the types of contaminants?
- Where do contaminants come from?

- What are the risks of different types of contaminants?
- Is there a way to predict when and where a contaminant will impact drinking water?

Next Step

Now that students understand how scientists and engineers track and predict groundwater movement, they are ready to investigate how groundwater becomes contaminated and how contamination moves through groundwater systems.

LESSON 5

Lesson Overview

Students explore how groundwater can become contaminated. They investigate common contamination sources, examine how pollutants move into and through groundwater systems, research real-world cases, and connect contaminant type and source to risk for communities and drinking-water supplies.

NGSS Learning Goals

- **Obtain, evaluate, and communicate scientific information** from text, videos, and data tables to explain how **cause-and-effect relationships** connect **human activities and contaminant sources** to **groundwater contamination pathways** and impacts on **drinking-water quality**.
- **Analyze and interpret data** from real **contamination cases** to identify patterns in **systems and system models**.
- Use **cause-and-effect reasoning and systems** thinking **to explain** how **contaminant type, source, and pathway influence where contamination travels** and what **impacts** it may have.

Lesson Question

How can groundwater become contaminated?

Time: 50 minutes (1 period)

Building Toward: HS-ESS3-1, HS-ESS3-4, HS-ESS3-3, HS-ESS3-6

Supplies

- Projector/Smartboard Tools - to watch videos as a class
- Computer(s) / Internet Access - to read online articles and research contaminants and case studies
- Class-Specific Driving Question Board
- (Optional) Contaminant Table Printouts - printouts of the contaminants table if providing a hard-copy to students
- (Optional) Worksheet Printouts - Aquifer Lab worksheet "***Groundwater Contamination***" printouts if assigning hard-copy to students

Resources

- [1]Students watch a video and read articles from The Groundwater Foundation, USGS, and the Environmental Protection Agency (EPA) to research common ways groundwater becomes contaminated.
- [2]Aquifer Lab Groundwater Contaminant Table (PDF) - a structured table of select groundwater contaminants with categories, uses, sources, and potential effects.
- [3]Students use a contaminant table to select and research two contaminants.
    - Contaminants Found in Groundwater (USGS)
    - National Primary Drinking Water Regulations (U.S. EPA).
- Research resources for students research a real-world case study for each contaminant and share a summary with the class.

Lesson Flow & Student Experience

- Students begin by watching a short video and reading articles[1] that introduce common ways groundwater becomes contaminated. The teacher can use this opening research step to help students connect contamination sources to earlier lessons about aquifers, wells, and groundwater movement, while also broadening the discussion to include additional sources such as septic systems, landfills, road salts, pesticides, and fertilizers.
- Next, students review a contaminant table[2] and select two contaminants to investigate[3], either independently or as part of a small group. As they research, the teacher can guide students to look for patterns in each contaminant's category, common uses, contamination pathways, and harmful effects so they begin linking contaminant type and source to groundwater risk.
- Students then research one real-world contamination case for each selected contaminant. Their case-study summaries can include the pollutant name and category, common uses, likely pathway into groundwater, where the contamination occurred, how far the plume traveled, which communities were impacted, and how the contamination might have been prevented.

- As students share their findings with the class, the teacher can help them compare cases and identify recurring patterns in how contamination enters groundwater systems and why some contaminants create different risks than others. This step helps students move from isolated examples to a broader systems understanding of contamination sources, transport, and impact.

By the end of the lesson, students have compared contamination sources, contaminant types, and groundwater pathways across multiple real-world cases. With that foundation in place, they are ready to synthesize what they have learned across the unit and apply it to a community contamination scenario.

What Students Figure Out

- Groundwater can become contaminated when pollutants are released onto or into the ground and then move into aquifers, so contamination at one site can create impacts miles away.
- Identifying a contaminant's source and type helps predict how it may travel through groundwater and what harm it may cause to people and ecosystems.
- Common sources of groundwater contamination include industrial sites, military installations, mines, septic systems, landfills, road salts, pesticides, and fertilizers.
- Different contaminants create different risks depending on their properties, uses, pathways, and persistence in the environment.
- Real-world contamination cases can be investigated by tracing the pollutant name and category, how it entered groundwater, how far the plume traveled, which communities were affected, and what prevention steps could have reduced or avoided the contamination.
- Understanding contamination sources, pathways, and contaminant type is essential for predicting risk and for designing prevention or mitigation strategies.

Driving Question Board Progress

By the end of this lesson, students have made progress on questions including:

Groundwater

- ***What is it?***
- ***Where is it?***
- ***How many people get drinking water from groundwater?***
- ***How does water move through the ground?***
- ***What ways do we access groundwater?***
- ***How is groundwater recharged?***
- ***Can we run out of groundwater?***
- ***How do we track groundwater if we cannot see it?***

Contamination Questions

- ***What are the types of contaminants?***
- ***Where do contaminants come from?***
- ***What are the risks of different types of contaminants?***
- ***Is there a way to predict when and where a contaminant will impact drinking water?***

Next Step

Now that students understand common contamination sources, pathways, and risks, they are ready to bring the whole system together by applying what they have learned about aquifers, wells, groundwater flow, and contamination to a community scenario.

Optional Homework / Graded Activity

- Aquifer Lab worksheet "***Groundwater Contamination***"

LESSON 6

Lesson Overview

Students synthesize what they have learned about aquifers, groundwater flow, wells, and contamination to explain the unit driving question and propose strategies for reducing drinking-water risks in communities. Lesson 6 is organized into two parts: a concept map synthesis activity followed by a culminating community contamination scenario.

Note: it is highly recommended that educators review the **Educator Guide - Aquifer Lab Modeling Application (PDF)** in depth and explore the Aquifer Lab modeling application themselves prior to sharing with students. Teachers will need to use the Teacher Portal for the culminating activity in this lesson.

Learning Goals

- **Use evidence from models and data to explain** how **systems thinking and cause-and-effect reasoning** can be applied to a **community contamination scenario** to identify **wells at risk**, estimate **contamination travel time**, and evaluate **prevention or mitigation strategies**.

Lesson Question

How can we use what we have learned about groundwater flow and contamination to explain drinking-water contamination miles away?

Time: 100 minutes (2 periods)

- Review Activity - 50 minutes
- Culminating Activity - 50 minutes

Building Toward: HS-ESS2-2, HS-ESS2-5, HS-ESS3-1, HS-ESS3-4

Supplies / Resources

- Supplies for a Review Activity - either the supplies needed for the concept map activity or another review activity of the teacher's choice
- Class-Specific Driving Question Board
- [Students] Computer(s) / Internet Access - to complete the culminating activity, specifically to access the Aquifer Lab Modeling Application
- [Teacher] Computer(s) / Internet Access - to prepare the test version of the modeling application activity for students to use in the culminating activity
- Calculators - basic calculators for students to use with the modeling application portion of the culminating activity
- **(Optional) Printouts for Culminating Activity** - the culminating activity consists of three parts, two of which have document resources that teachers may choose to printout and provide as hard-copies to students as well as the contaminant table.
  - **Contaminant Table Printouts** - printouts of the contaminants table
  - **Unit Written Test Printouts** - printouts of the teacher-created written exam
    - An example version of a test is available in the Aquifer Lab resources "***(Lesson 6) Aquifer Lab Written Test Example***"
  - **Contamination Scenario Worksheet Printouts** - Aquifer Lab teacher-adapted worksheet "***(Lesson 6) Contamination Scenario [Template]***"
    - Teachers may adapt the template to easily create a customized scenario. The Aquifer Lab "***(Lesson 6) Contamination Scenario [Example]***" can be used as a reference model.

Lesson Flow & Student Experience

- [1]Teachers may begin with a review activity that helps students organize key ideas, vocabulary, and relationships from previous lessons in preparation for the culminating activity. One option is a concept map in which students sort terms into categories such as aquifer structure, Earth materials, wells, groundwater flow, contamination sources, pathways, and community impacts. They then add arrows and linking phrases to show how the ideas connect, compare maps, revise incomplete connections, and use the finished map as a reference for the culminating scenario.
- Students then apply their understanding to a community contamination scenario using an adapted Aquifer Lab worksheet, the test version of the modeling application, and teacher-provided online resources. They identify which wells may be at risk, estimate how quickly contamination could spread, and support their conclusions with evidence from the model. They also investigate contaminant-specific health risks and use that information to recommend prevention or mitigation strategies for the community.

Culminating Activity

The culminating activity can be adapted to fit different classroom needs. Teachers may assign Part 1 separately, remove it, or create their own contamination scenario worksheet instead of using the provided template. The least flexible component is the test version of the modeling application, which cannot be changed, including the scenario, questions, or automated grading. However, teachers may decide how to use the results.

Composition (50 points)

1. **Part 1: Unit Written Exam** - a traditional style written exam composed of a variety of memory-recall questions to demonstrate knowledge of the major unit concepts. Specifically, defining key terms and features, demonstrating knowledge of main concepts such as porosity and permeability, groundwater contamination risks and concerns, groundwater modeling practices, etc. **(12 points)**

**Parts 2 & 3 are completed concurrently with students completing the Part 3 worksheet as they work through the model in Part 2.*

2. **Part 2: Contamination Scenario Modeling Application Test** - students receive a teacher-provided link to the test version of the modeling application. They use information from the application to answer questions on the Part 3 worksheet. Students should wait to submit Part 2 until they have finished both Parts 2 and 3. Once the test scenario is submitted, scores are sent to the teacher through the Teacher Portal and are not visible to students. **(26 points)**
3. **Part 3: Contamination Scenario Worksheet** - students complete a worksheet based on a community scenario in which a contaminant has been detected in a nearby groundwater well. Using the scenario, they identify which other wells may be at risk, estimate how quickly the contaminant could spread, explain the risks it poses, and address other basic community concerns. Students should be graded on response accuracy, explanation quality, and their ability to point to evidence from the model and contaminant table/research. **(12 points)**

**Part 2 is graded automatically through the modeling application. Parts 1 and 3 must be graded manually.*

Preparation

1. Decide how students will complete each part of the activity: individually, in pairs or groups, online, on paper, or in a mixed format. Prepare materials accordingly.
2. Create a written exam for Part 1. An example is included in the Aquifer Lab materials.
3. Develop a contamination scenario for Part 3 using the worksheet template provided in the Aquifer Lab materials.
4. Create an account in the Aquifer Lab Teacher Portal and set up classes and students based on your chosen format. Use the Modeling Application Educator Guide for support.
    - If students will complete the test in groups, you can enter “Group” as the first name and “#” as the last name.
5. Copy the test scenario link from the Teacher Portal and make it available to students. They must use this link for their scores to be submitted to the teacher.

What Students Figure Out / Review

- Groundwater is an important freshwater resource connected to surface water, so impacts can extend beyond a single location.
- Groundwater movement depends on aquifer structure, Earth materials, hydraulic conductivity, porosity, and the water-table gradient.
- Wells provide access to groundwater and data about groundwater conditions, but pumping can also change flow paths and draw contaminants toward drinking-water wells.
- Contamination can enter groundwater, form a plume, and move over time with groundwater flow, creating delayed and distributed risks for communities.
- Source type, contaminant type, and contaminant pathway all matter for predicting where contamination may travel and what risks it may create.
- Groundwater-flow models are useful for predicting risk, but they rely on assumptions and simplified conditions, so conclusions should be interpreted with care and supported by evidence.
- Prevention and mitigation strategies such as source control, monitoring, well protection, treatment, and remediation can reduce impacts, but choices involve trade-offs related to effectiveness, feasibility, time, and community needs.

Conclusion

Now that students have synthesized their learning and applied it to a community scenario, they are prepared to communicate evidence-based explanations and consider how science and engineering can help communities prevent and respond to groundwater contamination.